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Recent Trends In Solid Waste Management Techniques

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Abstract
India's rapid urban expansion and evolving consumption patterns have significantly heightened the challenges of solid waste management (SWM), calling for more sustainable and innovative approaches. This research evaluates the performance of contemporary SWM practices in five Indian cities, including Pune, Indore, Kochi, Ahmedabad, and Guwahati, by examining their operational efficiency, environmental outcomes, cost viability, and public satisfaction. Utilizing a mixed-methods design, the study integrates data from field surveys, stakeholder interviews, waste composition audits, and secondary municipal records. Findings indicate that biodegradable materials constitute the largest portion of municipal waste (ranging from 44.3% to 52.1%), presenting opportunities for composting and waste-to-energy initiatives. Indore demonstrated exceptional performance, achieving 97.2% waste collection efficiency, 82.1% source segregation, energy recovery of 245 kWh per tonne, and the lowest operational cost (INR 1480/tonne), alongside the highest satisfaction score (4.5/5). In contrast, Kochi and Guwahati faced challenges with lower segregation rates and weaker service coverage. The study concludes that sustainable SWM outcomes rely not only on technological advancements but also on integrated governance, strategic planning, and active citizen engagement.

Keywords: *Solid waste management, Biodegradable waste, Collection efficiency, Public satisfaction, Cost analysis*

INTRODUCTION

The rise in urban population, high industrialization rate, and emerging consumption trends have largely been responsible for the excessive generation of municipal solid waste (MSW) globally (Voukkali et al., 2024). The World Bank (2022) reports that in 2020, the world produced more than 2.24 billion tonnes of MSW, and the trend is expected to rise to 3.4 billion tonnes by 2050 unless remedial measures are taken (Louzizi et al., 2024). This increase in waste generation poses serious environmental, socio-economic, and health risks, especially in low and middle-income countries where the waste management system is usually not developed. The environmental degradation is influenced by soil, water pollution, air pollution, and greenhouse gas emissions due to the inappropriate handling, open dumping, uncontrolled landfilling, and burning (Siddiqua et al., 2022). Historically, waste disposal has relied on landfills and open burning or incineration. Although the use of such techniques has not been completely stopped due to their easy application and low short-term cost, multiple drawbacks are also associated with them in the long term (Maalouf and Agamuthu, 2023). The primary contributor of methane, a greenhouse gas (GHG), is landfills, where the global warming potential of this gas is 25 times greater than carbon dioxide in 100 years (Gupta et al., 2022). Due to poor emission control and poor energy recovery systems, such toxic fumes as heavy metals, dioxins, and furans were emitted during the incineration (Damgaard et al., 2010). Communities already burdened by environmental imbalances face heightened vulnerability to serious health risks, including respiratory diseases and colorectal cancer (Akai-Tetteh, 2021). Because of these developing problems, this area of solid waste management has changed completely during the last two decades. The multi-linear collect-transport-dispose system has gradually been replaced by circular systems, which concentrate on waste reduction, material reuse, and resource efficiency (Pribadi, 2017).

Innovations in solid waste technology are an example of breakthroughs in alternative and sustainable forms of waste management. Waste-to-energy (WTE) (e.g., anaerobic digestion, gasification, pyrolysis, refuse-derived fuel production) technologies are applied for converting combustible and organic waste materials to useful energy (Bishoge et al., 2019). Anaerobic digestion minimizes emissions of methane while the organic waste is decomposed, and generates biogas, enabling the energy to be utilized as renewable energy. Advanced emission control technologies are used to minimize pollutants, e.g., for thermal treatment processes.

Digitalization has transformed the waste collection, sorting, and treatment systems in conjunction with technological advances. Internet of Things (IoT), artificial intelligence (AI), machine learning, and geographic information systems (GIS) have been brought into play to enhance the efficiency of operations, reduce costs, and raise transparency through smart waste management (Sharma, 2023). For example, sensor-based waste bins that measure fill levels can optimize collection routes in real-time, helping to reduce fuel consumption as well as carbon emissions. AI-powered automated sorting systems can sort recyclables with high accuracy, and can improve material recovery rates and help reduce reliance on landfilling (Olawade et al., 2024).

Biological and biochemical development provide sustainable options, including biodegradability of waste streams. Microbial inoculants and controlled oxygenation have accelerated composting techniques, resulting in not only faster degradation but higher quality compost (Zhou et al., 2022). Enzymatic and microbial processes are solutions for dealing with plastic waste, which have been increasingly recognized as a recalcitrant (and damaging) pollutant in terrestrial and marine ecosystems (Dhali et al., 2024). At the moment, these options are mostly in the innovation phase, but they are promising biotechnological solutions to long-term mitigation of synthetic polymer pollution.

Irrespective of these developments, modern solid waste management practices are not adopted and effective in all countries and regions. This has been facilitated by strong institutional systems, investments in technology, and policy incentives. In contrast, most developing nations still have to contend with limitations like inadequate funding, technical advancements, divided governance systems, and poor awareness among the masses. Informal waste workers are crucial in waste recovery and recycling in such contexts; it is difficult to integrate them into formal systems because of regulatory and socio-economic complexities.

The policy and regulation environment is a determining factor in the practice of SWM. As an example, the Waste Framework Directive of the European Union lists a five-step waste hierarchy where prevention, reuse, recycling, recovery, and disposal are, in that order, the most preferred steps (Ongey, 2023). In other areas like Southeast Asia and Sub-Saharan Africa, other similar frameworks are being implemented, usually with the help of international development agencies. The Extended Producer Responsibility (EPR) policies, specifically, have become popular in the management of packaging and electronic waste because they make manufacturers responsible for the end-of-life management of their products (Compagnoni, 2022). Regarding the economic feasibility, the capital investment needed to install advanced waste management systems may be high, but a number of studies have indicated long-term advantages of these technologies about environmental compliance, energy recovery, employment, and health savings of the people. Such systems as smart collection, for example, have been found to save up to 30% of operational costs, and WTE plants help municipalities to secure energy and ease the pressure on landfills (Singh et al., 2024). The cost-benefit analysis and life cycle assessment (LCA) are becoming more common in determining the investment decisions made by municipalities and the sustainability of different SWM options (Soesanto et al., 2021).

The objective of the study is to assess the data of chosen urban municipalities that already have an installed modern system of solid waste management and consider the aspects of tech effectiveness, operational matters, issues, and environmental effects. It will adopt a mixed-methodology of field surveys, performance auditing, and stakeholder interviews to make decisions regarding evidence-based best practices and detect scalable solutions across different socio-economic environments.

METHODOLOGY

Study Design

It was a quantitative and qualitative research study that aimed to assess the practice, performance, and challenges of new solid waste management (SWM) practices within the urban municipalities of India. The research was a combined approach to analyzing the technical and situational performance of SWM. The research was conducted in five Indian urban municipalities with different population densities, socio-economic conditions, and utilization of modern SWM technologies, including smart bins, waste-to-energy (WTE), and digital monitoring systems.

Selection of Study Areas

The selection of study sites was done on three primary criteria such as the presence of at least two of the modern solid waste management methods, three years of consistent records of municipal waste, and geographical and socio-economic representation of varied urban dynamics. Based on these criteria, five Indian cities were selected, namely Pune, Indore, Kochi, Ahmedabad, and Guwahati. The cities offer different infrastructure and institutional capacity in waste management systems, and thus, a balanced framework could be developed to make comparisons.

Data Collection Methods

Data was gathered within the study period in the form of a structured field survey of 250 respondents who included municipal personnel, private waste operators, and community members. Also, the 30 stakeholders of urban-based governance and civil society organizations were interviewed as key informants. Audits of different waste management facilities were conducted on-site in order to evaluate the composition of waste and the performance of the facility. Informed consent was obtained from all the participants, and the data were collected under the accepted standards of ethics. Additional secondary information was provided by municipal records, government databases, facility reports, and published academic sources and was used to triangulate primary results and guarantee the reliability of the analysis.

Waste Stream Characterization

In each selected city, waste stream characterization was performed by collecting a minimum of 500 kilograms of waste from primary collection points. The samples were manually sorted, weighed, and categorized into five main types: biodegradable, recyclables, inert materials, hazardous waste, and sanitary waste. This classification enabled a detailed assessment of the composition and volume of each waste type, facilitating the evaluation of the technical suitability of various treatment and processing methods based on locally available waste fractions.

Data Analysis

Quantitative data were analyzed using IBM SPSS v22 and Microsoft Excel 365. Descriptive statistics were used to summarize values of performance indicators. An analysis of variance (ANOVA) followed by Tukey's post hoc test was applied to identify statistically significant differences across cities. Qualitative responses from interviews were transcribed and analyzed using thematic coding in NVivo 14. Emerging themes were mapped to institutional barriers, technology adoption experiences, and public perceptions, supporting a comprehensive interpretation of the quantitative trends.

Validity and Reliability

To ensure the integrity and reliability of the data, a pilot survey was conducted on 10% of the total sample to refine the structure and clarity of the research instruments. Methodological triangulation was applied by cross-verifying information obtained from field observations, municipal records, and stakeholder interviews. The internal consistency of the public satisfaction index was evaluated using Cronbach's alpha, which yielded a coefficient of 0.81, indicating a high level of reliability.

Ethical Considerations

The study received ethical clearance from the Institutional Review Board (IRB Approval No: ENV-IRB/2025/032). All participants were informed of the study's objectives, and participation was entirely voluntary. Waste handling and sampling were performed under the safety guidelines issued by the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India.

RESULTS

Waste Composition Profiles Across Cities

The waste composition analysis revealed significant variation in material categories across the five selected cities. Biodegradable waste consistently represented the largest fraction of the waste stream, accounting for 44.3% to 52.1% of the total waste. Kochi exhibited the highest proportion of biodegradable material (52.1%), followed by Guwahati (50.4%) and Indore (48.5%), as mentioned in Table 1 & visualized in Figure 1. This indicates a substantial opportunity for implementing biological treatment methods such as composting and anaerobic digestion in these locations.

Recyclables ranged from 24.3% in Kochi to 28.1% in Pune, suggesting a moderately strong potential for material recovery through segregation and processing at Material Recovery Facilities (MRFs). The inert waste fraction varied between 13.8% and 16.0%, while hazardous and sanitary components together remained below 12% in all city levels manageable under targeted collection and disposal protocols.

Table 1: Composition of Municipal Solid Waste by Type Across Selected Indian Cities

City	Biodegradable (%)	Recyclables (%)	Inert (%)	Hazardous (%)	Sanitary (%)
Pune	45.2	28.1	15.3	6.2	5.2
Indore	48.5	26.7	14.5	5.9	4.4
Kochi	52.1	24.3	13.8	4.7	5.1
Ahmedabad	44.3	27.5	16.0	6.5	5.7
Guwahati	50.4	25.8	14.7	5.6	3.5

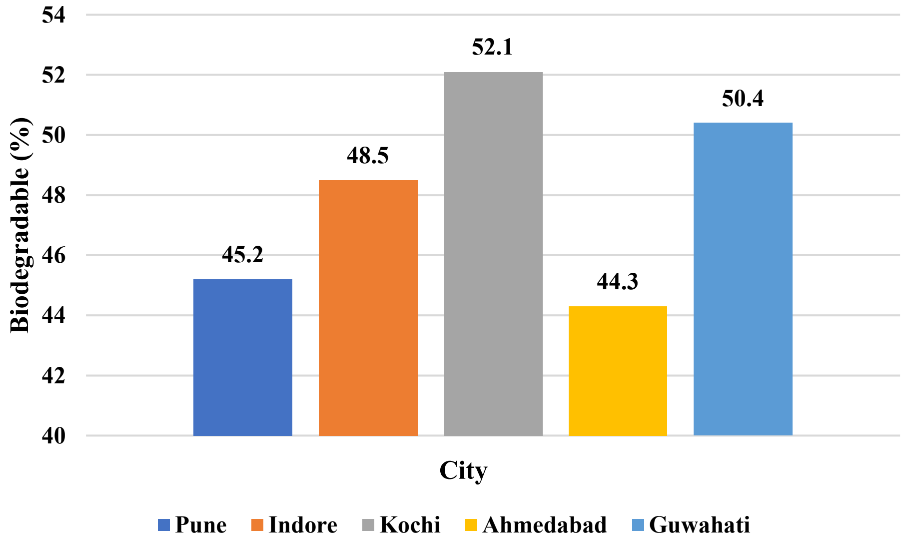

Figure 1: Biodegradable Waste Composition Across Cities

Figure 1 shows the percentage of biodegradable waste in each city. The presence of organic matter highlights the importance of organic waste valorization as a key part of current SWM systems. Cities like Kochi and Guwahati, with biodegradable fractions over 50%, have good opportunities for decentralized composting and anaerobic digestion projects. Proper management of this waste stream can not only reduce dependence on landfills but also promote nutrient recycling and renewable energy generation, supporting the idea of a circular economy.

Evaluation of Operational Performance Indicators

Among the five municipalities, Indore demonstrated the highest overall efficiency across multiple metrics. It achieved a collection efficiency of 97.2%, segregation at source of 82.1%, and a material recovery rate of 70.2%, outperforming the national urban average in all categories, as mentioned in Table 2. Energy recovery from WTE systems in Indore also peaked at 245 kWh/tonne, resulting in an estimated greenhouse gas (GHG) emission reduction of 16,700 tons CO_2e per year. Pune and Ahmedabad also exhibited strong performance, with collection efficiencies of 96.5% and 94.3%, respectively. Guwahati lagged in most parameters, particularly with lower collection efficiency (88.7%) and segregation rates (62.5%), despite its high biodegradable content, as illustrated in Figure 2. This discrepancy reflects operational bottlenecks in the collection infrastructure and public participation.

Table 2: Comparative Performance of Key Solid Waste Management Indicators Across Urban Municipalities

City	Collection Efficiency (%)	Segregation at Source (%)	Material Recovery Rate (%)	Energy Recovery (kWh/tonne)	GHG Reduction (tons CO_2e/year)
Pune	96.5	74.8	65.1	214	15,200
Indore	97.2	82.1	70.2	245	16,700
Kochi	91.8	66.4	58.9	180	13,400

Ahmedabad	94.3	71.2	60.3	205	14,900
Guwahati	88.7	62.5	55.5	173	12,750

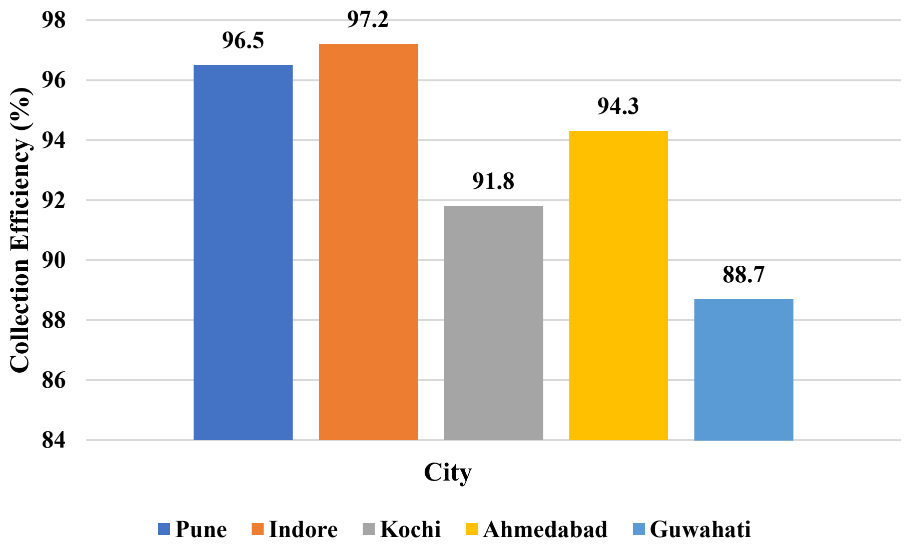

Figure 2: Comparative Analysis of Municipal Solid Waste Collection Efficiency Across Selected Urban Areas

Figure 2 illustrates a comparative view of collection efficiency across cities, highlighting Indore's sustained operational excellence, which is attributed to digital tracking systems, community involvement, and decentralized management. The almost full rate of waste collection in the city indicates a well-integrated infrastructure with responsive governance and real-time monitoring of services. This performance indicator shows that the synergy of smart technologies and inclusive civic participation can be used to streamline municipal waste activities.

Public Satisfaction and Cost Effectiveness

Public satisfaction with municipal waste services reflected the cities' operational outcomes. Indore received the highest average rating of 4.5 out of 5, followed by Pune (4.2) and Ahmedabad (4.1). These scores aligned with higher levels of cleanliness, service reliability, and responsiveness, as reported in household surveys. Guwahati and Kochi scored lower on the satisfaction index (3.7 and 3.9, respectively), with residents citing irregular collection schedules and poor communication as primary concerns, as mentioned in Table 3. Despite Kochi's high biodegradable fraction and moderate recovery rates, the lower satisfaction score suggests a disconnect between backend waste treatment systems and frontend service delivery.

Table 3: Public Satisfaction with Waste Management Services and Cost per Tonne

City	Satisfaction Index (0–5)	Cost per Tonne (INR)
Pune	4.2	1520
Indore	4.5	1480
Kochi	3.9	1580
Ahmedabad	4.1	1500
Guwahati	3.7	1600

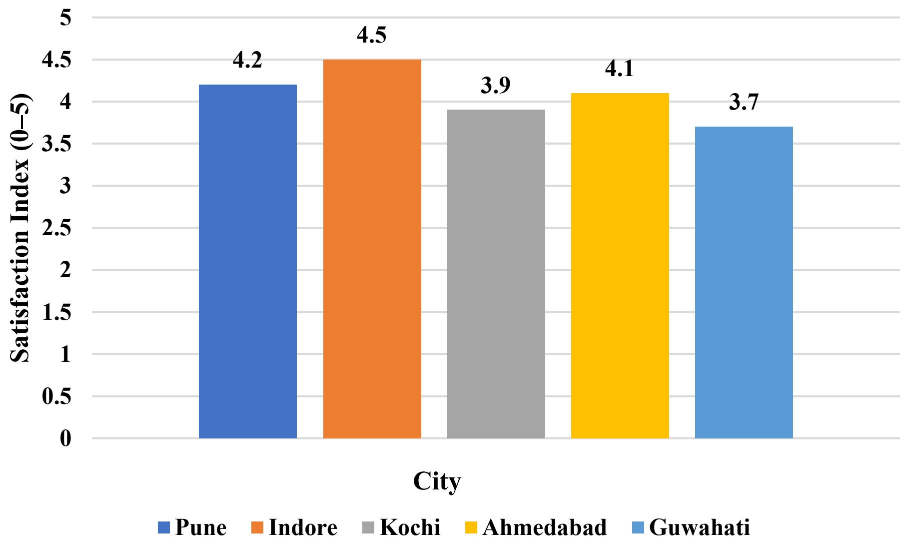

Figure 3: Comparative Public Satisfaction Index for Municipal Solid Waste Services Across Selected Cities

Figure 3 shows the satisfaction index by city, revealing a clear pattern: cities with higher segregation levels and transparency mechanisms reported greater citizen approval. Indore, Pune, and Ahmedabad, which exhibited strong operational metrics and public outreach, consistently achieved satisfaction scores above 4.0. This trend indicates that residents respond positively not only to service efficiency but also to visible accountability and consistent communication from municipal authorities.

DISCUSSION

The comparative assessment of recent solid waste management (SWM) techniques across five Indian municipalities revealed substantial variability in performance outcomes, technological integration, and public acceptance. The findings underscore the complex interplay between waste composition, operational infrastructure, governance mechanisms, and community participation in determining the effectiveness of modern SWM systems.

In all cities, biodegradable waste comprises 44.3% to 52.1%, which shows there is considerable opportunity to valorize organic waste through composting and anaerobic digestion. Kochi has the highest organic content (52.1%) and demonstrated the highest potential using decentralized composting systems, but did not show parallel success in segregation and collection efficiency. While Indore had slightly less biodegradable content (48.5%), operationally, it performed better because all levels of segregation, innovative technology use, and decentralized processing units were included. These findings support past research, which shows segregated collection and community-based composting improve organic waste utilization and reduce dependence on landfills (Widyatmika and Bolia, 2023).

Indore emerged as the benchmark city, demonstrating the highest collection efficiency (97.2%), source segregation (82.1%), and energy recovery (245 kWh/tonne). Indore's positive performance can be attributed to its well-working institutional setup that is digitized, involving GPS-enabled tracking of collection routes and smart bin systems. Conversely, Guwahati, which had the same organic content, recorded the lowest collection efficiency (88.7%) and segregation (62.5%). The two cities lack service delivery, community participation, and logistical controls. The observations in the case of Indore and Guwahati point to the importance of real-time surveillance and citizen engagement in the establishment of operational efficiencies. This conforms with the research and evidence indicating the role of digital technologies in the urban waste logistics process (Berigüete et al., 2024).

The higher the source segregation and material recovery rates, the greater the energy recovery and greenhouse gas (GHG) mitigation value in urban areas. For instance, Indore and Pune have recorded the highest waste processing into energy rates and annual GHG mitigation of over 16,700 and 15,200 tons $CO2e$, respectively. This indicates the linkage between the success of upstream segregation activities and the success of downstream processing. The process energy recovery technologies, like anaerobic digestion and incineration with energy

recovery, were discovered to be more appropriate for the waste streams that were stable and had better front-end segregation practices. These technologies were efficient in line with the international evaluations of the WTE technologies, meaning that the recovery efficiencies depend on the integrity of the feedstock and contamination levels.
Public satisfaction levels demonstrated a positive correlation with operational performance. Indore, Pune, and Ahmedabad, which reported high segregation rates and service coverage, also achieved satisfaction indices above 4.0. In contrast, Kochi and Guwahati scored lower despite having access to WTE facilities, indicating that technology adoption alone does not ensure user satisfaction. The results suggest that timely service, clear communication, and visible cleanliness improvements contribute significantly to citizen perceptions of SWM quality.
An examination of operational costs identified cost-efficient operations as closely linked to performance optimization. Indore exhibited the lowest cost per tonne (INR 1480) with the highest level of satisfaction and level of environmental benefits being provided, which reflects the ability to minimize or optimize resource use or manage procedures to minimize redundancy. The per tonne cost was higher for Kochi and Guwahati, indicating probably limited segregation efficiency and underutilized design capacity. The study provided evidence for the need to ensure that capital investments in SWM infrastructure are paired with whole systems planning, including operational capacity, human resource development, and long-term maintenance models. These results support evaluations of effective human and non-human resources over the long term and are aligned with UN-Habitat's (2021) consideration of the financial sustainability of municipal waste management as articulated in other critical areas by Kariuki (2025).
The comparative outcomes highlight that SWM performance cannot be solely attributed to technology procurement or facility installation. Rather, performance is influenced by the synchronization of regulatory frameworks, stakeholder coordination, public engagement, and adaptive operational models. Indore's success story reflects a synergistic application of decentralized planning, digital innovation, and performance-based accountability, serving as a potential model for replication in other Indian and Global South cities. Conversely, the underperformance in cities such as Guwahati points to the need for tailored capacity-building programs, behavioral change campaigns, and inclusive policy frameworks that consider local socio-economic constraints.

CONCLUSION

This study examined the characteristics of solid waste management SWM in five Indian cities and identified substantial differences in process performance outcomes, environmental emissions, and public perception of service. The highest amounts of the waste stream were biodegradable waste, 44.3% and 52.1% in Ahmadabad and Kochi, respectively, while the least was practically non-biodegradable, pointing to an opportunity for organic waste valorisation. Indore performed well with 97.2% collection efficiency, 82.1% source segregation, 245 kWh/tonne energy recovery, and savings of 16,700 te CO_2e annually – the lowest cost per city (INR 1480/tonne). Guwahati, with the highest biodegradable waste percentage of 50.4% exhibited the least collection and segregation, indicating implementation deficits. Both operational and environmental impacts were recorded in terms of public satisfaction level (for which Indore, Pune, and Ahmedabad scored above 4.0 out of 5.0, and Kochi and Guwahati scored below 4.0). The findings suggest that technology itself is not enough; community participation and good governance both play vital roles. The research has noted that there needs to be complementary policies to reinforce effective SWM practices to couple infrastructure with behavioral incentives and institutional support. It further suggests benchmarking approaches and performance-based, milestone-driven investment to achieve scalable outcomes. These findings thus contributed to existing empirical literature and to the body of knowledge needed to inform sustainable urban waste policies and mandates required to accomplish various global environmental and developmental targets.

REFERENCES

1. Kariuki, D. K. (2025). Factors Affecting Service Delivery by Solid Waste Collecting Firms Under a Public-Private Partnership Arrangement in Nairobi City County (Doctoral dissertation, COHRED-JKUAT).
2. Berigüete, F. E., Santos, J. S., & Rodriguez Cantalapiedra, I. (2024). Digital revolution: emerging technologies for enhancing citizen engagement in urban and environmental management. Land, 13(11), 1921.

3. Dhali, S. L., Parida, D., Kumar, B., & Bala, K. (2024). Recent trends in microbial and enzymatic plastic degradation: a solution for plastic pollution predicaments. Biotechnology for Sustainable Materials, 1(1), 11.
4. Louzizi, T., Chakir, E., & Sadoune, Z. (2024). A comprehensive review on solid waste management in Morocco: assessment, challenges, and potential transition to a circular economy. Euro-Mediterranean Journal for Environmental Integration, 1-16.
5. Olawade, D. B., Fapohunda, O., Wada, O. Z., Usman, S. O., Ige, A. O., Ajisafe, O., & Oladapo, B. I. (2024). Smart waste management: A paradigm shift enabled by artificial intelligence. Waste Management Bulletin.
6. Singh, D., Dikshit, A. K., & Kumar, S. (2024). Smart technological options in collection and transportation of municipal solid waste in urban areas: A mini review. Waste Management & Research, 42(1), 3-15.
7. Voukkali, I., Papamichael, I., Loizia, P., & Zorpas, A. A. (2024). Urbanization and solid waste production: Prospects and challenges. Environmental Science and Pollution Research, 31(12), 17678-17689.
8. Maalouf, A., & Agamuthu, P. (2023). Waste management evolution in the last five decades in developing countries–A review. Waste Management & Research, 41(9), 1420-1434.
9. Ongey, N. D. (2023). Legal aspects of sustainability in waste management (Doctoral dissertation, Vilniaus universitetas).
10. Sharma, R. (2023, July). Leveraging AI and IoT for sustainable waste management. In International Conference on Sustainable Development through Machine Learning, AI and IoT (pp. 136-150). Cham: Springer Nature Switzerland.
11. Widyatmika, M. A., & Bolia, N. B. (2023). Understanding citizens' perception of waste composting and segregation. Journal of Material Cycles and Waste Management, 25(3), 1608-1621.
12. Gupta, J., Ghosh, P., Kumari, M., & Thakur, I. S. (2022). Solid waste landfill sites for the mitigation of greenhouse gases. In Biomass, biofuels, biochemicals (pp. 315-340). Elsevier.
13. Compagnoni, M. (2022). Is Extended Producer Responsibility living up to expectations? A systematic literature review focusing on electronic waste. Journal of Cleaner Production, 367, 133101.
14. Siddiqua, A., Hahladakis, J. N., & Al-Attiya, W. A. K. (2022). An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. Environmental Science and Pollution Research, 29(39), 58514-58536.
15. Zhou, Y., Xiao, R., Klammsteiner, T., Kong, X., Yan, B., Mihai, F. C., ... & Awasthi, M. K. (2022). Recent trends and advances in composting and vermicomposting technologies: A review. Bioresource Technology, 360, 127591.
16. Akai-Tetteh, V. A. (2021). Environmental Health Impact of Waste Management Practices of the University of Cape Coast and its Surrounding Communities: Perception of Undergraduate Students (Doctoral dissertation, University of Cape Coast).
17. Soesanto, Q. M. B., Utomo, L. R., Rachman, I., & Matsumoto, T. (2021). Life cycle assessment and cost-benefit analysis of municipal waste management strategies. LIFE, 7, 30-2021.
18. Bishoge, O. K., Huang, X., Zhang, L., Ma, H., & Danyo, C. (2019). The adaptation of waste-to-energy technologies: Towards the conversion of municipal solid waste into a renewable energy resource. Environmental Reviews, 27(4), 435-446.
19. Pribadi, F. S. (2017). The Integration of Circular Economy into Municipal Solid Waste Management in Metro City, Indonesia: Challenges and Environmental Opportunities (Master's thesis, University of Twente).
20. Damgaard, A., Riber, C., Fruergaard, T., Hulgaard, T., & Christensen, T. H. (2010). Life-cycle-assessment of the historical development of air pollution control and energy recovery in waste incineration. Waste Management, 30(7), 1244-1250.