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**LEVERAGING HUMAN-ARTIFICIAL  
INTELLIGENCE (AI) AND MACHINE LEARNING  
(ML): COLLABORATIVE APPROACH FOR  
ENHANCING WASTE MANAGEMENT  
PRACTICES IN BANGLADESH TO ACHIEVE  
ZERO-WASTE**

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**ABSTRACT**

*Bangladesh struggles in managing the underdeveloped and poorly enforced waste management system, which has far-reaching consequences for the environment, public health, urban resilience, and long-term sustainability. In recent years, the transformation of waste management through AI and ML techniques into waste management enables innovative solutions for forecasting, classification and optimization, leading to more efficient, user-friendly, and cost-effective recycling systems which represents a significant step forward in enabling more efficient and zero-waste practices to reduce environmental challenges. This study aims to provide insights into the current waste management challenges and identify the effectiveness of the interventions of Artificial Intelligence (AI) and Machine Learning (ML) with human collaboration by adapting strategies from developed countries in*

*improving waste management processes and mitigating environmental pollution to achieve Zero-Waste goals by fostering more sustainable and efficient urban waste management practices. This study utilized a systematic literature review, analyzing peer-reviewed articles, previous research, case study and different strategies from developed countries to better identify best practices and technological approach and investigate how the application of artificial intelligence and machine learning can be applied in the waste management system of Bangladesh. The rate of waste generation in Bangladesh is increasing. According to Bangladesh Waste Database 2021, per capita waste is projected to rise from 0.52 kg/day to 0.74 kg/day by 2041 and pushing national waste to nearly 51.2 million tons. According to the "Food Waste Index Report 2024", 14.10 million tons of food is wasted every year by households in Bangladesh. Human and AI collaboration and machine learning combined with policy integration, community participation, and the adoption of strategies from developed countries along with inclusive solutions may provide a scalable pathway for Bangladesh to reduce waste, enhance recycling and achieve Zero-Waste goals in future.*

**Keywords:** Waste Management, Zero-Waste, Artificial Intelligence (AI), Machine Learning (ML), Bangladesh.

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## 1. INTRODUCTION

Bangladesh struggles with an escalating environmental and urban management challenge resulting from the rapid increase in waste generation, especially in large cities like Dhaka and

Chattogram. Bangladesh waste Database (2021) estimates that Bangladesh produces around 33,574.30 tons of municipal waste per day ( $\approx 0.5$  kg per capita per day), with Dhaka alone contributing nearly one-fourth of the total amount. Also, LightCastle Analytics Wing (2025) discussed that this figure is expected to rise to between 1.1 and 1.2 kilograms by 2024 and if these patterns persist then the total national waste generation could reach approximately 142,000 tons per day. Waste can be categorized broadly into hazardous and non-hazardous materials where industrial, medical and electronic waste (e-waste) are classified as hazardous waste and non-hazardous waste includes municipal waste, such as household garbage and debris from demolition of buildings and other structures (Islam, 2021).

The traditional waste management system in Bangladesh is constrained by several structural and operational limitations, including inadequate collection infrastructure, lack of segregation at source, limited data-driven decision-making and minimal integration of informal waste workers (Abedin & Jahiruddin, 2015). These issues have been further increased by the absence of real-time monitoring and analytics systems capable of predicting waste generation, optimizing collection routes, and improving recycling efficiency. Jumman Sani (2025) highlights that 82% of households dispose of mixed waste, decentralized composting facilities are absent, over 70% of collection vehicles are outdated, and informal waste pickers recover 15–20% of recyclables under unsafe conditions. Waste management challenges are no longer confined to individual countries; it poses a global threat. According to the World Bank (2018), the average waste generated per person is

approximately 0.74 kilograms per day but ranges widely from 0.11 to 4.54 kilograms, worldwide. In recent years, the usage of artificial intelligence (AI) and machine learning (ML) techniques have been increasingly utilized across the world to enhance waste management practices through automated sorting, intelligence routing and sensor-based monitoring. But in developing countries like Bangladesh, the full automation of such processes has been found to be limited due to infrastructural deficiencies, limited digital literacy, socio-economic dependence on informal labor. This study highlights the insights into the current waste management challenges and identify the effectiveness of the interventions of Artificial Intelligence (AI) and Machine Learning (ML) with the human collaboration by adapting strategies from developed countries in improving waste management processes and mitigating environmental pollution to achieve Zero-Waste goals by fostering more sustainable and efficient urban waste management practices.

## **2. REVIEW OF LITERATURE**

### **2.1 Waste Generation and Current Practices in Bangladesh**

Waste generation has been rapidly increasing due to population growth and changing consumption patterns, with urban waste production reported to have double the waste volume every 15 years over the last three decades (Islam, 2021). The United Nations Environment Program (2024) reported that urgent need is required to decouple waste generation from economic growth and shift to zero waste and circular economic approaches. According to the Asian Development Bank, only 56

percent of waste is collected and the remaining waste is dumped illegally which causes widespread pollution, water contamination, air quality deterioration and significant health hazards (Mamun & Khushi, 2024). Bangladesh currently approaches the 3R strategy which is often called the principle of reducing waste, reusing and recycling resources and products (Department of Environment, 2018).

## **2.2 Usage of AI-ML in Waste Management System**

Ahmed & Asadullah (2020) stated that Artificial intelligence (AI) and machine learning (ML) are considered as the key factors of technology that support the modern operation of Material Recovery Facility (MRF) automation. MRF is a specialized plant where recyclable materials are sorted, processed and prepared for reuse. Artificial intelligence and machine learning are increasingly integrated into automated sorting and optimized operations. Artificial Intelligence provides various approaches that can be employed to construct smart waste management systems and by using AI-based systems, complicated problems can be tackled, uncertainty can be managed, and the efficiency of smart systems can be enhanced (Sinthiya, Chowdhury & Haque, 2022). Successful implication demonstrates cost savings, improves recycling qualities.

## **2.3 Combination Approaches of Human-AI and Machine Learning and Human-in-the-Loop**

Hybrid Human-AI collaboration consistently produced better operational outcomes than purely automated or manual systems. The potential of artificial intelligence cannot be fully accomplished without effective Human-AI Collaboration

(HAIC) (Raftopoulos and Hamari, 2023). Human-AI Collaboration combines the complementary strengths of human intelligence and artificial intelligence, empowering teams to accomplish more collectively than either could accomplish independently (Dellermann et al. 2019).

### **3. RESEARCH METHODOLOGY**

#### **3.1 Design of the Study**

This study analyzed peer-reviewed articles, previous research, case study and different strategies from developed countries to better identify best practices and technological approach and investigate how the application of artificial intelligence and machine learning can be applied in the waste management system of Bangladesh.

#### **3.2 Data Collection Method**

The secondary data was obtained from various reliable sources, including Government reports, World Bank, Wikipedia, Dhaka Tribune, NEWAGE, ResearchGate, reports, publications and scholarly articles. Both qualitative and quantitative data were collected from the selected studies. Quantitative data included numerical outcomes such as waste generation rates, recycling percentages, efficiency improvements. Qualitative data captured descriptive findings on challenges, human-AI interaction, experiences and contextual insights.

#### **3.3 Data Analysis**

Microsoft Excel was used for quantitative data analysis. The quantitative part of the study is based on the secondary data including government reports and databases from 2010 to

2025 to ensure relevance to current applications. Additionally, the study also employed identifying other relevant articles that are cited within the previously reviewed papers to capture the relevant literature.

### 3.4 Ethical Considerations

Ethical considerations were observed meticulously and transparency, integrity and reproducibility were emphasized throughout the review process. Additionally, only publicly accessible and legally available data were used.

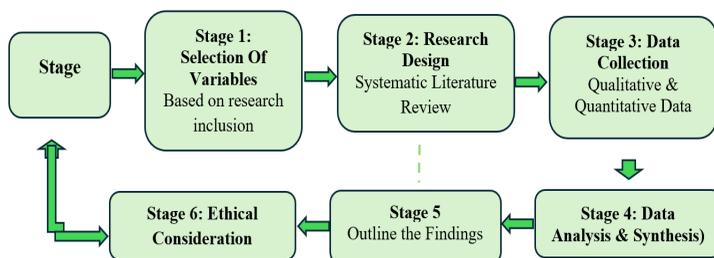


Figure 1. Flowchart of various stages employed in this study

The flowchart highlights a 6-step methodology process, and it begins with variable selection which is based on research inclusion and criteria. The second stage is research design which is based on systematic literature review. The next stage is data collection including Qualitative & Quantitative data. After collecting data, the fourth stage is data analysis and synthesis. Then, outline the findings that highlight the key results, insights from the waste management analysis. The final stage is ethical considerations which ensure transparency and integrity.

## **4. ANALYSIS AND DISCUSSION**

The analysis of this systematic review was conducted through a structured synthesis of peer-reviewed literature, policy reports, and empirical findings related to Human-AI and machine learning (ML) collaborations in waste management, with a particular focus on Bangladesh and comparable developing contexts. Following the methodology, both quantitative and qualitative data from 2010–2025 were reviewed and interpreted to identify major trends, opportunities, and constraints within the waste management ecosystem.

### **4.1 Analysis**

#### **4.1.1 Quantitative Data Analysis**

Quantitative findings indicate that the urban centers of Bangladesh such as Dhaka and Chattogram account for nearly 60% of the total output (LightCastle Analytics Wing, 2025). The per capita waste generation rate in urban areas averages around 0.5 kg/day, projected to exceed 1.1 kg/day by 2041 if no technological intervention is applied (LightCastle Analytics Wing, 2025). Globally, solid waste is generated over 2.01 billion tons annually, and this figure is estimated to rise to 3.4 billion tons by 2050, posing grave transboundary environmental threats through pollution, greenhouse gas emissions, and resource depletion (World Bank, 2018). The medical waste of Bangladesh is estimated to be increasing at a rate of 3% per year, with overall waste production reported to stand at approximately 25,000 tons per day, while nearly 6,500 tons are managed daily in Dhaka, a figure projected to reach 8,500 tons by 2032 (Dhaka Tribune, 2025).

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#### **4.1.2 Qualitative Data Analysis**

The qualitative data synthesis revealed a set of recurring challenges in the effective implementation of AI-driven waste management. Bangladesh is ranked sixth in the world for plastic pollution of aquatic environments and as vast amounts of unorganized plastic waste end up in the Bay of Bengal via river systems (LightCastle Analytics Wing, 2025). Bangladesh still relies on environmentally damaging practices like open dumping and waste burning, which release methane and other greenhouse gases, contributing to both air pollution and global warming (Al Mamun & Khushi, 2024). On average, only about 45–50% of urban waste is formally collected by municipal authorities while the rest is often dumped on streets, open fields, or into waterways and the collected portion is largely disposed of in open dumpsites and Additionally, the literature highlights that approximately 50-70% of Bangladesh’s municipal solid waste is biodegradable, primarily food and organic waste, which presents a substantial opportunity for AI-guided composting and bioenergy generation (LightCastle Analytics Wing, 2025).

#### **4.1.3 The Role of Human-AI and ML Collaboration**

Across the reviewed studies, it is observed that human expertise was crucial in contextual decision-making, especially in informal settlements and unplanned urban areas where AI predictions required social interpretation. Artificial Intelligence is used to augment human capabilities rather than replace them and the collaboration between Generative Artificial Intelligence (AI) and human expertise essential in addressing the ethical and societal implications of AI applications is essential as human

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experts can guide the development of AI algorithms to ensure they adhere to ethical guidelines, fairness principles, and legal regulations. (Dave and Mandvikar, 2023). The analysis suggests a balanced framework where AI provides analytical and operational insights while human actors offer contextual intelligence which can substantially enhance waste segregation, recycling, and policy enforcement efficiency. For successful implementation of Artificial Intelligence (AI) and Machine Learning (ML) often combine human oversight. The collective findings confirm that while AI and ML models can improve the technical and operational efficiency of waste management, their success depends on human engagement, institutional readiness, and ethical governance.

#### ***4.1.4 Application and Potential of AI and ML in Waste Management System***

Artificial Intelligence (AI) monitoring systems can not only detect illegal dumping incidents 95% of the time but also its assisted composition reduces methane emissions by 40%, greenhouse gas by up to 15 tons annually per vehicle, fuel consumption by up to 20% and operational costs by 35% (Eser, 2025). Machine learning uses time-series forecasting to predict daily/weekly waste generation by area which helps to optimize collection schedules and bin deployment.

#### ***4.1.5 Adoption Rates & Market Growth***

The global Artificial Intelligence (AI) in waste management market is projected to reach 4.8 billion dollars and 80% of waste management companies believe it can significantly improve operational efficiency (Eser, 2025). Barcelona city has

implemented an AI-powered waste management system, and this city has achieved significant cost savings and a remarkable 23% reduction in collection vehicle distances (fintelices, 2023).

## 4.2 Results

The systematic review reveals that the waste management system in Bangladesh remains a growing environmental, social and technological challenge with large population problems, rapid urbanization, and increasing consumption. The problem is most severe in major cities such as Dhaka, Chittagong where insufficient collection, lack of segregation, inadequate disposal facilities, open dumping, waste burning have led to serious environmental degradation and public health concern. It also highlights that most waste management still relies on manual labor, limited mechanisms, and waste burning.

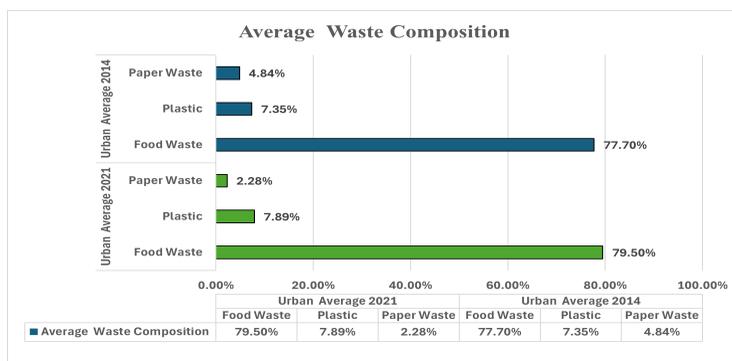


Figure 2. Average Waste Composition Rate in Bangladesh (Urban Areas)

Figure 2 illustrates the percentage of the average waste composition in urban areas of Bangladesh from 2014 to 2021. The graph compares the average composition of urban waste, and it focuses on three waste categories such as food waste, plastic waste and paper waste. The 2014 data highlights that food waste made up 77.70%, plastic waste 7.35% and paper waste 4.84%. In comparison, food waste accounted for 79.50% of total urban waste, followed by plastic waste at 7.89% and paper waste at 2.28% in 2021.

Overall, this graph highlights that food waste is the dominant component of urban solid waste in both years though it increases slightly from 2014 to 2021. This suggests that organic or biodegradable materials are the major contributor to municipal waste in urban areas. Then, plastic shows a slight increase, but it also creates concerns. On the other hand, paper waste decreased sharply from 4.84% to 2.28%.



Figure 3. Waste Generation Rate in Major Six City Corporations in Bangladesh (2022)

Figure 3 presents both the population size and the waste generation rate per day (in tons) for the six major city

corporations in Bangladesh including Dhaka City Corporation, Chittagong City Corporation, Khulna City Corporation, Rajshahi City Corporation, Borishal City Corporation, Sylhet City Corporation. The blue bars represent the population of each city corporation, and the orange line indicates the waste generation rate per day (in tons). In the figure, Dhaka stands out as the largest city both in population (9,206,783) and in daily waste generation (6,500 tons/day) which indicates the role of this city as the major contributor in Bangladesh. Chittagong is another major contributor city. It follows with a population of average 3,227,246 and waste generation rate of 3,000 tons/day, showing a high waste generation intensity relative to population size. The other cities generate considerably less waste. The overall pattern shows a strong positive relationship between city population and waste generation rate where larger urban populations correspond with higher daily waste output.

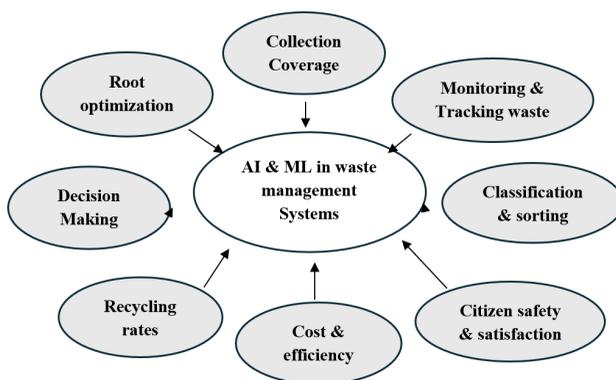


Figure 4. AI and ML in Waste Management Systems

In figure 4, the diagram shows how artificial intelligence (AI) and machine learning (ML) are applied in waste management systems. Artificial Intelligence helps to optimize routes for waste collection to reduce travel distance, save fuel and decrease collection time. The systems also classify waste types by using image recognition or sensor-based for recycling or disposal. It also helps to analyze service quality, predicts recycling trends and improves sorting process. Machine Learning predicts areas with higher waste generation and ensures all bins are collected on time. Additionally, implementing both helps to reduce waste generation and increase sustainability.

### 4.3 Discussion

#### 4.3.1 *Human-AI Constructive Collaboration and Local Barriers*

In practical terms, humans continue to play critical roles in overseeing waste segregation, managing recycling centers, and engaging communities, while artificial intelligence supports these efforts through advanced technologies. Human-AI constructive collaboration is not about replacing humans but about combining human creativity, empathy and judgement with speed, precision and data-processing power of artificial intelligence. The finding emphasizes a growing recognition of Artificial Intelligence (AI) and Machine Learning (ML) as transformative tools in improving waste management efficiency. While Artificial Intelligence (AI) and Machine Learning (ML) offer immense potential, the human component remains essential for successful implementation.

The findings also indicate that Bangladesh possesses significant potential for technological advancement in waste management

but must overcome the socio-technical barriers. These include limited technical expertise, inadequate funding, data fragmentation, policy gaps, human capacity and skill deficiencies, financial and resources constraints, lack of public awareness, data privacy, informal economic dynamic, urbanization, and lack of ethical implications.

#### ***4.3.2 Comparative Insights from Developed Countries***

When compared to developed countries, the progress of Bangladesh remains at an early stage, but using strategies from Japan, Taiwan, Singapore, Sydney, Barcelona, Denmark. Singapore is considered as the cleanest country in the world in 2025. Japan demonstrates strong environmental leadership by investing in clean technologies such as hydrogen fuel infrastructure and energy-efficient building codes, while promoting eco-conscious tourism through rural homestays and nature-based experiences. If Bangladesh adopts similar strategies, it could significantly enhance its sustainability efforts by integrating clean technologies, improving energy efficiency and promoting eco-friendly tourism and waste management practices. However, the contextual differences such as informal waste sectors, infrastructure limitations and socio-economic disparities require a localized implementation strategy rather than direct replication.

Overall, the synthesis of literature suggests that integrating Artificial Intelligence (AI) and Machine Learning (ML) into Bangladesh's waste management system through human-AI frameworks can significantly enhance operational efficiency, accountability and sustainability.

## **5. CONCLUSION**

This systematic review explored how Human-AI and Machine Learning (ML) collaboration can strengthen the waste management practices in Bangladesh by integrating data-driven decision-making with human oversight and community participation. Bangladesh faces critical challenges with inefficient waste collection, limited digital infrastructure, weak stakeholder coordination, Artificial Intelligence (AI) and Machine Learning (ML) offer transformative opportunities for the waste-management sector for Bangladesh. From smart collection systems to real-time landfill monitoring, these technologies can reduce environmental impact, lower costs, promote circular economic practices, and present new opportunities for transformation. Both national and global studies indicate that AI-assisted models can significantly enhance waste predictions, route optimization, recycling efficiency whereas the insights highlight the importance of human involvement in adoption and engagement.

The experiences and strategies from developed countries provide practical lessons for Bangladesh. The successful implementation of Artificial Intelligence (AI) and Machine Learning (ML) collaboration by pairing with human-in-the-loop frameworks can lead to more efficient, transparent and sustainable waste management systems. Therefore, future strategies should prioritize capacity building, cross-sector collaboration and ethical data governance to ensure responsible adoption of these technologies. Based on the findings, several strategic actions are recommended to effectively implement

Human-AI and Machine Learning (ML) collaborative approaches in Bangladesh's waste management sector:

- Develop a national AI framework and create strict laws for waste management.
- Strengthen data infrastructure and digital capacity to ensure reliable and real-time information flow for AI-based waste monitoring and forecasting.
- Promote Human-AI collaboration through training and upskills to ensure effective human-machine constructive interaction.
- Increase Public-Private Partnerships (PPP), pilot project, collaboration with academic institutions to accelerate the innovation and scaling of successful AI-driven waste management solutions.
- Encourage community participation and environmental awareness.
- Adopt international best practices locally especially in clean technology adoption, energy efficiency and community-based recycling.

By leveraging the strength of both human intelligence and machine learning, Bangladesh can move towards a circular, efficient and inclusive waste management ecosystem, supporting the broader targets of sustainable development to achieve Zero-Waste goals.

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