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Urban waste management and challenges in emerging smart city systems governance and circular economy perspectives

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ABSTRACT

Urban waste management has emerged as a critical public health and environmental issue globally, driven by rapid urbanization, population growth, and increased tourism. This study focuses on the urban waste management (WM) scenario in Guwahati, one of the fastest-growing smart cities in the eastern Indian Himalayan region, intending to assess its current practices, challenges, and technological interventions. The research employed a mixed-method approach, combining extensive field observations and secondary data analysis to determine the municipal solid waste management system in Guwahati. Special emphasis was placed on identifying model wards that have adopted technology-based solutions for waste handling, transportation, and disposal. The study revealed that Guwahati generates approximately 550–600 metric tons of waste per day, with significant gaps in segregation, collection efficiency, and disposal mechanisms. Only a small percentage of waste is processed in scientific treatment facilities, while the rest ends up in open dumps, posing serious public health and environmental risks. Model wards demonstrate up to 40% higher waste collection rates, a more circular economy perspective, and increased efficiency due to technological upgrades and improved infrastructure. The study provides a comprehensive snapshot of the overall WM scenario and offers valuable insights into the circular economy. Further, the study highlights the Guwahati Smart City of Assam, India and may not represent other Himalayan urban centres. The findings provide actionable insights for policymakers and urban planners, researchers and environmental experts to improve waste management in the fastest-growing urban centres through targeted infrastructure and smart technology interventions. This study is one of the holistic analyses of urban WM in a Himalayan smart city context, linking technological modernization with improved waste handling, urban waste management challenges and highlighting its public health implications. The study, which has been carried out in Guwahati city, can be a model study for other such urban centres.

Keywords: urban waste management, smart cities, public health, sustainable waste disposal, solid waste, circular economy.

INTRODUCTION

Urban waste management in urban areas is a complex socio-economic, environmental, and infrastructural issue. The ever-increasing rate of urbanization has drastically enhanced waste generation, thereby making the development and execution of management strategies crucial (Zhou, 2024). municipal solid waste (MSW) has a highly heterogeneous composition, including food waste, plastics, paper, glass, metals, and yard waste, and its heterogeneous composition changes with urban demographics (Gueboudji, 2024). Municipal waste management is contingent on many factors, such as levels of public welfare, economic activities, cultural customs, etc., which define the volumes and compositions of waste generated in urban areas (Lak et al., 2024). MSW generation has been recognized as a significant global problem, with global production surpassing 2.01 billion metric tonnes (Gueboudji et al., 2024; Zhou, 2024). A 70% increase is projected, reaching a total of 3.4 billion metric tonnes by the year 2050; this increase is mainly attributed to urbanization, industrialization, and population growth (Valavanidis, 2023). As the most populous country, China produces over 15% of the world's MSW second only to the United States (12%). MSW generation is growing in quantity and quality, requiring integrated environmental solutions able to manage risk for the environment and public health (United Nations Environment Programme (UNEP), 2024). Managing MSW is incredibly challenging in developed metropolitan smart cities and urban centres as the urban population grows, which promotes more consumer habits and the prevalence of non-biodegradable materials and increases the burden on dumping ground (Paul et al., 2019). In several urban contexts, the problem of urban municipal waste was also a serious concern for developing country and now it is also same for fastest growing economies of the world. Although, the improvement and adoption of latest smart technologies have improved the overall waste collection and treatment efficiency (Rajpal et al., 2024). However, many developing nations still face persistent challenges in expanding coverage and maintaining operational capacity. Among these challenges, landfill mismanagement stands out as one of the most pressing issues, with many sites lacking scientific design and systematic oversight which also concern for handling biomedical waste, hazardous waste and emerging contam- inants (Choudhury et al., 2024). These deficiencies have significant environmental consequences, with studies reporting groundwater and soil contamination near disposal sites, thereby increasing risks to public health. Harmless waste disposal causes transboundary pollution (Siddiqua et al., 2022; Vinti et al., 2021) and pollutes the land, water bodies, and the atmosphere, leading to degradation of the climate, biodiversity loss, and rising pollution (Cohen et al., 2015). To combat these problems, a comprehensive and integrated waste management plan must be established to consider the nature of urban areas. Practical and intelligent waste management systems are crucial to reducing the negative impacts of MSW on public health and the environment. One of the key strategies one could use is to turn to waste-to-energy technology (WTE-T), which enables converting wastes into energy and, therefore, reduces landfilling and increases energy efficiency (Zhou and Zhang, 2022). Regulatory policy and public participation will also significantly affect how successful sustainable waste management strategies will be. India has specific guidelines for MSW segregation, treatment, and disposal within the jurisdiction of the Solid Waste Management Rules, 2016, framed through the Environment (Protection) Act, 1986 (Ministry of Environment, 2016). Digital solutions like smart waste bins, automated collection systems, and real-time monitoring improve efficiency, making urban waste management sustainable in the long run (Mondal et al., 2023). Recent work has shown that integrating spatial intelligence into wastewater networks improves efficiency and resilience, offering transferable insights for municipal solid waste governance (Choudhary et al., 2025a; Choudhury et al., 2025c). Applying similar geospatial frameworks in solid waste systems could bridge operational gaps between infrastructure and sustainability outcomes in emerging smart cities.

The city represents a critical case where rapid urbanization intersects with fragile ecosystems, making its waste management challenges unique and underexplored. These deep-rooted issues necessitate substantial investment in newer collection and disposal systems for sustained legal waste disposal. Technological innovations offer opportunities to optimize waste management operations, more specifically, the application of Internet of Things (IoT) solutions. IoT-based systems facilitate the real-time monitoring of waste bin levels and collection routes, which could result in a 32% increase in operational efficiency (Addas et al., 2024). However, financial limits and the intricacies of the system implementation prevent the large-scale implementation of advanced automation systems, thus limiting their potential in smart cities, which lack technical infrastructure (Pandiyan et al., 2023). Although emerging technology has potentially transformative solutions, deployment is complex and needs to be well-planned and adequately funded. The success of waste management strategies depends upon the regulatory framework and community involvement (Thakur et al., 2024). Coherent legal frameworks will also lead to coordinated efforts for waste management, but political interventions and a lack of public participation hinder the progress (Awino and Apitz, 2024). This should be done by increasing transparency and encouraging engagement with relevant stakeholders regarding the project (Mishra, 2024). Nevertheless, emerging technologies, including blockchain and IoT, can provide viable opportunities to support the efficiency of urban waste management systems, which can be enhanced to generate waste systems that deliver improved sustainability and eco-friendliness of the systems to align with smart city objectives (Gaikwad, 2024). New sustainable and innovative waste management strategies are urgently needed to tackle the global waste crisis, such as plastic pollution, emerging contaminants, pharmaceutical and personal care waste caused by urbanization and population growth. These measures help promote ecological sustainability by minimizing waste build-up and pollution and improving operational efficiency and public health results. Advanced technologies, particularly the Internet of Things (IoT) and deep learning, have begun to transform waste management practices including current burning issues like plastic waste, hazardous waste, emerging contaminants and pharmaceutical waste all together shifting the focus towards data-driven decision-making and performance optimization (Choudhury and Roy, 2025; Chowdhury et al., 2024a; Kryvenko et al., 2023). Recent studies also demonstrate how artificial intelligence can be effectively applied to environmental systems, such as AI-enhanced air quality assessment in industrial cities, offering transferable insights for urban waste governance in smart city contexts (Halaktionov et al., 2025). These advances highlight the potential of AI-based predictive frameworks to strengthen monitoring, optimize resource allocation, and support sustainable waste and environmental management strategies. Technological updates, including apps and back-end systems, can play a vital role in improving the efficiency of waste collection, disposal, and recycling. For instance, innovative waste management systems based on IoT devices allow real-time monitoring of waste levels, optimizing the collection route to achieve a 29% fuel consumption reduction (Addas et al., 2024). Deep learning applications in waste sorting mechanisms processes enhance the recycling rate and reduce the waste deposited in landfills to endorse a circular economy (Chowdhury et al., 2024b). Parallel advances in wastewater management demonstrate how geospatial analysis can optimize resource recovery and climate resilience, a framework equally relevant for urban solid waste management (Choudhary et al., 2025a). Similarly, explainable artificial intelligence techniques, such as stacked ensemble regression with SHAP-based interpretation, have been successfully applied to predict water quality dynamics (Choudhary et al., 2025b). These approaches underline the potential of integrating interpretable AI into solid waste governance, where predictive models can enhance transparency, optimize system efficiency, and support policy decisions in emerging smart cities. Incorporating geospatial data layers into waste flow mapping and collection-route design could strengthen predictive, technology-driven governance in Indian smart cities. These innovations enhance efficiency and minimize environmental harm caused by improper waste disposal. Equally important is community engagement and policy support to make sustainable waste management a success. However, it must be supported, enforced, and maintained by the public and strong legislative frameworks to be effective (Leknoi et al., 2024). Cities like San Francisco and Freiburg serve as case studies for the advantages of integrated waste management strategies. Policy-driven initiatives and public involvement have been leveraged to foster the success of waste reduction and recycling efforts (Rani and Yendluri, 2024).

Against this backdrop, the present study critically examines the municipal solid waste management framework in Guwahati smart city, assessing existing practices, technological and policy interventions, challenges, opportunity and proposing sustainable pathways aligned with smart city governance and circular economy principles

(Pollans, 2017). The integration of circular economy approaches into waste governance is increasingly recognized as a transformative pathway for reducing landfill dependency, promoting resource recovery, and enabling sustainable urban transitions (Sreenath et al., 2025). This perspective strengthens the relevance of Guwahati's case by situating it within global discourses on sustainable chemistry and green engineering solutions. While technology-driven and policy-aligned measures can yield multiple benefits, issues still need to be overcome. Intelligent waste techniques are largely not adopted due to high implementation costs, infrastructure limitations, and a lack of behavioural change in new waste disposal habits. Realizing the end goal of smart waste management for cities will only be possible through continuous work to raise awareness among citizens, shift their behaviour, and promote practices that mainstream smart waste management as part of urban infrastructure. Urbanization is a trending phenomenon in developing nations. Among the objectives are assessing the effectiveness of existing waste management policies, evaluating the innovative technological interventions in waste, and suggesting a strategic framework for sustainable waste management. Urban municipal waste comprises diverse streams, including plastics, e-waste, liquid waste, construction and demolition debris, biomedical and industrial refuse, as well as household wastewater and grey water. The mismanagement of these streams is closely linked to severe environmental pollution and adverse public health outcomes (Hrynzovskyi et al., 2018; Hulai et al., 2022; Karlova et al., 2017). Among these, e-waste poses a particularly critical challenge because of its toxic components and long-term effects on wildlife and biodiversity (Chowdhury et al., 2025c; Tripathi et al., 2025). This highlights the urgency of targeted recycling strategies and regulatory interventions to mitigate ecological damage while addressing the broader urban waste crisis. Therefore, their effective management, safe disposal, and systematic recycling are essential to designing robust urban waste strategies and overcoming the critical challenges faced by municipal authorities globally. This research aims to elucidate environmentally friendly urban waste management systems that are a harmonious blend of policy and technology, ensuring a clean and sustainable environment, thus complementing urban sustainability targets. Insights for policymakers, operators, and researchers in the field of environmental science can be obtained from this comparative analysis of MSW management practices in developing and developed economies concerning urban settings and regulatory scenarios in India. Such findings will help create cleaner, healthier, more sustainable urban ecosystems.

This research aims to address the 'knowledge gap in understanding how governance mechanisms and circular economy principles can be effectively integrated into urban waste management systems' within emerging smart cities, particularly in the fastest-growing economies. While there is increasing global attention on smart technologies and urban sustainability, there remains a lack of comparative evidence on how municipal solid waste is managed differently across policy frameworks, technological readiness levels, and socio-economic contexts, especially between developing and developed countries. The study seeks to uncover 'how policy technology integration can enhance waste governance, improve system efficiency, and reduce urban public health implications. The authors hypothesise that cities which incorporate circular economy principles, supported by adaptive governance and smart technologies, achieve more sustainable and resilient waste management outcomes. By analysing Guwahati, the fastest growing smart city in the eastern Himalayas, the study expects to generate 'new insights into the effectiveness of local interventions', infrastructure development, and digital solutions in improving waste processing, treatment, and environmental health.

Description of city with its MSW management process

Guwahati, the largest city in Assam, is a crucial metropolitan hub in northeastern India, characterized by rapid urbanization, economic growth, and strategic geographical significance. Over 30 years, between 1990 and 2020, the total built-up area of the city increased from 27.18% to 47.87% (a clear indicator of rapid urban growth), which in turn, signifies tremendous infrastructural and demographic changes (Gogoi et al., 2023). However, its role as the primary gateway to the northeastern states has also led to a substantial expansion in trade, tourism and commerce, accompanied by emerging environmental sustainability and governance challenges. The problem of traffic congestion and scarcity of other resources thus requires a new framework for distributed urban centres and rural growth corridors to be implemented with a focus on developing such regions to address these issues of rapid urbanization (Bhattacharjee et al., 2023). Nevertheless, environmental vulnerabilities related to soil degradation and water constraints are growing and aggravated by unsustainable land expansion and climatic variability. Being in an earthquake-prone area makes the city's existing infrastructure even more vulnerable to climate change, necessitating climate-smart policies and disaster-impact mitigating urban management strategies to enhance long-term sustainability.

National Highways 31 and 37 (NH31 and NH37) also pass through Guwahati, further consolidating the city's role as a national and international transportation artery, as it is connected with Guwahati International Airport, which is also considered one of the top busiest airports in the country. Therefore, a massive influx of public movement for tourism, business, transit and education purposes in the Guwahati city.

Geographical location, administrative structure, and demographic significance

The Guwahati city is the biggest metropolitan area in northeastern India and the second largest city in eastern India after Kolkata, Guwahati, the central city in the region, is considered the entrance or gateway to northeast India and East Asia. Guwahati city is regarded as one of the oldest cities, around 2000–3000 years old, and was well-known as Pragjyotishpur in ancient times. It is also inside the Indo-Burma Biodiversity Hotspot. Guwahati is considered the second-largest city in terms of area (216.79 km^2) and has undergone significant overall developmental expansions after Kolkata. Guwahati is the state's capital city of Assam. It is the most significant, fastest-growing smart city in India and the hub and gateway for the Association of Southeast Asian Nations (ASEAN) countries as per its strategic geographical location and the "Look East Policy' and 'Act East Policy' by the Government of India. It is situated amidst the southern bank of the mighty Brahmaputra River, the Shillong plateau slopes, and is surrounded by multiple hillocks. The city has a population exceeding one million per the 2011 census (GoI). The city's elevation is 50 to 55 meters above mean sea level, and multiple high and medium-range hills encompass it. The GMC looks after urban governance, planning of industrial infrastructure and waste management throughout the city, which is spread across 60 municipal wards. Due to the concentration of economy and migration from rural to urban areas, the city is expanding quickly, with the urban population reaching over 1,594,545 residents in July 2010, including 100,000 floating residents and 298,909 registered households. This increase results in about 779.40 tons of waste as MSW daily, including 717.54 tons for households, while 61.90 tons are from commercial properties. With Guwahati emerging as an important metropolitan centre, it demands urban planning techniques with sustainable development to address the inevitable consequences of increasing population density, environmental problems and limitations in infrastructure.

GMC and its role in MSW management

The authority in Guwahati, the largest city in NE India, oversees the municipal solid waste management of the GMC (Figure 1). In a world of urbanization and an increase in waste generation, the GMC is challenged and needs to be available to collect, transport, process, and dispose of waste efficiently. The waste management process follows a structured two-tier system where the primary collection consists of door-to-door waste collection, street sweeping and NGOs operating in 60 municipal wards. Figure 2 illustrates the Guwahati municipal ward boundary.

Secondary collection includes compactors, dumpers, backhoe loaders, and road sweepers that help take waste from the secondary bins to the dump site. There are four transfer stations in the city, namely Zoo road, Bhangagarh, VIP road, and Chatribari, and there are proposals to set up more in Adabari, Old jail, Mathagharia, and Purbi dairy. GMC has initiated multiple waste-to-resource conversion projects to reuse solid waste and avert the need to send it to the landfill, including a 2.5 TPD organic waste converter at Bhangagarh that produces compost and a 5 TPD bio-methanation plant at Chatribari that generates 800 electricity units per day. The projects in the pipeline include the 150 TPD compost-RDF plant at Belortol and bio-methanation plants at Adabari (50 TPD) and Paltan Bazaar (10 TPD), besides material recovery facilities to improve recycling and repurposing of waste. Historically, the waste was disposed of at the

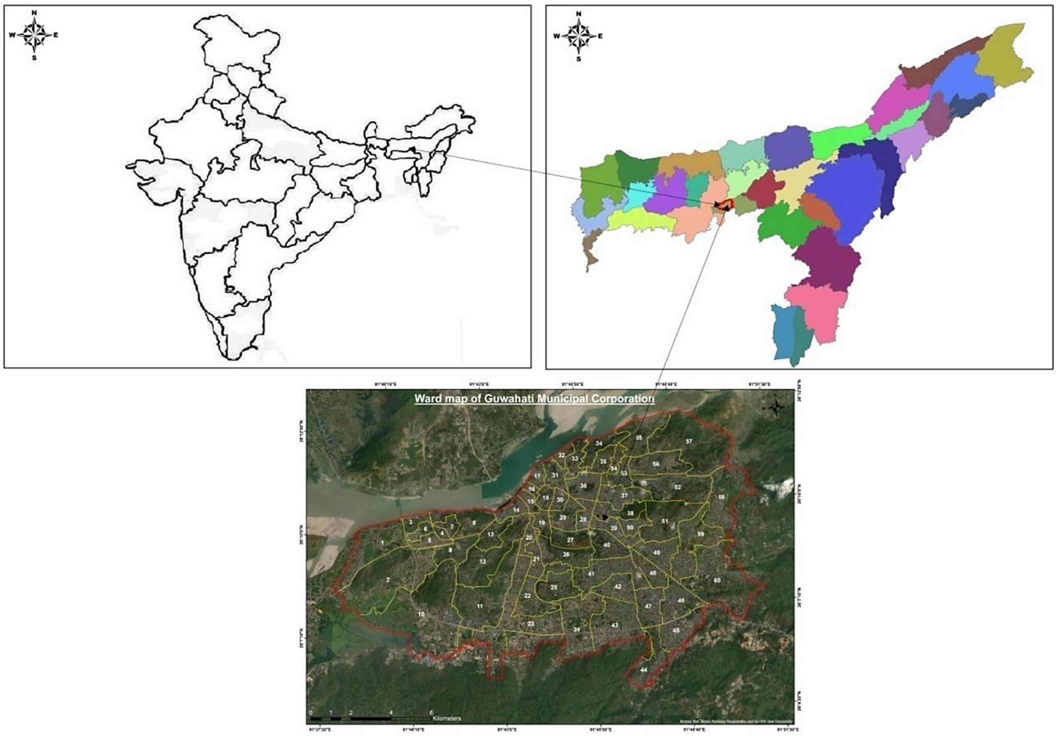

Figure 1. Study area

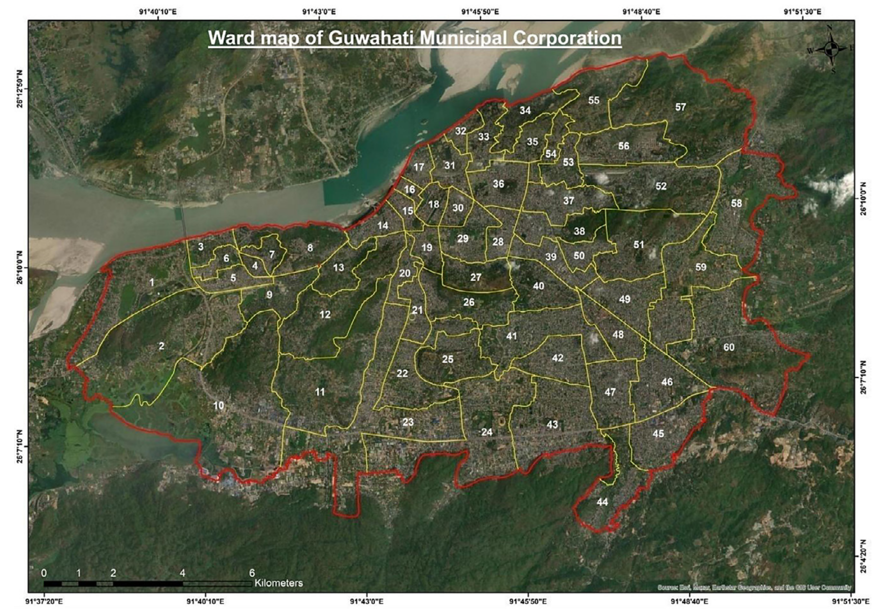

Figure 2. Ward boundaries of Guwahati municipal corporation GMC administrative units for urban waste management and planning

entire Boragaon dumping site, which occupied 120 bighas of land, with an estimated 1.7 million metric tonnes of waste accumulated. GMC has launched large-scale bio-mining projects for legacy waste with private players like NEET Pvt. Ltd. and Zigma Global Environ Solutions, as of July 2024, processing 711,000 metric tons of waste, assisting state land restoration and environmental sustainability.

In addition, a QR code-based waste tracking system has been implemented in 10 model wards with 17,372 QR installations, allowing for real-time tracking and monitoring and freeing up to 80% of the workforce through technological support. Meanwhile, initiatives such as GPS tracking of waste vehicles and plans under the innovative city program to set up sensor-based smart bins have aimed at improving automation in disposal. Despite this progress, issues such as workforce shortages, lack of proper waste segregation, and insufficient transfer stations still linger. You must strategically expand the workforce, infrastructure, and public awareness initiatives to promote waste segregation and recycling. Governance improvements and adherence to policy will be critical to sustain these long-lasting outcomes.

The GMC has also made significant strides in waste-to-energy initiatives, bio-mining and digital waste tracking as the state authority for waste management and urban sanitation. Greater processing capacity, robust monitoring, and community integration will be critical for scaling these efforts. Through high technologies in waste management systems, efficient governance, and systematic and institution building, GMC intends to achieve a circular economy and make Guwahati a pioneer in waste-to-wealth initiatives.

Overview of MSW handling, collection, processing, treatment, and disposal systems

Municipal solid waste management in Guwahati involves a complex multi-stage process for handling, collecting, processing, treating and disposing trash. The Guwahati Municipal Corporation oversees these activities and aims to maintain an efficient and sustainable system. The handling process begins at the neighbourhood level, with door-to-door collection, street sweeping, and accumulation at secondary gathering points. Each city's 60 divisions are assigned a specific non-profit to facilitate primary waste retrieval, with sanitation supervisors monitoring the effectiveness within each division. Collection relies on a mix of auto tippers, electric rickshaws, tricycles, pushcarts and handcarts to amass residential and commercial refuse. However, separating compostable and non-compostable trash at the source remains a significant challenge, as homes and businesses often fail to segregate before disposal, hindering efficient processing and recycling efforts. Figure 3 illustrates the GMC primary collection machine.

After collecting primary waste, either by pushcart or automated vehicles to transport it to several secondary bins and transfer stations before being processed or disposed of in another location. Currently, 101 secondary collection containers and 97 vulnerable garbage points are managed by the GMC, which temporarily stores garbage before it is dispatched for final disposal. Waste movement to the treatment/storage facility is done through garbage compactors, dumpers, backhoe loaders, and skid-steer loaders in the secondary collection process. The four refuse transfer stations in the city, Zoo road, Bhangagarh, VIP road, and Chatribari, have been generating direct transportation costs. In contrast, the parameters are being designed so that the stations can efficiently identify future expansion for Adabari, Old jail, Mathagharia, and Purbi dairy. Waste processing and treatment are crucial to sustainability and reducing reliance on landfills. GMC runs a 2.5-ton-per-day (TPD) organic waste converter in Bhangagarh, which converts biodegradable waste to compost, and a 5 TPD bio-methanation plant in Chatribari, where electricity is generated from organic materials.

Current expansion projects – a 150-ton capacity compost and RDF plant at Belortol, a

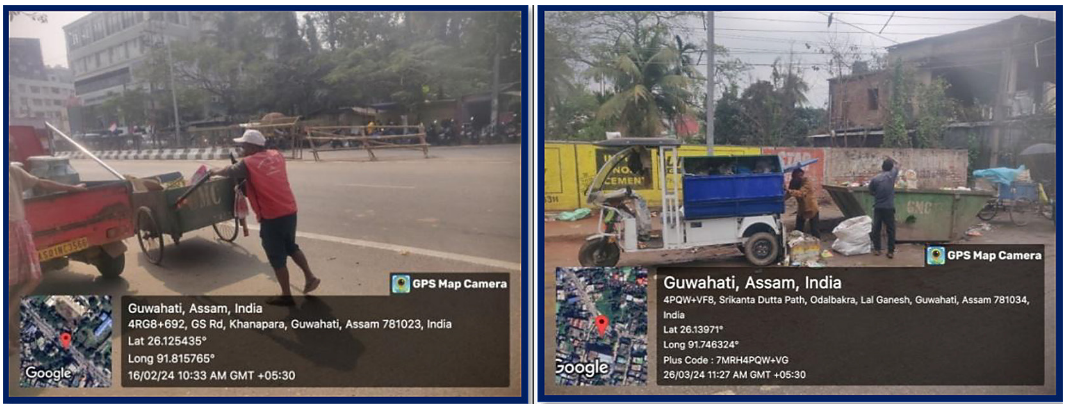

Figure 3. GMC primary collection vehicle

bio-methanation plant at Adabari (50 TPD) and another at Paltan Bazaar (10 TPD). GMC even set up a materials recovery facility (MRF) at Adabari, which started processing 5 tons per day and can be expanded to 10 tons per day per the 2024 waste management report for Guwahati City. While progress has been made, disposal management challenges remain. From 1997 to 2021, 1.7 million metric tons of wastes were dumped on a 120-acre site at Boragaon. GMC stopped functioning at Boragaon in June last year, relocating disposal to Belortol following environmental threats, especially the risk of polluting Deepor Beel, a wetland listed under the Ramsar Convention. GMC engaged in biomining projects to treat legacy waste, mitigating 711,000 metric tons of accumulated waste (by July 2024), thus reducing the landfill burden and maximizing resource recovery (2024 waste management report, Guwahati City). This large-scale biomining effort illustrates how legacy waste treatment can simultaneously recover resources and restore environmentally sensitive sites like Deepor Beel, aligning MSW practices with ecological conservation goals.

Technology and intelligent operations in waste management as part of its initiative, GMC implemented digital tracking systems in 10 prototype neighbourhoods, where over 17,000 QR have been installed to monitor waste collection in real-time. Some of the GPS navigation systems in the garbage truck have incredibly optimized routes and efficiency. Such integration of QR-based monitoring and GPS tracking represents a decisive shift towards data-driven waste governance. Visions of sensor-enabled smart dumpsters are designed to increase automation of waste collection systems. These initiatives demonstrate GMC's vision of modernizing waste management infrastructure and building an information-based and technology-driven waste administration system. Despite notable achievements, the sector faces vital challenges like labour shortages, improper waste segregation, lack of adequate recycling facilities, and proper landfill management. Solutions to throwing enhance public awareness campaigns, increase investments in waste-to-energy projects, and promote secondary waste processing facilities. Most recently, GMC has introduced the latest technologies, focusing on intensive cleaning drives that include the use of a super sucker machine for drain desilting, among other measures. The company has also shifted its emphasis from road waste bins to door-to-door waste collection, segregation, and recycling of urban waste. In short, while Guwahati city is showing significant strides in its smart waste management efforts, filling the ongoing gaps in segregation, workforce capacity, and recycling infrastructure will be necessary to develop a functional circular waste economy. GMC's integrated vision of technocratic policy and public participation is a crucial step towards sustainable urban development.

MATERIALS AND METHODOLOGY

Data collection

This research utilized a mixed method that combines primary and secondary data sources to analyse Guwahati's MSW management system. The primary data collection consisted of extensive fieldwork and stakeholder engagement. The primary focus was to directly understand the realities of MSW handling by engaging in on-ground activities with the participants of the waste management process such as waste workers, street sweepers, drain labourers, hand cutters, auto tripper drivers and helpers. Data were also collected from the municipal corporation office, divisional offices, and various wards of Guwahati city. The primary data collection phase of the study was designed to capture both quantitative and qualitative insights into the MSW management system in Guwahati city. To achieve this, the research employed a field-based approach that combined direct observation with multi-level stakeholder engagement. Instead of relying on stakeholder interviews or discussions, this study focussed for a defined period as an intern paired with different participants of the waste management chain (e.g., municipal employees, divisional officers, sanitation and hygiene workers, garbage collectors, private contractors, and community-based organizations). This approach ensured that the research study outcomes were based on first-hand experiential understanding rather than reported opinions. This mixed-method strategy enabled a holistic understanding of how waste is generated, handled, transported, treated, and perceived at various administrative and community levels.

'Extensive fieldwork' was conducted across all the wards of the Guwahati Municipal Corporation

(GMC), with a focus on both model wards where smart waste management initiatives have been implemented and non-model wards. This component involved systematic site visits to waste collection points, secondary transfer stations, open dumping sites, and treatment facilities. The researchers documented key processes through field notes, photographs, and spatial mapping. Observational data were gathered on the condition of infrastructure, vehicle movement patterns, and segregation practices at the source and during collection. Community-level waste practices also play a significant role in shaping collection efficiency, as studies have shown that reliance on shared or community bins often leads to inefficiencies and localized environmental risks (Bredun et al., 2024). Instead, the research-based process provided direct immersion into different layers of the MSW system, allowing the researchers to experience first-hand the operational workflows, constraints, and systemic inefficiencies. This method strengthened the reliability of the field data by ensuring that the documentation reflected actual practices across collection, transportation, and disposal.

Mainly, site visits to secondary collection points, refuse transfer stations (RTS), and disposal sites provided insights into the challenges of waste segregation, transportation logistics, and processing inefficiencies, especially during festival occasions that further overload the waste management infrastructure. In Figure 4, the SWM system in Guwahati City is presented.

Waste collection and transportation

The waste collection methods in Guwahati aim to promote sustainable practices through efficient primary and secondary removal operations managed under the auspices of the Guwahati Municipal Corporation. Primary collection involves door-to-door retrieval and street cleaning to prevent accumulation, facilitated by GMC partnerships with local NGOs. Volunteers are responsible for household, commercial, and public space waste intake, which is deposited at secondary points using an assortment of conveyances to ensure broad access. A dual daily schedule entails morning and evening household rounds and daytime commercial retrieval. Colour-coded bins have been placed throughout residential and commercial districts to cultivate appropriate disposal habits. However, the lack of sorting at the source remains an enormous obstacle, necessitating heightened awareness initiatives to foster sustainable behaviour modification.

In the secondary phase, waste is transported from primary drop-offs, receptacles, and transfer stations to final destinations. GMC maintains 101 secondary collection containers and 97 vulnerable access points for temporary warehousing prior to ultimate removal. The secondary fleet comprises compacters, dump trucks, backhoes, skid steers, and vacuum trucks deployed to transport waste to four functioning refuse transfer stations, which serve as consolidation hubs optimizing movement. Additional proposed stations at Adabari, Old jail, Mathagharia, and Purbi dairy aim to reduce costs and accumulations at vulnerable points. Material from these transfer points is ultimately delivered to the Belortol dumping site, which replaced the former Boragaon landfill that was decommissioned due to environmental concerns surrounding Deepor Beel. GMC has also initiated biomining endeavours at Boragaon to reclaim resources from legacy refuse, treating approximately 711,000 metric tons as of July 2024. Integrating GPS monitoring in collection vehicles and QR-based oversight in model districts enhances efficiency through live-tracking progress and routes despite innovations, shortages, limited transfer stations, and inadequate segregation persist, demanding further investments and policies to advance systems. Table 1 illustrates the statistics of QR code in model ward.

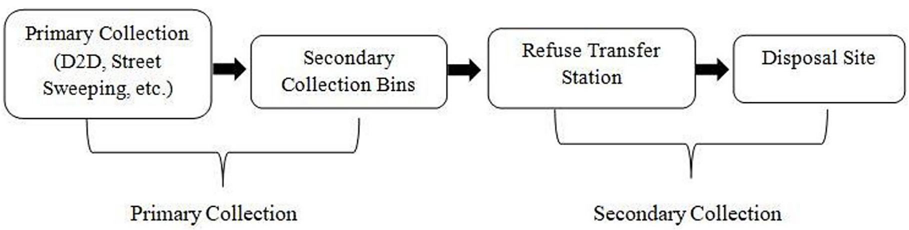

Figure 4. SWM system in Guwahati City

Segregation of waste

Ward-wise assessments of door-to-door waste collection but limited to residential and commercial waste retrieval through auto tippers, e-rickshaws, tri-cycles/ pushcarts/ handcarts formed the basis of primary data collection. The NGOs dropped collected waste into bins for secondary collection under the monitoring of Junior Technicians of the Organisation (JTOs) and sanitary inspectors of the jawans. In order to dispose of waste, GMC has installed a colour-coded roadside dustbin at commercial and residential buildings. Residential waste settings ranged from 5:00 to 8:00 A.M. and from 6:00 P.M. onwards. Meanwhile, commercial waste was collected from 6:00 to 9:00 A.M. and from 6:00 to 11:00 P.M. For secondary collection, commercial vehicles such as compactors, dumpers, backhoe loaders, and skid steer loaders collect wastes from multiple points for disposal at RTS facilities.

Secondary data were collected from GMC Headquarters, divisional offices, and annual reports, as well as from governmental databases that provided quantitative information about waste generation, collection efficiencies, and infrastructure status. To analyze waste transport performance, data from the Janxala Branch (Garage), which manages the allocation of the fleet for waste transport and historical information about landfill capacity performance, waste processing performance, and smart waste tracking systems were studied. Critical insights on evolving disposal strategies were gathered from reports of MSW disposal at Boragaon (earlier disposal site) and Belortol (new site). We categorized regulatory frameworks governing MSW management, including the Solid Waste Management Rules, 2016, as policy documents. Further data on waste-to-compost and waste-to-energy initiatives, material recovery facilities (MRFs), and QR code-based waste trackings implemented to ensure efficient segregation have helped to undertake a cross-sectional assessment of efficiency, systemic challenges and improvements in GMC's waste management strategy.

Table 1. Statistics of QR code in model ward

Sl. No.	Ward number	Division	QR linstallation (numbers)
1	18	IV	523
2	28	IV	2546
3	29	IV	877
4	31	II	948
5	32	II	1590
6	33	II	753
7	36	II	2411
8	48	V	765
9	49	V	1661
10	59	V	5298
Total			17372

Source segregation of waste is the first and most important step in waste management. The segregation is necessary since otherwise; mixed waste can be dumped in landfills without processing. Proper waste separation improves waste collection operation and recycling, especially in industries like construction, demolition and other waste-producing activities. In MSW, separating non-hazardous waste into wet and dry fractions is essential for enhanced recycling. The SWM systems in Guwahati are not segregated at the household and GMC levels. Today, rag pickers make money by segregating waste like paper, plastic or metal so that they can resell it. Per capita garbage generation has been derived from household and commercial sources in Guwahati. Based on the latest information from the GMC (tax department), there are 298,909 kitchen households in the city. With an average household size of five members, the total population comes out to be 1,494,545. This would estimate a total of 1,594,545 for the population considered in terms of waste generation with the addition of an estimated floating population of 100,000 The per capita household waste generation rate is 450 GPCD (grams per capita per day); turnout of total household waste generation:

$$1{,}594{,}545 \times 450 \text{ g} = 717{,}545{,}250 \text{ g} = 717.54 \text{ tons/day} \tag{1}$$

Similarly, commercial establishments, numbering 36,414, contribute waste at a rate of 1.70 kg per establishment per day, resulting in:

$$36{,}414 \times 1.70 \text{ kg} = 61{,}903.8 \text{ kg} = 61.90 \text{ tons/day} \tag{2}$$

So, the total MSW produced in Guwahati is 779.40 T/day. A study by Chakraborty et al. (2023) had previously estimated the average waste generation in the city at 550 tons per day. Nonetheless, it is now a high-volume waste generation case that must be managed. The gap between earlier estimates (550 T/day) and current data (779.40 T/day) highlights the accelerating pace of urban waste accumulation and underscores the urgency for scalable waste segregation and treatment strategies.

RESULTS

The current study highlighted a comprehensive investigation of MSW and its management scenario in Guwahati City. Guwahati is the largest metropolitan city in north-eastern India and the second largest metropolis in eastern India after Kolkata. It is also the capital city of the state of Assam, and the city is also listed under the 100 smart cities of India. The study investigated municipal waste handling, management, disposal, and treatment processes. GMC is divided into six (6) divisions, which are further divided into sixty (60) wards across the city (Table 2). The research aimed to identify the present status of waste management, which comprises the handling, processing, and disposal of waste, treatment facilities, waste-to-energy facilities, and sanitation. The investigation also identifies the model wards and their technology intervention and modernization for waste management, infrastructure development, transportation, and vehicle upgrades.

The spatial division of wards shows how GMC has distributed urban governance and waste collection responsibilities, enabled localized monitoring but also increased coordination challenges across zones. Table 3, 4 and 5 shows division Wise Bin point and GVP details, vehicle details for secondary collection, transportation and vehicle details for primary collection, transportation respectively.

The presence of 97 garbage vulnerable points (GVPs) indicates weak collection efficiency in certain zones despite adequate bin points, underlining the persistence of unregulated dumping.

The vehicle fleet for secondary collection shows moderate mechanization; however, the relatively low number of compactors and sweepers compared to city size highlights an operational gap.

The reliance on auto tippers and tricycles indicates that primary collection is still labour-intensive, requiring capacity upgrades to handle rising waste volumes.

Refuse transfer station (RTS)

The GMC is utilizing the disposal site near Boragaon to address the need to dispose of municipal solid waste. However, in major urban areas such as Guwahati, RTS (Table 6) is built to minimize the additional transportation expenses associated with directly transferring waste to the disposal location. The concept underlying the transfer station is to relocate waste within a confined area instead of an exposed one (Figure 4). All vehicles, including door-to-door vehicles, tractors, and trucks, deposit garbage at designated RTS (Figure 5) in different divisions. Table 7 shows proposed RTS by Guwahati Municipal Corporation.

Waste processing and treatment

The term ”processing and treatment” refers to any procedure that alters the waste’s physical, chemical, or biological properties or composition in order to lessen its volume and hazardousness like biomedical waste. The goal of waste treatment is to lessen the waste’s toxicity, increase its physical and chemical properties, and decrease its overall volume (Choudhury et al., 2024b). GMC has two waste processing facilities as mentioned in (Table 8). Figure 7 illustrated treatment facilities & disposal site of GMC.

Table 2. Distribution of wards

Sl. No.	Divisions	Ward number	Revenue zone
1	I	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15	West zone
2	II	17, 31, 32, 33, 34, 35, 36	South zone
3	III	37, 38, 39, 40, 50, 52, 53, 54, 55, 56, 57, 58	East zone
4	IV	16, 18, 19, 28, 29, 30	Central zone
5	V	41, 42, 43, 44, 45, 46, 47, 48, 49, 51, 59, 60	Dispur zone
6	VI	10, 20, 21, 22, 23, 24, 25, 26, 27	Lokhora zone

Table 3. Bin point and GVP details division wise

Sl. No.	Division	Existing bin point (Nos)	Garbage vulnerable points (GVP)
1	I	14	9
2	II	10	18
3	III	18	10
4	IV	8	25
5	V	27	35
6	VI	24	NIL
Total		101	97

Waste to compost

Excel Industries Limited, India's oldest and largest indigenous agrochemical company, installs organic waste converter equipment. The plant was officially opened on March 27, 2018. The Guwahati Municipal Corporation has erected an organic waste converter near the Guwahati Medical College and Hospital (GMCH) in Bhangagarh under division 3 (Figure 8). The purpose of this installation is to recycle the organic waste generated by hospitals and city hotels. The purpose of its design is to transform 2.50 metric tonnes of organic waste. Approximately 250 kilograms of manure is expected to be generated on a daily basis. GMC has also proposed compost cum RDF plant, as mentioned in (Table 9).

Waste to energy (bio-methanation plant)

The Guwahati Municipal Corporation has undertaken the task of reinstating the operation of the Bio methanation plant located in the Paltan Bazaar area. The GMC has employed GPS renewable technology to develop commission, operate, and maintain a bio methanation cum Electric Energy plant (Figure 8) with a capacity of 05 TPD. This plant generates energy from organic municipal waste. The technique involves the controlled decomposition of organic waste without oxygen. On August 13, 2020, the facility opened in Chabipool, Paltanbazar, Guwahati under division 4. It occupies an area of 3000 square feet. The apparatus is a bio-methanation reactor with a high conversion rate that transforms organic waste into energy in the form of biogas. This biogas is subsequently utilized to produce environmentally friendly power. The plant can transform 5000 kilograms of biowaste into 800 units of power and 450 kilograms of manure. The generated electricity can illuminate the street lights in the surrounding areas. GMC has also proposed a bio-methanation plant for more energy generation, as mentioned in

Table 4. The vehicle details for the secondary collection and transportation

Sl. No.	Type of vehicle	No. of vehicles on road	Capacity
1	Backhoe loader	19	-
2	Skid steer loader	11	-
3	Dumpers	25	5 Cu M–6, 8.5 Cu M–6, 10 Cu M–15
4	Garbage compactor	16	14 Cu M
5	Portable compactor	1	14 Cu M
6	Road sweeper	2	5 Cu M
7	Water sprinkler (NCAP)	3	3000 ltrs
8	Desilting machine (super sucker)	22	10000 ltrs
9	Dump tank	20	-
10	Vacuum machine	10	-
11	Cesspool vehicle	5	3000 ltrs–1, 1500 ltrs–3, 500 ltrs–2

Table 5. The vehicles engaged for the primary collection and transportation

Sl. No.	Type of vehicle	No. of vehicles on road	Capacity
1	E-Cart (primary collection)	67	0.9 Cu M
2	E-Cart (divisional work)	24	0.9 Cu M
3	Auto tipper	117	2 Cu M
4	Tricycle (NGO-maintained)	98	-

Table 6. Refuse transfer station details of GMC

No.	SWM Facility	Capacity (TPD)	Location	Latitude	Longitude	Status	Division
1	Near nursery, RGB road	20 TDP (as per waste received)	Zoo road	26.15	91.78	Running	3
2	Near GMCH, Bhangagarh	12 TDP (as per waste received)	Bhangagarh	26.16	91.77	Running	3
3	Pathar quarry, VIP road	15 TDP (as per waste received)	VIP road	26.16	91.74	Running	3
4	Chabipul near Borsola Beel	7 TDP (as per waste received)	Chatribari	26.16	91.82	Running	4

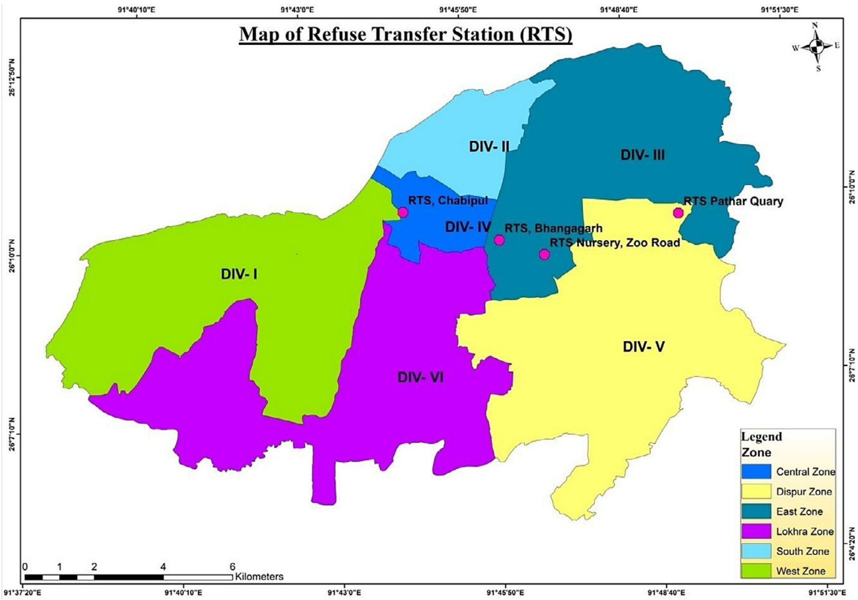

Figure 5. Existing RTS

Figure 6. RTS near nursery, RGB road

(Figure 9). GMC has also proposed a Bio methanation plant for more recycling and reuse of waste products, as mentioned in (Table 10).

Material recovery facility plant

According to the SWM rules, 2016, a materials recovery facility (MRF) is a facility where the local body or any other party can temporarily keep non-compostable solid waste.

A material recovery plant receives waste materials, whether sorted by source or mixed, and then separates, processes, and stores them for future use as raw materials in remanufacturing, reusing, and reprocessing. The function of the MRF plant is an intermediary stage in collecting

Table 7. Proposed RTS by GMC

Sl. No.	Name of transfer station	Capacity (TDP)
1	Adabari RTS	150
2	Old jail	150
3	Mathagharia	75
4	Purbidairy	50

recyclable materials from waste generators and selling them to the recycling market, as well as for other processes and industries. They also handle non-recyclables, RDF, and inert materials. GMC has an MRF plant near the Adabari Bus stand (Figure 10), which is under division 1, with a capacity of 5 TDP, which is also extendable to 10 TPD productions. GMC has also proposed an MRF plant for more recycling and reuse of waste products, as mentioned in (Table 11).

Disposal of waste

Since 2004, GMC has been depositing the garbage collected during the secondary collection at the Boragaon disposal site. The GMC established

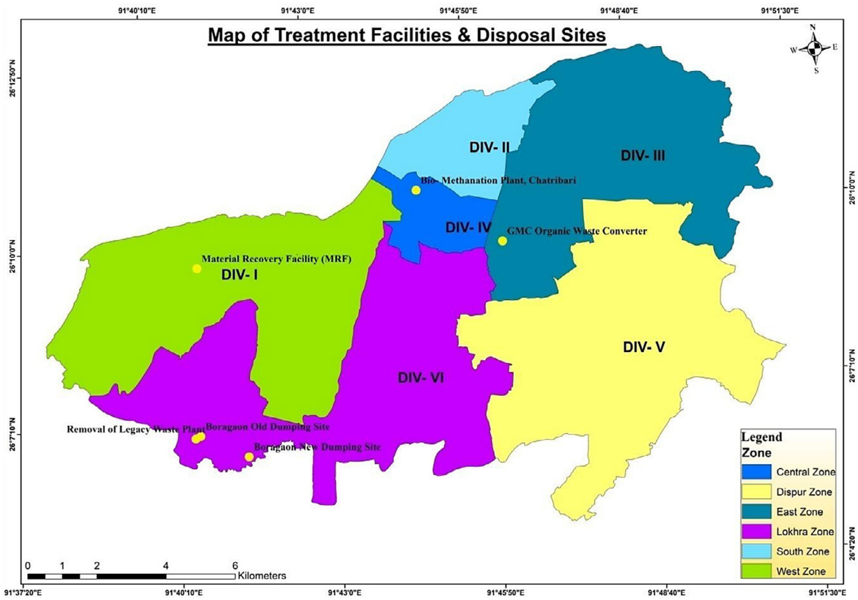

Figure 7. Treatment facilities and disposal site of GMC

Table 8. Waste processing plant

Sl. No.	SWM facility	Capacity (TPD)	Location	Status	Division
1	OWC: organic waste converter (compost)	2.5	Bhangagarh	Running	Div-3
2	Bio-methanation plant (waste to energy)	5	Chatribari	Running	Div-4

Figure 8. Organic waste converter, Bhagagarh, Guwahati

Table 9. Proposed compost cum RDF plant by GMC

Sl. No	Compost cum RDF plant	Capacity
1	Belortol, Guwahati	150 TDP

Table 10. Proposed Bio-Mithanation Plant by GMC

Sl. No	Bio-mithanation plant	Capacity (TDP)
1	Adabari	50
2	Paltan Bazaar	10

the Boragaon dumping site (Figure 11), which spans an area of 120 bighas. In this area, almost 1.7 million metric tons of municipal solid trash is deposited. The location is 10 km away from the city. Insufficient segregation at the source and collection in the city makes it challenging to process and recover materials, resulting in the need to discard all garbage in a mixed state.

To preserve the delicate ecosystem of the water body known as Deepor Beel, the GMC ceased the transportation of solid waste to the previous dump site in West Boragaon on June 28, 2021. Starting on August 10, 2021, the (GMC) relocated the solid garbage to Belortol in West Boragaon (Figure 11). The property is situated 700 metres away from the previous dumping facility.

GMC took the initiative to process the legacy waste. The technique involves removing legacy waste through the bio-mining process. In the first phase, 3.61,000 tonnes of legacy waste were treated by engaging NEET Pvt. Ltd. In the second phase of the treatment of remaining waste, M/S, Zigma Global Environ Solutions Private Limited (January 19, 2024) has been engaged with a 36-month completion period. 3 50,000 tonnes of waste have been treated up to July 18, 2024. As of now, a total of 711,000 metric tonnes of waste have been treated.

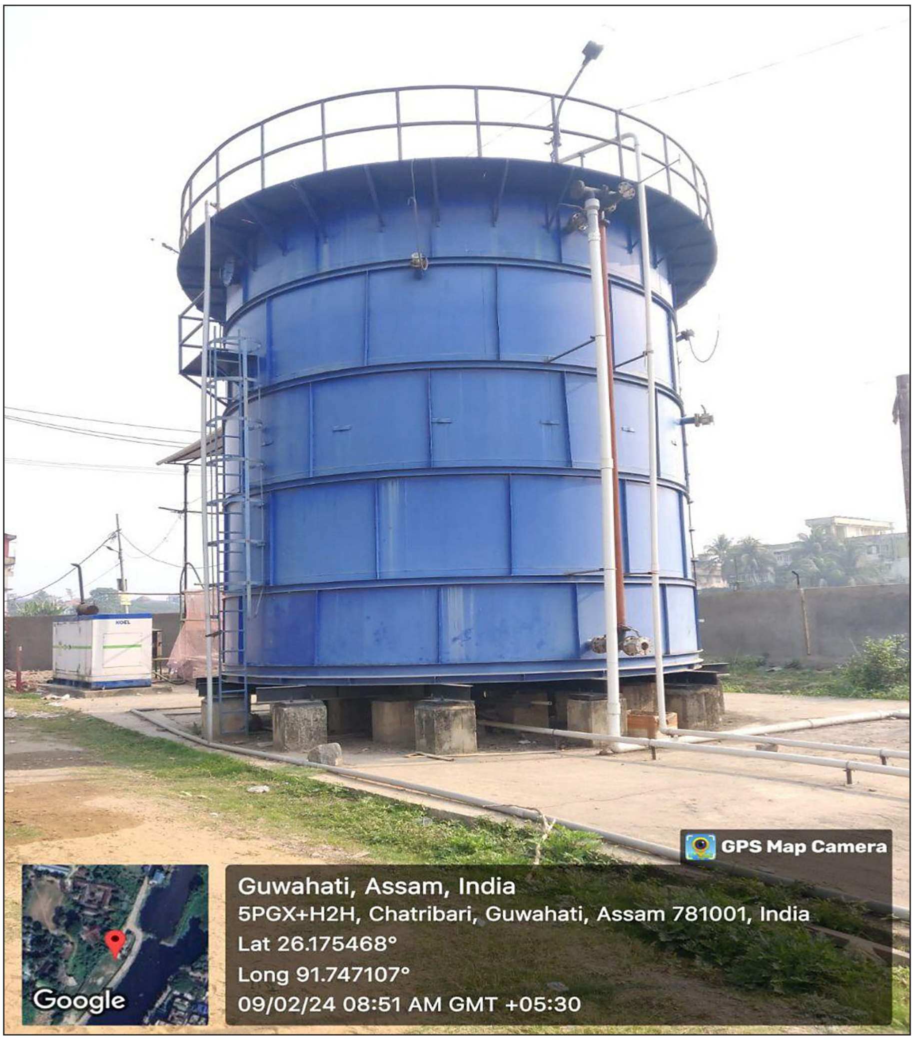

Figure 9. Bio-methanation plant, Chatribari

Table 11. Proposed MRF by GMC

Sl. No	MRF plant	Capacity (TDP)
1	Adabari	100
2	Old jail	100
3	Mathagharia	25
4	Purbi dairy	15

The by-product from the bio-mining process is as follows: glass metal, stainless steel, footwear, RDF, HD plastic (more than 6 mm), tyre, 6 mm soil, in-ward MSW, C & D, iron, wood (Figure 12).

Model wards

GMC has recognised ten numbers of wards as a model ward (Table 12) GMC has some criteria indicators for the model wards, as they have chosen ward no 48, which comes under division V as the first model ward because 100 per cent of the garbage in the ward is collected by primary collection. It was also seen that the household does the proper practice of storing and accumulating waste in a proper dustbin and in an adequate way. CCTV cameras have also been installed to monitor the activity of residents regarding the appropriate storage and disposal of garbage. In this regard, the corporation has taken a few steps with the help of technological intervention to better manage the city's waste management system. In these model wards, the GMC has developed an application with a QR code (Figure 13) for real-time information regarding door-to-door waste collection. The process involves adhering QR codes to the exterior walls of the household. The waste collection personnel install the application to facilitate QR scanning. With the help of QR code scanning by the waste collector, real-time waste collection can be measured accurately.

Figure 10. Material recovery facility (MRF), Adabari, Guwahati, Assam, India

Figure 11. Old dumping site (Boragaon)

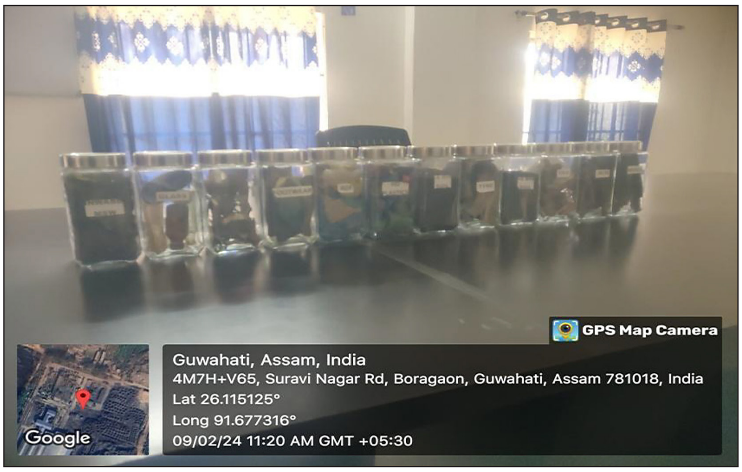

Figure 12. Sample of output by-product of bio-mining process

Table 12. Statistics of QR code in model ward

Sl. No.	Ward number	Division	QR installation (numbers) as of June/2024
1	18	IV	523
2	28	IV	2546
3	29	IV	877
4	31	II	948
5	32	II	1590
6	33	II	753
7	36	II	2411
8	48	V	765
9	49	V	1661
10	59	V	5298
Total			17372

In terms of technological intervention, GMC has taken the initiative of using a tracker and monitoring device in the primary collection vehicle for real-time updates and finding the efficiency of garbage collection from the household.

Technological innovations

In a bid to make MSW management more efficient, transparent and real-time, the (GMC) has brought in technological innovations.

Notably among these innovations are tracking of waste through QR codes, GPS monitoring of waste collection vehicles, and the spread of digital monitoring systems to optimize waste collection and reduce operational logistic gaps while improving overall waste governance. Innovative waste management solutions are being integrated as part of the city's objective to make a shift toward a data-driven and technology-enabled urban sanitation system. Among them, the QR code-based waste tracking system is one of the significant technological interventions introduced by GMC, which has been installed in 10 model wards with a total of 17,372 QR codes. Door to door waste management system will monitor (in real-time) various door-to-door waste collection details (completed, work pending, collection missing, garbage not picked up) by municipal (rajuk, mustaq etc) authorities. A unique QR code is issued to each household and commercial establishment, which is scanned by the waste collection personnel as an authentication for waste pickup. The e-waste digital verification system – like other efficient waste management processes, this digital verification system adds accountability to waste management operations, maximizing efficiency and minimizing incidents of missed or delayed waste collection that directly impact the sanitation of selected wards. A citywide rollout of QR code tracking to monitor solid waste management across all municipal wards will also help optimize the solid waste collection process and adherence to segregated waste disposal at the household level.

Apart from the QR-based tracking system, the GMC has installed a GPS tracking system in waste collection vehicles to optimize the waste transportation routes and monitor the fleet in real-time. Vehicles are equipped with GPS trackers that can help municipal authorities keep track of route efficiency and fuel savings and provide information to serve the community, allowing cities to avoid running pickups out of schedule." In regions where waste generation rates are high, and transportation logistics are complicated, we have seen even better returns on investment in the form of improved route optimization, decreased collection delays, and overall improvements in operational efficiency with the integration of

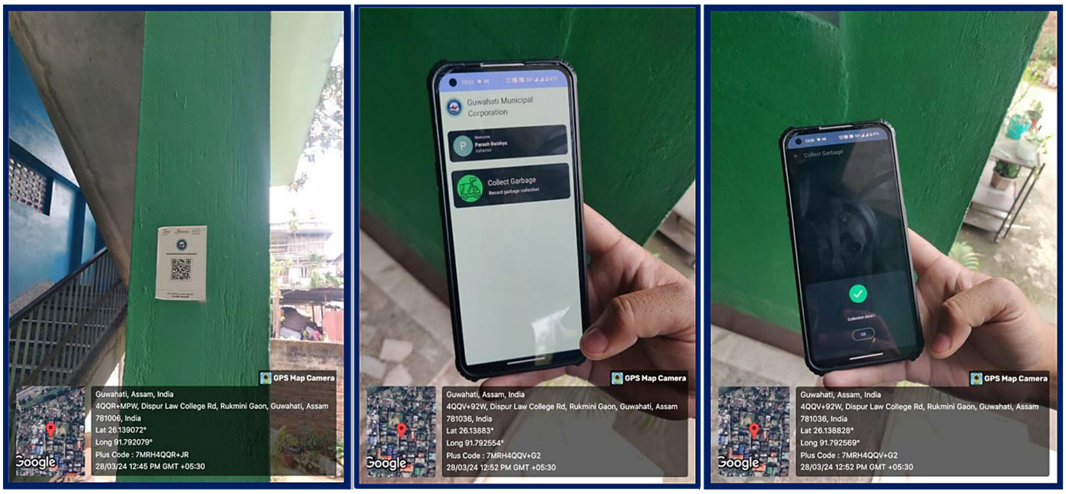

Figure 13. QR code scanned by the garbage collector

GPS tracking. Moreover, this delay also prevents proper integration between phases of waste collection at primary and secondary locations where waste needs to be moved from door-to-door collection to transfer stations and eventually to garbage vulnerable points (GVPs) and to disposal or processing shelters.

GMC has also started to take steps to ensure that its waste management systems are more effective through the introduction of digital monitoring systems, sensor-based smart bins, automated waste segregation technologies, and AI-driven waste analytics. Smart bins with fill-level sensors will be deployed, allowing them to automatically notify when they need to be emptied, reducing overflow. Moreover, the incorporation of cloud-based waste management platforms helps municipal officials acquire real-time data related to collection frequency, waste volumes, and scheme performance. It will yield data-driven decision-making pertaining to waste management in terms of policy and infrastructure planning. These ranges of digitalization efforts encourage efficiency, facilitate better resource allocation, and strengthen citizen participation in sustainable waste disposal activities.

These advancements notwithstanding, limitations such as gaps in peripheral infrastructure, low levels of digital literacy among waste collection personnel, and the need for increased public participation in waste monitoring efforts abound. Increasing awareness of the need for waste management, as well as training workforce cases would be necessary for the scaling of waste management solutions across Guwahati. Smart waste ideas for Guwahati Job street includes the following solution for the smart cities – ideal smart cities local initiative, community owned/funded plastic circular economy, producers are responsible for waste natural gas from wastewater disposal. Provide a dumpster wapping – send volunteers to collect wastewater collecting staff, dumpster, education and counselling for the community to use the dumpster.

DISCUSSION

Current status

The state of MSW management in the city of Guwahati reflects both the challenges of a fast-growing city and the promising measures that some local authorities have taken to address the growing waste problem. GMC has been in charge of waste collection, transportation, processing, and disposal, although key challenges like infrastructural deficiencies, inadequately allocated workforce, and lack of source-level waste segregation persist. The total waste generated in Guwahati is approximately 779.40 metric tons per day (TPD), of which households contribute 717.54 TPD and commercial establishments contribute 61.90 TPD. Guwahati's solid waste management system suffers from terribly sore operational bottlenecks adversely impacting service efficiency, environmental sustainability and regulatory compliance despite the adoption of contemporary waste collection technologies and decentralized waste processing initiatives.

Waste collection and transportation, one of the main problems of cities, also suffers from uneven service efficiency between the wards of the town. Waste collection methods differ dramatically between wards, with some enjoying door-to-door collection, street sweeping and NGOs picking up waste. In contrast, others receive delayed or sporadic waste pickup, insufficient waste disposal points and lack of secondary collection infrastructure. Furthermore, the presence of GVPs in different areas suggests that there are gaps in waste disposal due to rampant uncontrolled dumping. In addition, the lack of collection vehicles, old road-sweeping machines and maintenance delays prevent effective waste management operations, especially within high-density urban concentration and informal settlements.

Recommendations for Improvement

Proper waste segregation at the household level is also another significant issue that has a direct impact on the outcome of any waste processing and recycling initiatives. The waste generated at the household and commercial levels is mixed primarily, thus limiting composting, bio-methanation, and material recovery facilities (MRFs). Then there is this informal sector of waste collectors (rag pickers) who sort and recover recyclable materials. Still, lack of formal integration with municipal waste management systems comes in their way to operate effectively. Efforts towards education and enforcement of regulations on source segregation continue to remain deficient, leading to sustained challenges in recycling and sustainable waste utilization.

GMC shifts landfill site – in waste disposal and management of landfill, Guwahati Corporation shifted to dump in Belortol from Boragaon Tinsukia in view of the environmental issue of Deepor Beel (a Ramsar site). However, basic engineered landfill infrastructure is not available, unscientific disposal continues, and the capacity for landfill waste processing remains grossly inadequate to all of which keeps groundwater contamination, methane emissions and ecosystem degradation at risk. Bio-mining initiatives, such as the one at Boragaon, which has treated 711,000 metric tons of legacy garbage, can be considered progress since landfills are getting cleaned up, and resources are being recovered. The need for growth in waste-to-energy projects, composting, and modern recycling centres still exists, as these are vital to lessening landfill reliance of growing waste cities.

Even with the introduction of QR code-based waste tracking systems, GPS tracking for waste collection vehicles and expansions in the availability of digital waste monitoring systems, 10 the city still suffers from several obstacles regarding the integration of technology and the scalability of innovative waste management systems. Workforce component training gaps, lack of public involvement in digital waste monitoring, and infrastructure limitations have reduced the efficiency of innovative waste interventions. To overcome the challenges mentioned above and develop an efficient and environmentally responsible waste management system in Guwahati, policy enforcement must be strengthened, financial investment in waste management infrastructure must be increased, and citizen engagement in sustainable waste practices must be fostered.

One of the most crucial aspects that take place in relation to the recycling process is public awareness, as segregating waste and disposing of it responsibly is essential for sustainable development. This often affects the effectiveness of composting, bio-methanation and material recovery facilities (MRFs), as many households and commercial units throw waste in mixed form. Making people aware in their localities and educating them about the imminent threat of waste, combined with incentives, which is the process of offering an incentive (often monetary) for adherence to environmental policy measures, would significantly enable citizens and the local authorities right from the individual household level up till the community levels to manage waste effectively. The collaboration between GMC, NGOs, and RWAs should be further strengthened in order to promote waste segregation at source, minimize the waste bound for landfills, and maximize recycling efficiency.

Improving waste-to-energy (WTE) and recycling projects is also an essential recommendation for enhancing Guwahati's waste management system. The 5 TPD bio-methanation plant at Chatribari currently generates 800 units of electricity/day, which is considerably less than the city's processing capacity of organic waste in total waste. Moreover, the project is expected to augment renewable energy production and reduce organic waste disposal as the bio-methanation plants at Adabari (50 TPD) and Paltan Bazaar (10 TPD) will help augment biogas production. Furthermore, the construction of a 150 TPD compost-cum-RDF (refuse-derived fuel) facility at Belortol will process organic waste and recover energy, ensuring alignment with the circular waste economy of the region. The existing MRFs at Old jail, Mathagharia and Purbi dairy will also be expanded to improve segregation, sorting, and reuse of recyclable materials so as to minimize the burden on landfills and recover sustainable materials.

Enhancing monitoring of waste practices and ensuring policy enforcement is also critical for holding people accountable, adhering to regulations and operating efficiently. 10 model wards have implemented QR code-based waste tracking systems, with 17372 QR installations that help facilitate real-time monitoring of waste collection services. Scaling this program citywide will only improve transparency and service delivery. There is also a need to scale up GPS tracking of waste collection vehicles to optimize transport routes, reduce fuel consumption and avoid collection delays. Strengthening mechanisms for regulatory enforcement will also provide incentives to adhere to waste management policies, for example, by increasing penalties for erroneous waste segregation norms and incentivizing sustainable disposal practices. Overall governance of waste management in Guwahati can further be improved through regular audits, performance assessments and stakeholder participation in policy-making.

Preventing the fraud from cropping up again would require working hand-in-hand with government authorities, private stakeholders, and citizens to implement these recommendations. However, by combining workforce extension, infrastructure improvement, the latest waste treatment technologies, and regulatory enhancement, Guwahati can develop a waste disposal mechanism that is less efficient and more environmentally friendly, among the best for any city in the world.

Role of citizens and authorities

The role of citizens and authorities is vital for the efficient management of MSW in Guwahati as sustainable waste management involves a synergistic approach toward behavioral change, policy implementation and infrastructure development. Absence of adequate waste segregation at the source has been one of the core challenges for the GMC, severely curbing the scope of waste processing, composting and recycling efforts. Citizen behavioral change, such as making sure waste is separated into biodegradable and non-biodegradable ingredients, limiting littering behavior, and encouraging proper waste disposal, will be a key contributor to reducing the burden on landfills and enabling a circular economy. Most homes and commercial establishments today dispose of mixed waste resulting in the burden of such waste on the waste processing facilities, biomethanation plants and MRFs. Improving public awareness campaigns, as well as school-based education programs and incentivized waste segregation could also encourage behavioral change in the long term, resulting in better adherence to sustainable waste disposal norms.

Government authorities, municipal bodies, and regulatory agencies are equally crucial partners in ensuring the successful implementation of MSW management policies together with citizen participation. The GMC has also added initiatives such as implementing door-to-door waste collection and QR code-based waste tracking, as well as GPS monitoring of waste collection vehicles, in order to improve efficiency and service accountability at the same time. This is especially true as far as waste segregation and greater penalties for non-compliance go, along with more investment for waste processing as sustainable waste management is important. The authorities need to expand waste-to-energy facilities, establish more refuse transfer stations (RTS), and develop decentralized composting systems to support waste collection and reduce direct disposal to landfills.

By working together with public and private organizations, non-profit organizations, and local residents to increase the efficiency of waste treatment and create more responsibility for our planet. Facilitating community engagement initiatives, forming citizen-led waste monitoring committees, and integrating rag pickers (informal waste collectors) into formal recycling networks can drastically improve waste recovery rates. Furthermore, using smart waste monitoring technology, AI-based waste analytics and automated segregation technologies, authorities must develop data-driven decision-making processes that can take waste management operations to the next level. Regular audits, transparent reporting and involvement of stakeholders in waste management policy formulation will enhance the long-term sustainability of Guwahati's waste management system.

So, the onus of MSW management falls upon the effort of both citizens and municipal authorities. A cleaner, healthier and more environmentally sustainable urban ecosystem is achievable through these collective strategies of cultivating responsible waste disposal behaviours, enforcing sustainable waste management policies, and investing in innovative waste processing technologies.

The way forward perspectives

The future of municipal solid waste management in Guwahati depends on sustainable evaluation, technological innovation, and policy-driven sustainability. City development and waste generation growth implications indicate that the GMC should leverage data-centric strategies, technological advancements, and sustainable management to secure long-term efficiency. Ongoing performance evaluations of waste collection, processing, and management systems will help identify key operational challenges and enhance service delivery. For example, QR code-based waste-tracking expansion, GPS-enabled tracked garbage vans, and Artificial Intelligence-based waste analytics will optimize waste logistics and increase accountability and evidence-based decision-making for urban cleanliness planning. Moreover, investments in refuse segregation technology, sensor-based can technology, and their installation should be made. Then, the resource recovery and waste management system can be more efficient and sustainable. Beyond that, Sensor-based technology can also be used for waste collection management, and then the can will indicate how much waste is disposed of purposely, the tracking systems assist AI in analytics to track waste, compare day-after data, and verify AI analytics.

Technological development initiatives should also prioritize waste-to-energy production and recycling to promote circular waste economics and reduce dependence on landfills. In parallel, exploring bio-based alternatives, such as the use of seaweeds with demonstrated antioxidant potential, highlights the broader opportunities of integrating natural resources into sustainable environmental management (Cokrowati et al., 2025). Such approaches not only support waste valorization but also contribute to ecological resilience and green innovation within smart city frameworks. Bio-methanation plants in Adabari should be expanded by 50 tons per day, and Paltan Bazaar should be developed by an additional 10 tons per day. The proposed 150 tons per day compost cum-RDF plant is to be shifted to Belortol for additional phases owing to the increased requirement of organic waste conversion to be designed in waste segregation. Rented plants are located in the Old jail, Mathagharia, Purbi dairy, and district compost plants. Integration of waste sorting technology, robots for processing waste, and decentralized composting achieves sustainability. Long-term policies for stability should focus on enforcement, public interaction, and investment in infrastructure and financial waste management. Regular monitoring and compliance with enacted laws, particularly relevant to data management enterprises, can encourage citizens to participate actively. Public-private partnerships enable private investors to explore innovative tech waste management solutions. Policies can be developed to reduce Waste and its effects, capture carbon emissions, and support waste management policies. Conducting periodic reviews, involving the public, and enacting property-based laws are vital for building sustainability and achieving waste management. A comprehensive approach that combines technology, policy, and citizenship participation is necessary to establish a zero-waste system and environmentally responsible urban culture.

Branched smart management systems and WTE manufacturing solutions, supported by sound regulations, are essential steps toward achieving zero landfill waste, with recycling being a chief priority. By employing such strategies, the capital Guwahati will ensure zero waste and a secure ecosystem. A pulse air sorting plant and vegetable waste management shall be proposed. Ecomark can be used to sell various products, including beverage cans. Rented plants, such as Old jail, Mathagharia, and Purbi dairy, can also be managed by the waste department, as can the material recovery facilities maps for the second and third districts. Furthermore, the installation and coordination of senior plants are described above. Energy extraction, as a result, will lead to enviably efficient and sustainable resource recovery and waste management systems.

CONCLUSIONS

Proper and effective MSW in Guwahati is timely and relevant, with direct implications on environmental sustainability, public health, and economic optimization of resources. Urban sanitation has improved due to the establishment of structured waste collection systems, waste processing technologies, and the introduction of policy-driven interventions to reduce urban waste and minimize pollution. Effective MSW management prevents air, soil, and water pollution and the consequent adverse effects on biodiversity and human health. By composting or treating organic waste in bio-methanation plants, Guwahati has been preventing this waste from rotting in landfills, where it emits methane is one of the potent climate change-inducing gases. At the same time, the scientific management of municipal waste at the Belortol landfill has been vital for maintaining the ecological balance by protecting the Deepor Beel Wetland, which is a Ramsar site of international significance. From a perspective more centred on the people, an efficient waste management system directly enhances public health by reducing disease transmission, limiting its spread through hazardous waste, and improving general urban hygiene. Similarly, the accumulation of garbage has provided a breeding ground for vectors like mosquitoes and rodents and increased the spread of infectious diseases such as dengue and malaria, as well as gastrointestinal diseases. The systems of door-to-door waste collection, tracking waste via QR code, and tracking waste collection vehicles using GPS technology have increased transparency and efficiency of service, making it easier than ever for service providers to ensure that waste is picked up when it should be and not put the public at risk of sanitation problems.

Public awareness campaigns promoting source segregation and responsible waste disposal practices have also motivated local citizens to contribute to a cleaner urban setting. An efficient MSW management system is also essential in promoting the principles of the circular economy and conservation of resources. The proposed compost-cum-refuse derived fuel (RDF) plant at Belortol, together with the expansion of MRFs, will go a long way in repurposing and recycling waste that otherwise would have led to extracting raw materials. From bio-methanation plants at Chatribari, Adabari, and Paltan Bazaar to renewable energy production, the implementations of such projects embody a shift in urban energy you would expect to see in a greener future. Bio-mining efforts at the legacy landfill site at Boragaon have processed 711,000 metric tons of old waste and succeeded in recovering recyclables such as PET bottles for reuse in industrial processing to make new products, also successfully reclaiming valuable land. By utilizing these waste recovery techniques, economic sustainability is improved, new jobs are established in the waste management industry, and continuous landfill upkeep costs are minimized over time. In the future, further development of waste processing facilities, stricter enforcement of waste management regulations, and increased public involvement will be crucial for maintaining and improving waste management outcomes in Guwahati. This ambition may seem far-fetched as the nation contemplates strategies for 5 million + tons of waste per annum. Still, better policy frameworks, data-driven waste management solutions, and more decentralized waste treatment technologies will build efficiencies with sustainability and resilience and drive them into the city's MSW system. Thus, by embracing technological innovations along with behavioural change programs and the principles of a circular economy, Guwahati city can create a remarkable, holistic, sustainable, and economically feasible waste management system that will promote a cleaner and healthier future for its citizens, as recently, Guwahati city has been awarded the Promising Swachh Shehar Award under the 3–10 lakh population category in the national Swachh Survekshan 2024 rankings by the Government of India for its remarkable improvement in urban waste management process.

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