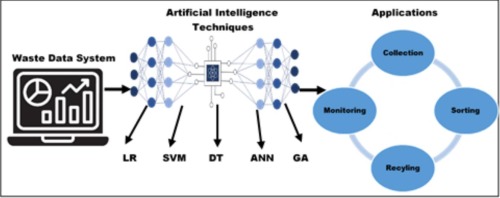
Waste management poses a pressing global challenge, necessitating innovative solutions for resource optimization and sustainability. Traditional practices often prove insufficient in addressing the escalating volume of waste and its environmental impact. However, the advent of Artificial Intelligence (AI) technologies offers promising avenues for tackling the complexities of waste management systems. This review provides a comprehensive examination of AI’s role in waste management, encompassing collection, sorting, recycling, and monitoring. It delineates the potential benefits and challenges associated with each application while emphasizing the imperative for improved data quality, privacy measures, cost-effectiveness, and ethical considerations. Furthermore, future prospects for AI integration with the Internet of Things (IoT), advancements in machine learning, and the importance of collaborative frameworks and policy initiatives were discussed. In conclusion, while AI holds significant promise for enhancing waste management practices, addressing challenges such as data quality, privacy concerns, and cost implications is paramount. Through concerted efforts and ongoing research endeavors, the transformative potential of AI can be fully harnessed to drive sustainable and efficient waste management practices.

Graphical abstract



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* [Next article in issue](https://www.sciencedirect.com/science/article/pii/S2949750724000427)

Keywords

Artificial Intelligence

Waste Management

Machine Learning

Waste Sorting

Recycling

Sustainability

Introduction

Waste management is a pressing global challenge, with the escalating volume of waste necessitating innovative and sustainable solutions ([Amaral et al., 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0140), [Cheng et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0355), [Chien et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0375), [Codinhoto et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0380), [Horton, 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0615), [Mahyari et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0880), [Zhang et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1495), [Zhou et al., 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1525)). Current challenges in waste management persist despite advancements in technology and awareness. One significant challenge is the inadequate infrastructure for waste collection and disposal, particularly in developing regions (Chiem et al., 2023). Insufficient funding and resources hinder the establishment of proper waste management systems, leading to illegal dumping and [environmental pollution](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/environmental-pollution) ([Bundhoo, 2018](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0295)). Additionally, there is a lack of standardized waste management practices globally, resulting in varying levels of efficiency and effectiveness across different regions ([Olawade et al., 2023a](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1075)). Another challenge lies in the complexity of waste composition, with the increasing prevalence of non-biodegradable and hazardous materials complicating disposal and recycling processes ([Wang et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1390)). Moreover, issues related to waste segregation and contamination persist, impeding recycling efforts and diminishing the quality of recovered materials (Olawade et al., 2023). Furthermore, inadequate public awareness and education about proper waste disposal practices contribute to improper waste handling and disposal behaviors, exacerbating environmental and health risks ([Ziraba et al., 2016](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1555)).

In recent years, Artificial Intelligence (AI) has emerged as a transformative technology that can revolutionize waste management practices and challenges ([Abdallah et al., 2020a](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0005), [Chew et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0360), [Hojageldiyev, 2019](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0605), [Karbassiyazdi et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0705), [Kumari et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0770), [Maiurova et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0890), [Mohammadiun et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0935), [Ramya et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1160), [Ye et al., 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1455), [Zhu et al., 2019](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1545)). By leveraging AI's capabilities in data analysis, pattern recognition, and decision-making, waste management systems can be optimized to enhance efficiency, resource utilization, and environmental [sustainability](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/environmental-impact-assessment) ([Aniza et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0165), [Hu et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0625), [Huang and Koroteev, 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0630), [Paul and Bussemaker, 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1135)).

Current trends in AI applications within waste management demonstrate its growing impact and potential ([Di Vaio et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0425), [Pallathadka et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1110), [Papagiannis et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1120), [Yigitcanlar et al., 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1465)). From intelligent waste collection systems to advanced sorting technologies and predictive analytics, AI is reshaping the waste management landscape in numerous ways ([Bamakan et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0225), [Hoque and Rahman, 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0610), [Krishna and Sharma, 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0745), [Kulisz and Kujawska, 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0750), [Wilts et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1420), [Zhang et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1485)).

The first prominent trend is the implementation of AI in waste collection processes. Traditional waste collection methods often suffer from inefficiencies such as suboptimal routing and irregular schedules ([Cubillos, 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0400)). However, AI-powered systems are addressing these challenges by optimizing waste collection routes ([Solano Meza et al., 2019](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1275), [Yadav and Karmakar, 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1440), [Yu et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1475)). Smart bin systems equipped with sensors and AI algorithms can monitor waste levels in real-time, enabling efficient collection planning and resource allocation ([Hussain et al., 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0640), [Pamintuan et al., 2019](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1115)). Route optimization algorithms, driven by AI, analyze historical data, traffic patterns, and waste generation rates to determine the most efficient routes for waste collection vehicles ([Ghahramani et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0525), [Lin et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0820)). Dynamic scheduling algorithms further optimize collection schedules based on real-time data, ensuring timely waste removal, and reducing operational costs.

Another significant trend is the integration of AI in waste sorting operations. Conventional waste sorting methods often rely on manual labor, which can be time-consuming and error-prone ([Das et al., 2019](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0405), [Guo et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0580)). AI technologies, such as image recognition and machine vision, are increasingly being employed to automate and improve waste sorting accuracy ([Lu et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0840), [Zhang and Yan, 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1510)). Advanced image recognition algorithms can analyze visual data and identify different waste materials with high precision, facilitating efficient segregation of recyclables, organic waste, and non-recyclables ([Dong et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0435), [Kumar et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0765), [Majchrowska et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0895), [Sundaralingam and Ramanathan, 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1320)). Additionally, robotic sorting systems equipped with AI algorithms can effectively separate and sort waste materials, streamlining the sorting process, and increasing recycling rates ([N. M. Kumar et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0755)).

AI is also playing a crucial role in waste recycling by optimizing various stages of the recycling process. Material identification and sorting technologies driven by AI enable accurate identification and separation of recyclable materials, maximizing resource recovery and minimizing waste contamination ([Wu et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1425)). Process optimization models, powered by AI, analyze data on recycling parameters, such as temperature, pressure, and composition, to identify optimal operating conditions and improve efficiency. AI-driven quality control and inspection systems ensure the production of high-quality recycled materials by detecting defects, contamination, and non-compliance. Furthermore, robotics and automation, guided by AI algorithms, streamline recycling operations, reducing human error, increasing throughput, and improving overall recycling efficiency ([Onoda, 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1095)).

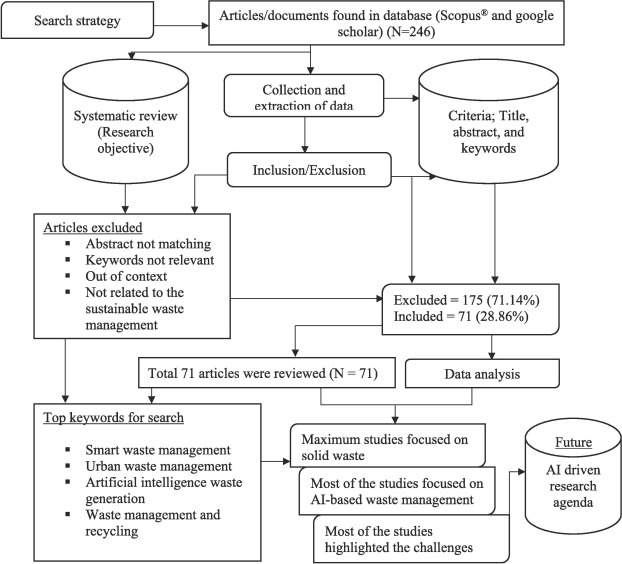
Waste monitoring is another area where AI is making significant advancements ([Khanal et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0720)). Real-time monitoring systems, integrated with IoT devices and sensor networks, collect, and analyze data on waste generation, collection, and disposal processes ([Sharma et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1220)). AI algorithms process this data, providing actionable insights for optimizing waste management operations. Predictive analytics models leverage historical and real-time data to forecast waste generation patterns, optimize resource allocation, and enable data-driven decision-making in waste management practices ([Ghanbari et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0530), [Lu et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0835), [Nguyen et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1025), [Rosecký et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1180), [Soni et al., 2019a](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1290), [Sunayana et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1315), [Zhu et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1540)).

While the integration of AI in waste management offers numerous benefits, some challenges and limitations must be addressed ([Sharma et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1230)). These include ensuring data availability and quality, addressing privacy and security concerns, managing the cost of implementation and infrastructure requirements, and considering ethical implications ([de Sousa et al., 2019](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0415)). Collaborative efforts between waste management agencies, technology providers, researchers, and policymakers are crucial for overcoming these challenges and fostering responsible and sustainable use of AI in waste management ([Abdullah et al., 2019](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0015), [Oyedotun and Moonsammy, 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1105)).

The use of AI in waste management and practices is rapidly evolving, driven by current trends and advancements. From optimizing waste collection and sorting processes to enhancing recycling operations and enabling data-driven decision-making, AI has the potential to transform waste management into a more efficient, sustainable, and environmentally conscious endeavor. By harnessing the power of AI, waste management systems can tackle the growing challenges associated with waste and contribute to a greener and more sustainable future ([Banjar et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0230), [Delanoë et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0420), [Güleryüz, 2020](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0560), [Herath and Mittal, 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0600), [Kamali et al., 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0690), [Kurniawan et al., 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0775), [Murthy and Ramakrishna, 2022](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b0985), [Rafew and Rafizul, 2021](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1145), [Rapati et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1165), [Wang et al., 2023](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "b1395)). This review aims to explore the current state of AI applications in waste management and practices. It examines how AI can enhance various aspects of waste management, including waste collection, sorting, recycling, and monitoring. The review discusses the benefits, challenges, and prospects of incorporating AI into waste management strategies to create more sustainable and efficient processes.

Methodology

To compile this review, we conducted a comprehensive search across academic databases, research papers, [industry](https://www.sciencedirect.com/topics/economics-econometrics-and-finance/industry) reports, and relevant publications. Specifically, we retrieved articles from Google Scholar and [Scopus](https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/scopus). [Fig. 1](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "f0005) shows the flow chart for literature search strategy. Key terms such as “artificial intelligence,” waste generation,” “intelligent waste management system,” “smart waste management,” “urban waste management” etc. were used to identify relevant studies and examples of AI applications in waste management. The selection criteria includes abstract, title and keywords.



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Fig. 1. Literature search strategy flowchart.

The database contained 246 items with publication years ranging from 2021 to 2023 as shown in [Table 1](https://www.sciencedirect.com/science/article/pii/S2949750724000385" \l "t0005). This window of time made it possible to find the most relevant and up-to-date publications for the research's purpose. Before the final analysis, 175 (71.14 %) ineligible articles were carefully eliminated to achieve reliability, and 71 (28.86 %) articles published between 2021 and 2023 that had undergone critical analysis were added to the study to provide an overview of the current state of AI in waste management practices.

Table 1.