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Study on the Role of Artificial Intelligence in Sustainable Waste Management

Akhila M. Panicker[1*], Deepa T. S[2].

[1]Research Scholar, Department of Commerce, St Michael's College, Cherthala, Kerala
[2]Assistant Professor, St Stephan's College, Pathanapuram, Kerala
[*]E mail: akhilapanicker12@gmail.com

Abstract

Rapid urbanization and an increase in population result in the generation of a huge amount of waste which is very difficult to manage. Tons of waste are generated in different sectors of the society. Proper waste management is essential for environment protection, climate change mitigation, public health, economic benefit, more sustainable practices have to be adopted in order to manage the wastes generated. Artificial intelligence offers solutions for proper waste handling and management and also to improve efficiency. The study examines the role of AI in advancing sustainable waste management. The main objective is to assess how AI technologies can improve collection, sorting, transportation, recycling, and energy recovery, while also identifying the challenges associated with their implementation. The study adopts a descriptive research design and relies entirely on secondary data collected from published reports, academic journals, and government sources. The findings reveal that AI integration enhances efficiency, reduces carbon emissions, and supports circular economy practices, although high investment costs, limited infrastructure, and lack of skilled manpower remained significant barriers. The study concludes that AI-driven waste management provides a cost-effective and sustainable solution for mitigating the growing waste crisis, and emphasizes the need for supportive policies, capacity building, and public–private collaboration to maximize its impact.

Keywords- Artificial intelligence, environment protection, sustainable, sustainability, waste management.

Introduction

The world is facing a severe waste management crisis, tons of waste are being generated daily. This increase is due to increase in population, urbanization and also many other natural processes such as natural disasters, decomposition. The waste generated has so many negative impacts on environment and also public health. These include environment pollution, economic losses, climate change etc. Proper management of waste is essential for protection of earth and life on earth. Ineffective waste management severely affects the environment. According to reports India produces around 48 million tons of urban solid waste alone annually with 0.4kg per capita per day (CPCB, 2020). 5.4 million tons of bio-medical waste are also generated annually and hazardous waste amounts to around 7.2 million tons (MoEFCC, 2021).

In India nowadays, waste management primarily consists of collecting waste from industrial and residential areas and disposing of it in landfills. The customary procedure

is to lift solid trash from the point of origin and transport it to remote locations known as dumping grounds and/or landfill sites for disposal. The authorities, who are typically municipal, are required to handle solid waste created within their respective boundaries. Traditionally, waste management **was carried out** through manual sorting and disposal, which was inefficient and time-consuming. Today, however, the integration of Artificial Intelligence in waste management **has produced** promising results. Artificial intelligence enhances waste management practices by sorting and disposing of waste generated in efficient, more economical and also in a sustainable manner. Thus, in today's world inculcating Artificial intelligence in waste management is very essential for the protection of environment.

Significance of the study

AI in waste management uses technologies that consist of machine learning, computer vision and IOT which allows increased recycling rates and reduces the impact on environment. This study contributes to a shift from traditional waste management process to a more advanced and sustainable method. It helps in developing new policies, regulations and standards for waste management. AI in waste management helps in creating a more sustainable and environmentally conscious future through modern technology. It paves the way for future research and development in this field.

Research Methodology

This study adopts a **descriptive research design** and relies exclusively on **secondary data** from academic journals, government reports, policy documents, and reputable online sources. Secondary data was chosen because AI in waste management is a developing field with abundant published studies and statistical evidence already available. Using such sources allows for broader coverage of global and national perspectives without the time and resource demands of primary data collection. Moreover, reliance on peer-reviewed and official reports enhances the credibility and reliability of the findings.

Review of literature

B. Fang, J. Yu, Z. Chen, A. I. Osman, et al. (2022) found that with the use of AI, transportation was reduced, and that AI could improve waste pyrolysis, carbon emission estimation, and energy conversion.

D. B. Olawade, O. Fapohunda, O. Z. Wada, S. O. Usman, A. O. Ige, O. Ajisafe, B. I. Oladapo, Smart waste management (2024) **studied** the role of AI in waste management, collection, sorting, and recycling. They **noted** that AI had the capacity to revolutionize waste management but emphasized that it was essential to address the challenges associated with its implementation.

Prabhakar, Vikram (2024) Prabhakar, Vikram (2024) **discussed** the changes that could be brought about with AI in collection, sorting, and recycling. He **explained** the four key stakeholders involved: recyclers, consumers, government, and brands.

Ahmed, A. A. A., & Asadullah, A. (2020) **discussed** artificial intelligence and machine learning in waste management and recycling. They **reported** that plastic recycling was carried out by robots in building a fully automated home." Use of smart automation methods in waste management was highly feasible and time saving.

Sharma and vaid (2021) **discussed** the emerging role of Artificial Intelligence in waste management practices. They **argued** that solid waste was a serious threat to the environment and that the use of AI in waste management could save time and significantly reduce carbon emissions."

Objectives of the Study

- To assess fund allocation for waste management in India.
- To identify the role of AI in improving sustainable waste management in India.
- To identify the problems and challenges in implementing AI in India.

Artificial Intelligence and India

Artificial intelligence is computer system that mimics human intelligence. It is a tool that people use all over the world to make better decisions. It has gained popularity in less time due to its wide application. Many countries in the world **have adopted** the use of AI in waste management." For the sake of the Indian economy, the Indian government established Many of the counties in the world have adopted the use of AI in waste management the Task Force on Artificial Intelligence in 2017. However, three industries—healthcare, agriculture, and fintech—continue to be the emphasis. Tons of waste are generated from Indian cities. Plastic waste is mostly generated from Indian cities like Delhi, Mumbai, Chennai and Kolkata. According to studies Maharashtra and Delhi generated MSW and plastic waste than any other states in India. If AI is introduced in these places waste can be reduced to a large extend. According to recent report in Times of India Cochin Smart Mission is planning to introduce AI based solid waste management. One of the reasons of neglecting waste management is lack of fund at municipal level and in most of the countries in Asia private sector is not interested in engaging in waste management due to lack of incentives and low rate of return.

AI can provide solutions to various problems India is facing now, such as unsustainable agricultural practices, food security, healthcare, education and inequality urban waste, management etc. AI enabled smart irrigation system, climate monitoring tools, and online-based market places can create and enhance sustainability. AI and machine learning advancements can transform India, s energy sector. For urban waste management more efficient and cheaper recycling system can be created.

Waste Management Using Artificial Intelligence

Generation of municipal waste is expected to increase by 165 million tones by the year 2030 (World Bank, 2018). Waste is generated due to factors such as rapid urbanization, lack of collection infrastructure, ineffective way of sorting waste. Reducing waste requires active community participation, recycling, proper segregation, use of technologies.

With the use of Artificial Intelligence process of collection, sorting, classification can be done effectively. Following are some of the methods

Smart bin system

Garbage bins use sensors, data analytics and automation to collect waste, smart bins are more efficient way of collecting and segregating waste. It contains sensors that help to track waste management process. It focuses on two factors such as automatic waste collection and monitoring. This bin reduces the wide spread of diseases and also enhances the city's overall environment.

Waste sorting robots

Waste sorting robots identify and sort different types of waste, they use a computer vision system to sort waste. These types of robots are efficient but at the same time it requires huge maintenance cost. The robots use a computer vision system and deep machine learning to identify and classify different types of waste, including plastics, metals, paper, and organic waste. This information is then sent to a robotic arm, which picks the classified items, before sorting them into their designated bins.

Material recovery facility

Carbon tracker

AI monitors emissions from coal- burning through satellite data. So, it helps in reducing carbon footprints.

Sensor-based waste monitoring

Senor-based waste monitoring systems use senors to track the amount of waste that has been disposed, and identify the sources of waste and it also controls the waste treatment process effectively.

E- waste management

AI sorts and segregates electronic waste, Generative AI helps in designing the products which uses less raw materials thus e- waste can be reduced to a large extend. AI also helps in identifying the reusable parts of e- waste which is considered to be a difficult task.

Use of AI for Waste Management in India

Bhopal Municipal Corporation has implemented AI- enabled waste management system, GPS and sensors are installed on waste collection trucks.

Pune Municipal corporation employed AI based sorting technology. This technology sorts Recyclable and Non-Recyclable waste by using computer vision and machine learning. This technology proved to be 90% success

Bengaluru uses advanced analytics and machine-driven algorithms to analyses data and waste generation patterns. This analysis helps in identifying areas with high waste generation, peak waste generation times and type of waste generated.

In Delhi AI has been applied to waste to energy plants. AI software is installed. This reduces waste and increases energy recovery.

In Mumbai a startup has been set up at low cost to identify and separate recyclable waste from mixed waste.

Maharashtra has implemented decentralized micro- recycling centers. This helps in reducing transportation cost of carrying waste and helps in re-cycling the waste.

Challenges Faced by AI in India

Data concern- AI is based on a huge amount of confidential data. Thus, in order to implement AI needs high security and keep data secure.

Lack of skilled people- AI needs skilled people to use the system effectively. Proper training and education have to be provided to increase skill of people in using AI but the cost of training and education is high.

Huge investment- implementing AI in waste management requires huge investment but India lacks investment which is a major challenge for implementing AI in India. So there is a need for cost- effective AI solution.

Limited infrastructure – Many regions in India lack proper infrastructure facilities to implement waste management technologies. Infrastructure development is essential for proper implementation of AI for waste management.

Expenditure for Solid Waste Management and Sanitation in India

In 2014 government of India's Ministry of Housing and Urban Affairs launched a flagship 5-year Swachh Bharat Mission for achieving 100% open defection free status and 100% scientific solid waste management. Since the launch of the SBM in 2014, the national government's per capita expenditure on sanitation and SWM in urban areas has increased from ₹6.5 (6.3% of total expenditure for urban development) in fiscal year 2015 to ₹13.9 (2.7% of total expenditure for urban development) in fiscal year 2022 a cumulative annual growth rate of 11.5%.

Table 1

Expenditure for Solid Waste Management and Sanitation in India, 2015–2022

Fiscal Year	Budget Estimates (₹ Crores)	Actual Expenditure (₹ Crores)	Utilization (%)
2015	16,905.0	8,595.0	50.8
2016	14,000.0	11,081.0	79.1
2017	23,000.0	21,372.0	92.9
2018	25,500.0	25,406.0	99.6
2019	30,000.0	25,097.0	83.7
2020	13,000.0	13,377.0	102.9
2021	10,008.0	10,002.0	99.9
2022	20,000.0	19,692.0	98.5
Total	153,500.0	134,623.0	—

Note. Data adapted from Government of India, Ministry of Housing and Urban Affairs (2023).

Findings and Conclusion

Waste management is a major concern that world is facing today. Population growth and rapid urbanization will increase the amount of waste generated. In order to tackle the issue proper waste management is necessary. his study finds that waste management remains a major challenge in India, driven by rapid urbanization, population growth, and limited infrastructure. Government expenditure on sanitation and solid waste management has increased steadily since 2015, with utilization rates exceeding 98% in recent years, showing strong financial commitment. However, the adoption of Artificial Intelligence in waste management is still limited due to high investment costs, lack of skilled manpower, and weak municipal-level infrastructure. According to reports, waste generation is projected to rise by **73% by the year 2050** (World Bank, 2018, *What a Waste 2.0)*

The evidence suggests that AI can significantly improve efficiency in waste collection, sorting, recycling, and energy recovery, while reducing environmental impacts such as carbon emissions. Policy implications include the need for stronger public–private partnerships, incentives for technology adoption, and capacity-building programs to train professionals in AI applications.

Future research should focus on evaluating pilot projects of AI-enabled waste systems in Indian cities, developing cost-effective AI models tailored to local conditions, and exploring the integration of AI with circular economy approaches. By aligning technological innovation with supportive policies, AI-driven waste management can play a transformative role in achieving sustainability goals.

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