Cureus Journal of Engineering

Open Access Review Article

Assessment of Solid Waste Generation, Management, Recycling Potential, and Artificial Intelligence (AI)-Driven Solutions for Jammu City, Jammu and Kashmir, India—A Review

Received 07/03/2025
Review began 08/18/2025
Review ended 09/15/2025
Published 10/29/2025

DOI:
https://doi.org/10.7759/s44388-025-05381-3

Pervez Alam [1] , Amreen Farooq [1]

1. Department of Civil Engineering, Baba Ghulam Shah Badshah University, Jammu, IND

Corresponding author: Pervez Alam, pervez@bgsbu.ac.in

Abstract

Solid waste management (SWM) is a leading challenge in Jammu City owing to rapid urbanization and increasing population with very few waste processing infrastructures. About 350-400 metric tonnes of municipal solid waste is generated by the city, the major portion of which is constituted by organic waste (40%), inert waste (25%), plastic (15%), textiles (13%), and paper (7%). Inefficient waste collection, uncontrolled waste dumping, and absence of waste segregation at source have subjected the environment and human health to very serious risks. This review highlights waste generation and disposal practices and the scope for recycling and waste-to-energy (WtE) in the context of Jammu City. Recent attempts involving Integrated SWM facilities in Kot Bhalwal and bio-remediation projects of Jammu City appear to be a little promising in terms of solving issues regarding the accumulation of waste. However, considerable challenges remain, such as a low level of awareness among members of the public, minimal infrastructure for the practice, and carelessness in the execution of the policies. Therefore, improving waste segregation at source, recycling facilities upgrading of landfills with scientific treatment methods, and mass awareness campaigns are essential for ensuring sustainable waste management in Jammu City. In addition, artificial intelligence (AI) can also present a transformative solution by optimizing waste collection routes, automating segregation, and enhancing recycling. Further, AI-powered smart bins, WtE technologies, and detection of illegal dumping can improve efficiency and sustainability. Integrating AI with community engagement and policy measures such as incentives for eco-friendly practices can drive Jammu toward a smart, data-driven waste management system, reducing pollution and conserving resources. Finally, the imposition of fines on businesses for improper disposal and penalty on people involved in improper disposal practices can enhance the efficiency of waste management as well.

Categories: Environmental and Sustainable Engineering, Environmental Engineering, Environmental Engineering and Sustainability
Keywords: pollution, disposal, municipal solid waste, solid waste management, health impact, waste treatment, artificial intelligence

Introduction And Background

Solid waste refers to discarded materials that are generated from various human activities including household, industrial, and commercial activities, that are no longer useful [1]. It can also be defined as leftover material arising from human, animal, or plant activities that are discarded [2]. Rapid urbanization, urban growth, and economic development have not only altered the physical size of the cities but are also placing considerable additional strain on infrastructural services throughout India cities [3]. Due to increase in population and urbanization, annual waste generation is projected to rise by 73% from 2020 levels, reaching 3.88 billion tones by 2050 [4]. It is important to manage solid waste in scientific manner. This problem can be solved by effective solid waste management (SWM). It refers to complete process of collecting, treating and also disposing of solid waste. SWM is the act of collecting, handling, and disposing of solid waste [5]. For achieving proper management of solid waste, it is important to know the characteristics of solid waste. Characterization of solid waste involves the systematic analysis of its composition, physical properties, and generation patterns, providing crucial insights for effective waste management strategies [6]. Solid waste can be categorized into various fractions including organic, recyclable, and non-recyclable materials, each with distinct characteristics influencing their handling and disposal methods. However, the increase in the level of solid waste has become a severe concern in today's generation, thus it is critical to recycle waste so that we can reuse it and limit solid waste generation [7]. The ability to recycle solid waste is determined by various factors, including the type of waste, accessible recycling technology, and the effectiveness of the recycling system. Paper, glass, plastic, and metal can be effectively recycled if proper collection and processing mechanisms are in place [8]. Compositing, for example, can recycle organic waste and minimize trash in landfills while also producing beneficial soil additions. The problem of improper disposal of solid waste is more complex in semi-urban region in comparison to urban region due to lack of management facilities [9]. By collecting, treating, and disposing of solid waste in an environmentally friendly manner, scientific solid waste disposal will decrease its negative effects on the environment. The environment and public health are negatively impacted by the inappropriate disposal of solid waste mostly in Indian cities due to lack of sufficient control and treatment. Due to its economic viability and lack of professional skills, unsanitary land filling is the most common disposal method in India [10]. The waste generation rate in Jammu, a major city in the UT of J&K and a popular tourist and pilgrimage destination, is drastically increasing [11]. Over the years, River Tawi has turned into a landfill site with mountains of solid waste distributed on its shoreline, contaminating its

How to cite this article
Alam P, Farooq A (October 29, 2025) Assessment of Solid Waste Generation, Management, Recycling Potential, and Artificial Intelligence (AI)-Driven Solutions for Jammu City, Jammu and Kashmir, India—A Review. Cureus J Eng 2 : es44388-025-05381-3. DOI https://doi.org/10.7759/s44388-025-05381-3

water as well as ecosystem [12]. The city is facing a sharp contrast between growing rate of generation and the lack of adequate funding. In Jammu and Kashmir, the three landfill sites Bhagwati Nagar and Kot Bhalwal in the Jammu division, and Achan in the Kashmir division are already overflowing, having reached their maximum capacity. It is always difficult to locate more land in J&K for waste disposal because of the area's fertile nature, steep terrain, and rapid urbanization [13]. This paper examines the current state of Jammu's solid waste generation, management and disposal system of Jammu City to identify the key challenges such as poor segregation, inadequate infrastructure, and to explore recycling and waste-to-energy (WtE) opportunities. Further, it also aims to highlight the potential of artificial intelligence (AI) in optimizing collection, segregation, and recycling for sustainable waste management solution.

In Jammu, there has been tremendous urbanization and industrialization from last few years. This has led to a steep rise in the quantum and types of solid waste generation in and around the city [14]. Though Jammu Municipal Corporation (JMC) is entrusted with the responsibility of carrying out the task of keeping the city clean, owing to its resource limitations and lack of a systematic approach, the desired results have not been achieved [15]. There is a need to adopt a systematic approach to tackle this problem. The situation can be improved by the application of appropriate technology and adopting modern methods of solid waste collection, treatment, and disposal, and also by involving the community in these improvement initiatives [16]. It was found that the majority of expenditures on public health in developing countries are on curing diseases rather than preventing it and one of the main causes of disease is from environmental pollution.

Research significance

Many attempts have been made across India to address issues related to SWM; however, a holistic and integrated approach is still lacking. Most urban areas, including Jammu, continue to rely on the collection of mixed waste without effective segregation at source [17]. The absence of a robust centralized or decentralized treatment infrastructure further exacerbates the problem [18]. These longstanding systemic issues have resulted in inefficient waste handling practices that persist even today. This review highlights the critical gaps and missing interlinks within the existing waste management framework of Jammu. Further, a comparative analysis of mid-sized cities with technical integration, along with behavioral aspects, has been carried out. A significant concern is that many municipal bodies implement strategies without conducting a thorough assessment of the local SWM scenario [19]. Consequently, valuable solid waste resources are often discarded at unscientific dumpsites, lacking proper treatment or recovery mechanisms.

Gap analysis of municipal SWM

Major challenges have been articulated through review papers that pertain to the metro cities, while mid-sized cities like Jammu remain overlooked. Data related to waste generation and its composition available are often outdated, incoherent, or generalized leading therefore to poor planning and decision-making at the local level. There exists no comparative study between centralized and decentralized systems on the feasibility of treatment of wastes in different urban topography. Though acknowledged informally by a large number of people, inadequate integration into any formal framework and study regarding its socio-economic impact and inclusion within the policy has not been done.

Furthermore, most of the studies keep sticking to the infrastructural solution and miss out on governance, technological solution, and behavioral aspects. Largely speaking, there has been very little research evaluating the effectiveness of public awareness campaigns and other behavioral interventions that can inculcate the habit of source segregation as well as recycling in the people. Digital technologies GIS, remote sensing, and AI have not been exploited to their full potential in Indian SWM research for monitoring, prediction purposes, or strategic planning that could be extremely helpful. Therefore, there is a urgent need to fill these gaps for designing context specific data-driven inclusive waste management systems in such cities where unscientific dumping is a major challenge along with a lack of integrated approaches like Jammu.

Current scenario of municipal solid waste generation in Jammu City

The generation of solid waste in Jammu city is a significant concern, with a city producing a substantial amount of waste daily. In urban areas, solid waste generation is primarily driven by household activities, commercial activities, as well as from industries [20]. The type and quantity of waste generated vary depending on factors such as lifestyle, economic status and cultural practices. According to estimates, Jammu city generates around 350-400 tons of solid waste per day, with a significant portion being household waste, followed by industrial, commercial, and agricultural waste as shown in Figure *1*, with an individual generation rate of around 0.40 kg/c/day [21]. The rapid urbanization and population growth in the city have led to an increase in waste generation, putting a strain on the existing waste management infrastructure. The Jammu Municipal Corporation is responsible for collecting, transporting, and disposing of solid waste but segregation of waste is still a challenge. This waste must be collected, transported, and disposed of by the JMC. Municipal solid waste (MSW) is being dumped to an open landfill in Kot Bhalwal, which is 10-15 kilometers away from the city. Approximately 300,000 tons of waste have been collected on this 19.5-acre site without any prior treatment [22]. As shown in Figure *1*, the waste generated through domestic activity is approximately 67%. This is followed by commercial at 22%, institutional at 7% and finally road sweeping waste at 4%. The large percentage of household waste indicates how critical waste management at the household level is, while the substantial quantity of commercial waste also indicates the responsibility of businesses in sustainable waste management. While small, institutional waste includes paper, cafeteria, and medical waste and thus has to be managed

effectively. The least category road sweeping waste, which contains rubbles, dust, and refuse, points to the need for good sanitation in urban centers. Further, the pie chart shows Figure *1b* waste composition, with organic waste (40%) being the largest, followed by inert (25%), plastic (15%), textile (13%), and paper (7%). The high organic content suggests composting potential, while plastic and inert waste highlight recycling and landfill concerns. Sustainable waste management strategies are crucial for reducing environmental impact. A structured review was undertaken using academic databases such as Google Scholar, Scopus, Web of Science, and ScienceDirect, employing keywords including "solid waste management," "MSW characterization," "IDW technique in waste mapping," and "QGIS in waste." The review considered studies published between 2000 and 2024 that were in English, peer-reviewed, and focused on MSW and GIS-based waste analysis, with particular emphasis on India and other developing countries. Studies were excluded if they were non-English, concentrated on industrial or hazardous waste, or lacked methodological clarity. From an initial pool of over 100 sources, 32 studies met the criteria and were selected to form the theoretical and methodological foundation of this research.

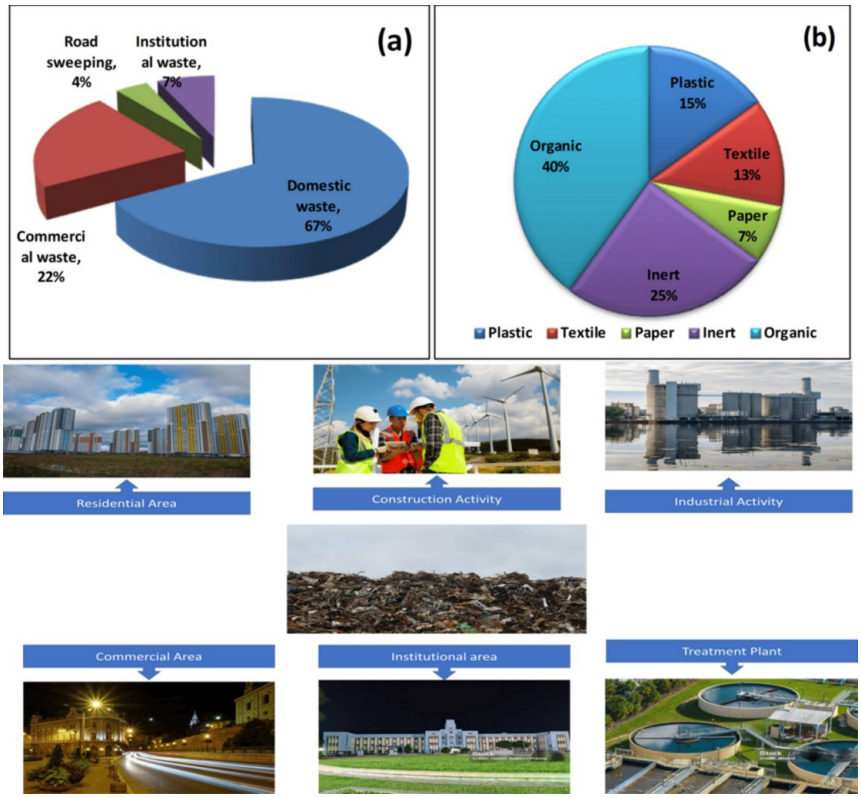

FIGURE 1: Compositional distribution of MSW along with (a) categorization of MSW based on source and (b) composition of MSW based on material type

MSW, municipal solid waste

Comparative account of trends of solid waste generation in different Indian cities

Solid waste generation trends and management practices across major Indian cities are highlighted in Table *1* revealing high disparities in waste handling efficiency somewhat irregularly. Metropolitan cities like Delhi and Mumbai produce over 9000 tons daily of solid waste but face challenges like low segregation rates and a huge reliance on landfilling, which results in overburdened dumpsites and various environmental hazards. Cities like Bengaluru show relatively higher segregation levels and a stronger focus on decentralized treatment solutions such as composting pretty effectively. Indore emerges as a model city with 100% waste segregation and an efficient recycling system reflecting the impact of consistent municipal policies and strict monitoring currently in place. Common challenges generally persist across most cities despite numerous policy and heavy infrastructure investments being made over time. Poor source segregation exists alongside a lack of public awareness and woefully inadequate waste treatment infrastructure and inefficiencies in formalizing informal waste workers. Cities like Hyderabad and Ahmedabad are experimenting with recent technology such as WtE and refuse derived fuel (RDF) but mixed waste reduces efficiency considerably. Smaller cities like Srinagar face myriad logistical and geographic hurdles hindering adoption of centralized processing systems rather effectively nowadays. The analysis underscores necessity of effective waste management frameworks, coupling advanced waste management approaches with robust governance community engagement and environmental awareness nationwide.

City	Waste Generation (TPD)	Waste Segregation (%)	Treatment/Disposal Method	Key Challenges	References
Delhi	~11,400	~33%	Landfilling, composting, WtE plants	Overloaded landfills, poor segregation	[23]
Mumbai	~9,600	~28%	Composting, landfilling, biomethanation	High population density, informal sector issues	[24]
Bengaluru	~4,000	~45%	Decentralized composting, dry waste collection centers	Lack of uniform policy, citizen non-participation	[25]
Chennai	~5,200	~22%	Composting, RDF, landfilling	Lack of space for disposal, plastic waste issue	[26]
Hyderabad	~5,800	~30%	WtE plant, composting, landfilling	Illegal dumping, incomplete door-to-door collection	[27]
Pune	~2,000	~50%	Decentralized composting, biogas, landfilling	Waste worker integration, awareness	[25]
Ahmedabad	~3,500	~35%	RDF, composting, WtE	Unscientific landfilling	[28]
Indore	~1,200	~100%	Composting, recycling, zero waste model	Maintaining high standards consistently	[29]
Lucknow	~1,200	~25%	Composting, landfilling	Limited infrastructure, low awareness	[27]
Srinagar	~520	~20%	Dumping, small-scale composting	Terrain challenges, lack of waste processing units	[30]

TABLE 1: Solid waste generation, management, and challenges in different cities of India

WtE, waste-to-energy; RDF, refuse derived fuel; TPD, tons per day

Review

Current scenario of MSW disposal in Jammu City

Solid waste disposal is a crucial component of waste management, requiring careful planning and execution to minimize environmental and health impacts [31]. The disposal of solid waste involves the final placement of waste in a landfill, or other treatment facilities. Effective solid waste disposal involves segregation of waste at the source, transportation to disposal sites, and proper disposal using techniques such as sanitary landfilling, compositing, or WtE conversion [32]. The solid waste disposal scenario in Jammu City is a mix of ongoing challenges and gradual improvements, primarily managed by the JMC. The city produces between 350 and 400 metric tons of municipal solid waste every day, the majority of which is collected and transported to the Kot Bhalwal landfill as shown in Figure *2*, an open dumping site [12]. Environmental problems like groundwater contamination, air pollution, and greenhouse gas emissions have been caused by the city's reliance on open dumping and lack of scientific waste treatment facilities [33-35]. Since the city depends on open dumping instead of an engineered landfill, this directly causes severe environmental problems. Starting with air pollution due to the burning of solid waste at the landfill. Secondly, precipitation percolates leachate into the ground water, since the landfill is without protective lining. Finally, the anaerobic decomposition of organic waste within the dump generates massive quantities of methane, a potential greenhouse gas that is released directly into the atmosphere, exacerbating climate change.

FIGURE 2: Solid waste disposal facilities of Jammu City

Overview of SWM technologies

Effective SWM requires technology selection based on waste type and local conditions [1,6]. Key technologies relevant to Jammu's high organic and plastic content include:

1. Composting and Vermicomposting: Suitable for biodegradable waste; low-cost and eco-friendly, but requires space and segregation [1,7].

2. Biogas (Anaerobic Digestion): Converts organic waste to renewable energy; ideal for decentralized setups but involves high setup costs [3,13].

3. Recycling: Applicable to plastics, paper, and metals; needs efficient sorting systems and clean input streams [4,5].

4. Waste-to-Energy (WtE): Useful for dry, high-calorific-value waste; capital-intensive and less suitable for high-moisture Indian waste [1,11].

5. Sanitary Landfills: Needed for non-recyclable inert waste, but require large land areas and leachate control [1,10].

Quantitative analysis of recycling potential

Over the past few years, many studies have been carried out by researchers to evaluate the recycling potential of municipal solid waste generated in Jammu city. Based on these studies, the following observations have been reported.

1. Plastic waste (~18.7%) and paper waste (~11.5%) offer substantial recycling potential if collected cleanly [6,9].

2. Organic waste constitutes over 68%, making it suitable for composting or biogas [2,13].

3. Inert materials, though non-recyclable, can be used for road sub-bases [15].

These findings align with previous studies showing that more than 70% of Indian MSW is potentially recoverable through composting or recycling [1,6].

MSW recycling potential in Jammu City

Jammu City generates roughly 350-400 metric tons of MSW every day. Understanding the composition of this garbage is critical to discovering recycling prospects [36]. According to studies, organic matter makes up a considerable fraction of garbage, with quantities varied depending on socioeconomic class. Low-Income Groups generate around 61% biological matter, Middle-Income Groups generate approximately 55% organic content and High-Income Groups produce approximately 42% organic matter [37]. This high organic content suggests a significant potential for composting and biomethanation processes. Additionally, the non-biodegradable part, which accounts for 40% of total MSW, contains recyclable items such as paper, plastics, metals, and glass. To capitalize on this recycling potential, Jammu City has

developed many initiatives, such as Material Recovery Facility (MRF) at Bandurakh. An MRF with modern gear was inaugurated in July 2021, with the goal of recovering 100% of dry trash. This facility collects, segregates, and processes diverse waste materials such as paper, cardboard, and plastic, making a substantial contribution to environmental sustainability. Figure *3* shows the recyclable waste generation in Jammu city. Since more than 50% of the waste is organic in nature, composting and bio-methanation are effective recycling solutions. Paper/cardboard and plastic/polythene, while in smaller quantities, can be effectively recycled using material recovery facilities. Wooden pieces and rubber/leather also hold potential for reuse or energy recovery. However, as shown in Figure *3*, a significant portion of inert waste (around 25%) presents recycling challenges, highlighting the importance of proper waste segregation at the source to maximize resource recovery and reduce landfill dependency.

Further, in collaboration with the Regional and Urban Development Agency (RUDA), JMC has processed between 150 and 200 tons of waste monthly. This approach not only cuts carbon emissions but also improves the incomes of approximately 450 rubbish collectors called as "safaie mitras." Despite these efforts, obstacles remain, including poor infrastructure, low public knowledge, and environmental concerns caused by open dumping. Addressing these concerns would require improved facilities, stricter policy enforcement, and extensive public awareness efforts to promote trash segregation and appropriate disposal [31,36].

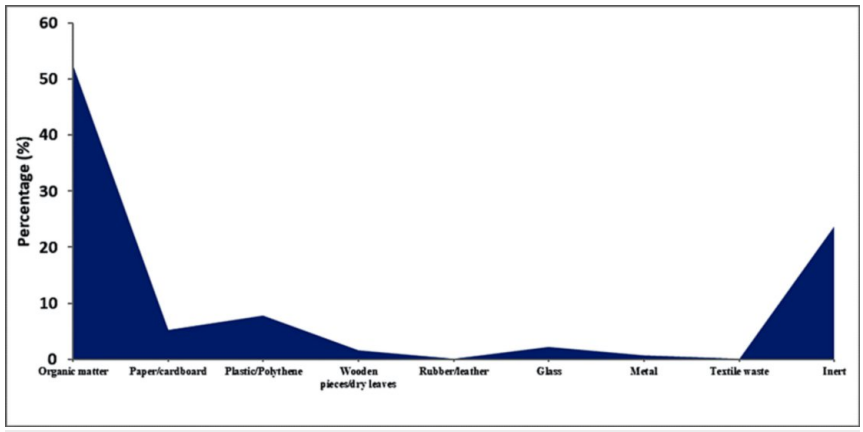

FIGURE 3: Generation of recyclable waste in Jammu City

Current scenario of MSW management in Jammu City

The city lacks an effective waste management system leading to environmental and health risks to the residents of Jammu city [38]. In order to preserve cleanliness, public health, and environmental well-being, municipal solid waste management (MSWM) in Jammu City is a critical issue that needs attention and long-term solutions. For waste management techniques to be efficient, it is essential to understand the composition of the solid waste produced in the city [39]. A substantial portion of the waste stream is composed of organic waste, which is primarily made up of yard waste and food leftovers. As urbanization and population growth have increased waste generation, Jammu City faces challenges in efficiently collecting, disposing of, and recycling solid waste to maintain a clean and healthy environment [40]. Jammu City works to minimize the environmental impact of waste disposal by encouraging recycling and composting, reducing landfill use, and implementing WtE initiatives where possible [41]. The Municipal Corporation of Jammu is responsible for managing, transporting, and disposing of solid waste. Solid waste collection, transportation, and disposal fall under the responsibility of the Corporation. In certain wards, garbage segregation has been started. However, in 32 municipal wards, door-to-door collection of waste from homes has been partially implemented [21]. A significant portion of the waste stream is also made up of non-biodegradable garbage, such as metals, paper, glass, and plastics. Sustainable waste management techniques depend on controlling this varied waste composition [42].

To address this issue, Jammu City's municipal officials have taken a number of actions [43]. These include the construction of waste processing facilities, door-to-door waste collection as shown in Figure *4*, and source segregation to distinguish recyclables from non-recyclables. Further, to improve waste management, the city has started several projects, such as a large SWM facility in Kot Bhalwal and an integrated SWM plant in Bandhurakh. The Kot Bhalwal SWM facility was developed in collaboration with the National Agricultural Cooperative Marketing Federation of India. JMC initiated the construction of a 350 metric tons per day (MTD) ISWM plant at Kot Bhalwal in August 2021. This project aims to process waste more effectively and includes a bio-CNG generating plant and bio-landfill components. Another facility, the ISWM Facility at Bandhurakh, with a capacity of 350 MTD was started in September 2021 at Bandhurakh (Zone-03). This project is also managed by JMC and aims to enhance waste processing capabilities in the region. In addition, legacy waste bio-remediation efforts to address accumulated waste include bio-remediation projects at sites like Bhagwati Nagar and Kot Bhalwal. As of early March 2025, approximately 3.88 lakh metric tons of legacy waste have been bio-remediated across various locations, including Jammu [44]. Additionally, old waste is being cleared from Bhagwati Nagar and Kot Bhalwal. However, there are still many problems, like a lack of proper facilities, low public awareness, and pollution

caused by open dumping. In addition, to manage waste better, Jammu needs better infrastructure, stricter rules, and awareness programs to encourage proper waste disposal.

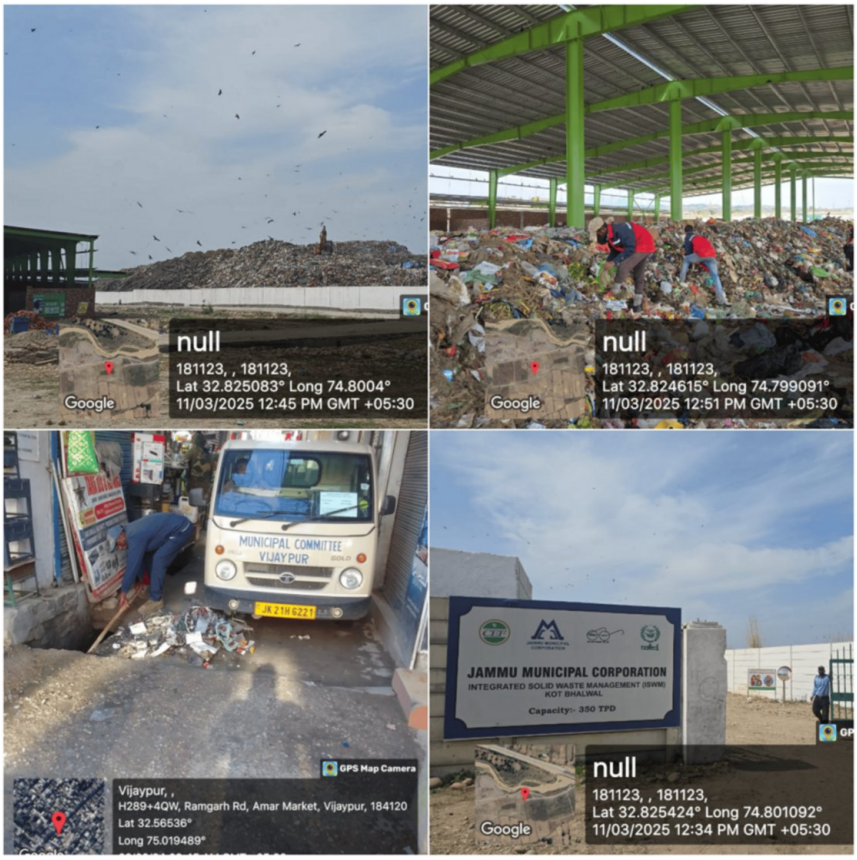

FIGURE 4: Solid waste management i.e., door to door collection system and segregation

The status of MSWM has been presented in Table *2* for Jammu City. The population density is high for the given area with 3,076 persons/km^2 as well as a high total waste generation of 374 tons per day (TPD). The waste generated is further divided, with 56% considered wet waste, 43% dry, 1.5 tons of sanitary, and 2.5 tons hazardous. Each person generates 0.45 kilograms of waste daily, which a workforce of 3,000 with an adequate vehicles of 350 collects via a door-to-door system prescribed by SBM 2.0 and SWM 2016. To increase efficiency, there is a need for better source segregation, enhanced facilities for composting and recycling, better collection point routing, and disposal measures for hazardous waste.

Parameters	Status	Reference
Population density	3,076 person/km	[3]
Waste generation rates (kg/c/d)	0.45	[3]
Total waste generation	374 TPD	[13]
Wet waste	210 TPD	[13]
Dry waste	160 TPD	[13]
Sanitary waste	1.5 TPD	[13]
Hazardous waste	2.5 TPD	[13]
Current waste collection system	Door to door	[21]
Number of workers	3000	[21]
Number of vehicles	350	[21]

TABLE 2: MSWM status of Jammu City

MSWM, municipal solid waste management; TPD, tons per day

Challenges in MSW management in Jammu City

Despite efforts by the JMC and other stakeholders, the city faces several challenges in managing MSW effectively. Some key issues are minimal waste segregation at the source, inefficient recycling, and landfill overuse. The city lacks adequate waste processing facilities. Moreover, open dumping at the Kot Bhalwal landfill causes environmental hazards. Inefficient waste collection and transportation further contribute to unregulated dumping. Public awareness about responsible waste disposal is low, and recycling efforts remain largely unorganized. Additionally, improper disposal leads to soil and water contamination, air pollution, and health risks. To improve waste management, Jammu needs better infrastructure, stricter policy enforcement, public awareness campaigns, and investment in WtE solutions. Additionally, investment in WtE solutions and circular economy approaches can help make the city's waste management system more sustainable.

Proposed strategies for sustainable waste management

In India, SWM is primarily governed by the Solid Waste Management Rules, 2016, along with other regulations such as the Plastic Waste Management Rules and E-waste Rules. These regulations, enforced by judicial interventions from the Hon'ble Supreme Court and the National Green Tribunal (NGT), mandate source segregation, door-to-door collection, decentralized processing, engineered landfill management, and active public participation. Cities like Indore, Pune, and Bengaluru have demonstrated how strict policy enforcement, integration of waste pickers, decentralized waste processing centers, and continuous public awareness campaigns can transform urban waste systems, earning national recognition for achieving near-complete segregation and collection. These cases highlight that legislation alone is not sufficient; successful implementation depends on administrative commitment, infrastructure investment, and community engagement.

In contrast, Jammu City, despite being under the same legal and judicial obligations, continues to face challenges such as inadequate source segregation, overflowing landfills at Kot Bhalwal and Bhagwati Nagar, and limited recycling infrastructure. For proper waste management, Jammu must prioritize infrastructure upgrades, ensure mandatory household-level segregation with color-coded bins, and expand decentralized waste-processing centers to reduce pressure on landfills. Door-to-door collection should be modernized with GPS tracking, while recycling facilities for paper, plastic, metal, and e-waste need urgent development. Public participation must be strengthened through mass awareness campaigns in schools, social media, and community events, with NGOs and waste pickers actively involved in collection and recycling. Finally, stricter enforcement through fines for improper disposal, alongside incentives such as tax benefits for eco-friendly practices, will help Jammu align more closely with the successful practices demonstrated in leading Indian cities.

Potentials and opportunities for Jammu cities SWM in the future using AI

AI is increasingly being integrated into SWM systems at both national and global levels. Smart bin technologies, as implemented in Indore, utilize the Internet of Things and AI to monitor waste levels in real time, ensuring timely collection and preventing overflow in densely populated areas. Similarly, AI-powered sorting machines, which are employed in several European and Asian cities, provide high-accuracy segregation of recyclables from non-recyclables, reducing human exposure to waste. Route models, used in Bhopal, leverage real-time data to determine the most fuel-efficient collection paths, while citizen reporting platforms, like those in Surat and Dubai, enable immediate feedback, thereby

increasing responsiveness and accountability in waste services [45].

In terms of efficiency, AI has demonstrated significant potential to enhance SWM operations by enabling predictive analytics, process automation, and performance optimization. For instance, cities such as Barcelona, Singapore, and Coimbatore have adopted AI-based forecasting tools to estimate waste generation trends, design cost-effective recycling programs, and monitor compost quality. In addition, AI-driven behavior analysis and digital education platforms, as observed in Mumbai, support awareness campaigns that promote household-level waste segregation and citizen participation in sustainable waste practices, as shown in Table *3*.

The implications of AI for advancing the circular economy are profound. By optimizing material recovery, enhancing recycling efficiency, and supporting WtE initiatives, AI fosters resource conservation and reduces landfill dependency. A notable example is Delhi's Okhla WtE facility, where AI integration helps maximize energy recovery from municipal solid waste. If similar models are adapted for Jammu, AI could facilitate the design of localized recycling strategies, improve composting processes, and strengthen community participation. Ultimately, by embedding AI into SWM systems, cities can transition from linear waste disposal models toward circular resource loops, thereby promoting sustainability, economic viability, and environmental stewardship.

S. No.	City/Case Reference	Impact Observed	AI-Based Solution	Opportunity for Jammu	Reference
1	Indore, India	Improved collection efficiency, reduced overflow issues	Smart Bin Monitoring System	Install IoT-enabled bins with AI-based fill-level prediction for timely collection	[46]
2	Pune, India/Seoul, South Korea	Reduced manual labor, increased segregation accuracy	AI-Powered Waste Segregation Robots	Deploy AI-vision robots at MRFs for automatic dry/wet/hazardous waste segregation	[47]
3	Bhopal Smart City, India	Fuel savings up to 20%, better coverage and fewer complaints	Predictive Route Optimization for Waste Trucks	Use AI to plan optimal routes and schedules based on real-time bin data and traffic	[48]
4	Surat, India/Dubai Smart City	Improved citizen participation and complaint resolution time	Citizen Feedback & Reporting	WhatsApp or app to report uncollected waste or illegal dumping	[49]
6	Barcelona, Spain/Bengaluru, India	Better revenue recovery from recyclables, improved planning of recycling programs	AI for Recycling Stream Optimization	Analyze composition of recyclable waste and predict market value/demand patterns	[50]
7	Singapore NEA Model	Informed infrastructure planning, optimized facility design	AI-Driven Waste Generation Forecasting	Use machine learning to predict future waste generation by ward/locality based on population trends	[51]
8	Coimbatore, India/Netherlands	Enhanced compost quality, compliance with FCO standards	AI in Compost Quality Control	Monitor and regulate compost parameters using AI for organic waste processing units	[52]
9	Mumbai, India/Helsinki, Finland	Increased source segregation compliance and citizen engagement	AI-Based Education & Awareness Analytics	Analyze behavior trends and tailor awareness campaigns for low-performing areas	[53]
10	Delhi Okhla (WtE), India	Improved energy recovery and plant efficiency	AI Integration in WtE Plants	Predict calorific value and composition of waste to optimize WtE operations	[54]

TABLE 3: AI-based solution for solid waste management along with case references

WtE, Waste-to-Energy; AI, Artificial Intelligence; IoT, Internet of Things; FCO, Fertilizer control order; NEA, National environment agency; MRF, Material Recovery Facility

Conclusions

Jammu City's SWM situation is representative of the difficulties faced by many fast-growing urban places worldwide. Although steps have been made toward improvement in waste processing, a substantial challenge remains in attaining a sustainable system. In such circumstances, a multi-disciplinary approach is required with infrastructure development, policy enforcement, and active community participation. There exists an opportunity for the reduction of excessive pressure on the landfill with mandatory source segregation supported by door-to-door collection optimization along with GPS tracking and decentralized processing units. Additionally, the landfill must be enhanced, and Kot Bhalwal should contain leachate treatment as well as gas recovery systems. In addition, mass awareness campaigns should be undertaken through schools, social media, and local events. This will initiate responsibility among residents in waste disposal, setting a precedent and making some difference. A mix of these strategic interventions, apart from reducing waste generation, will boost recycling rates and, most importantly, reduce the ecological

footprint when it comes to waste disposal to ensure a cleaner and more sustainable future for Jammu City. Further, adoption of AI-driven solutions, such as smart bins, predictive route optimization, and automated segregation, can enhance efficiency by 20-25%, reduce landfill dependency, and align Jammu's waste system with circular economy principles.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Pervez Alam

Acquisition, analysis, or interpretation of data: Pervez Alam, Amreen Farooq

Drafting of the manuscript: Pervez Alam

Critical review of the manuscript for important intellectual content: Pervez Alam, Amreen Farooq

Disclosures

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Acknowledgements

The authors gratefully acknowledge the financial support provided by the Government of Jammu & Kashmir through the J&K Science, Technology & Innovation Council, Department of Science & Technology.

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