Artificial Intelligence Based Smart Waste Management—A Systematic Review

Nusrat Jahan Sinthiya, Tanvir Ahmed Chowdhury, and A. K. M. Bahalul Haque

Abstract Smart waste management is an approach that utilizes modern technology to manage waste materials in effective, efficient, and economical way. Artificial intelligence offers various approaches which can help to construct smart waste management systems. AI based systems are used to tackle complicated problems, handle uncertainty, and exhibit the efficiency of smart systems. This article aims to conduct systematic literature review on artificial intelligent-based smart waste management systems. In this study, we have identified and analyzed 40 research papers published between the years 2001 to 2021. These papers have proposed various frameworks and smart models for different types of waste management. The main goal of this study is to summarize the findings of selected research papers, provide comprehensive analysis and identify the future research avenues of waste management. This chapter has addressed various waste management domains like municipal solid waste management, smart bin management, domestic waste management, medical waste management, construction and industrial waste management, and so on. Furthermore, categorical representation of most extensively used machine learning and deep learning algorithms along with their contribution have been elaborately discussed as well.

Keywords Smart waste management · Artificial intelligence · Systematic literature review (SLR) · Machine learning · Deep learning

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M. Lahby et al. (eds.), *Computational Intelligence Techniques for Green Smart Cities*, Green Energy and Technology, https://doi.org/10.1007/978-3-030-96429-0_3

1 Introduction

Green cities are required if the human species is to have a long-term future in anything like the environmental abundance that humanity now enjoys. It is important to keep in mind that inequality is not caused by a lack of wealth; rather, it is caused by an inadequacy or desire to share it equitably amongst residents. Our premise during this whole chapter will be that green cities are already emerging. Their future transformation requires significant assistance, as this positive advent must therefore transition from experiment to mainstream. Avoiding cataclysmic climate change is not a debate [1, 2]. Therefore intelligent waste management is a critical component of a smart green city. Waste generation is severe in emerging cities like- Laogang in Shanghai, China; Sudokwon in Seoul; the now-full Jardim Gramacho in Rio de Janeiro, Brazil; and Bordo Poniente in Mexico, etc. Each of them produces 10,000 tons of waste everyday [3]. According to a study, 10 billion tons of waste is generated worldwide. Domestic, commercial, and industrial construction contribute to the production of over two billion tons of garbage [4]. According to a projection of the World Bank, by 2050 the municipal waste generation can rise up to 3.40 billion. It was also said that 33% of those wastes was not effectively managed [5]. Which means that a large amount of waste is deposited at random, posing a risk to people and the environment. Because of the mismanagement of these wastes, a number of issues like groundwater pollution, land deterioration and health risks including cancer incidence, childhood mortality and birth anomalies can occur [6].

Waste management is a term that encompasses different procedures like proper exertion, waste disposal, removal, recycling, etc. These procedures have complicated operations, since there are various interrelated processes and socioeconomic aspects involved. Therefore, strategic planning is required to compete with the alarming rate of waste production. Smart waste management employs a variety of techniques. For instance, improved recycling tactics, disposal technology, optimized routing, IoT-based system, efficient sorting, reliable estimation of waste generation, etc. In light of these, Kellow Pardini et al. has stated an IoT-based solid waste management solution [7], Shwetashree Vijay et al. implemented a smart waste management system using ARDUINO [8], Similarly, Md. Shafiqul Islam et al. described a smart solid waste bin monitoring and collecting system [9]. Md. Abdulla Al Mamun et al. supervised an automated solid waste bin management [10]. Despite these, new technologies such as artificial intelligence, deep learning, and robotics are becoming more prevalent in this industry.

AI technologies involves advanced computer systems and programs which can effectively mimic human characteristics for instance—self learning, reasoning, problem-solving, and et cetera. Different AI models such as artificial neural network (ANN), expert system, genetic algorithm (GA), fuzzy logic can solve critical problems, predict reliable results, and solve complex mapping [11]. Although, the idea of expert systems for waste management was introduced long before [12]. Based on that decision support system (DSS) in order to promote the concept of clean cities by intelligent management was introduced too [13]. Artificial intelligence can be applied from garbage collection and transportation to central management, control, and adequate surveillance. Therefore, manual monitoring and traditional waste management methods can be replaced with AI-based smart solutions.

There have been few comprehensive reviews of AI based waste management. Xia W et al. presented a mini review regarding the application of machine learning algorithms in Municipal solid waste management. Different machine learning algorithms and their advantages and disadvantages along with their uses in different areas in MSW Management have been highlighted in this study [14]. Similarly, Abdallah M et al. presented an extensive discussion about the artificial intelligence application in solid waste management. This review basically focused on the assessment of various AI models used in solid waste management. The advantages and limitations of different AI applications were pointed out as well [16]. On the contrary, V. Agarwal et al. focused on the involvement of artificial intelligence in waste electronic and electrical equipment treatment. Data extraction and synergy methodology was applied to collect all the data regarding the topic and they did the analysis through graphs to illustrate the scope of artificial intelligence in E waste management [15].

However, there are currently no systematic reviews that can examine the existing artificial intelligence methods utilized in different domains of waste management. In this chapter, we have done a review of those papers which includes artificial intelligence as a major tool for different fields of smart waste management. The goal of this chapter is to collect and analyze the existing research trends, conduct a systematic literature review on the topic and answer the following research questions:

1. RQ 1) What are the waste management fields that involve AI as a major tool?
2. RQ 2) What are the AI techniques that are used as a solution for those?
3. RQ 3) What are the research gaps in the artificial intelligence and smart waste management domain?

We conduct a systematic literature review by following the methodology set by Kitchenham and Charters [17]. After all the analysis and applying the inclusion and exclusion criteria, we selected 40 research articles for this SLR. We observed each research article thoroughly and prepared a categorized representation. The rest of the chapter is structured as follows. After this introductory section, we introduce artificial intelligence technology and smart waste management briefly in Sect. 2. Next in Sect. 3, we present the SLR methodology. In Sect. 4, we present the findings from SLR, answer the research questions and provide overall discussion. In Sect. 5, we describe the contribution of this chapter and finally Sect. 6 concludes the chapter.

2 Background

Artificial intelligence (AI) is an enormous branch of computer science AI applications attempt to mimic human traits and solve different problems more efficiently and precisely. The range of AI applications includes automated reasoning, machine learning, natural language understanding, intelligent robots, automated programming and so on [18]. AI-based knowledge management software, automated systems, virtual agents, identity analytics, cognitive robotics and autonomous systems recommendation systems, speech analytics et cetera are few examples of AI applications that are used extensively [19].

Smart Waster Management

Every day, six tons of rubbish are created in Europe [20]. People generate 2.12 billion tons of garbage each year [21]. Wikipedia has listed almost 50 types of waste. One of them is E-waste (Electronic Waste). Roughly 20 to 50 million tons of E-waste are produced in a year throughout the world [22]. Another type of waste is municipal solid waste, almost 2.01 billion tons of municipal solid waste is generated in a year globally [23]. By 2050 it will increase by 70 percent reaching 3.4 billion tons a year. About 400 million tons of hazardous waste are produced every year that means 13 tons in every second [24], those wastes may do substantial harm to our health and environment because they are toxic, infectious, and radioactive. In 2017 China produced about 3.3 billion tons of industrial waste, with a total stockpiled over 60 tons over the year [25]. Another waste in construction waste and it is estimated that this industry is responsible for overall 35% of the generated waste [26]. Researchers are trying to find a way to solve this problem but still the percentage of construction waste in the US, Canada, Australia, UK are 33%, 35%, 30%, and 50%, respectively [26, 27].

Traditional waste management procedures are still used in many countries. Overcoming the flaws of traditional wastes is too crucial in order to ensure healthy living. Smart waste management is an effective solution in this regard. Unlike typical waste management systems, this method is automated by which it offers the possible shortest route, intelligent monitoring, saves unnecessary fuel cost of vehicles, and ensures time efficiency. To assure advancement and efficiency in this industry, intelligent systems are developed. Smart waste management using Internet of things (IoT) is a quite popular approach. Different frameworks and applications have been developed using this [28, 29]. Big belly smart waste and recycling system is considered as one of the finest solutions of collecting waste and recycling for public spaces [30, 31]. B. Chowdhury et al. implemented RFID-based smart waste management [32]. On the contrary, S. Sharmin el al. proposed an intelligent waste management platform which is a cloud-based dynamic system [33]. One of the most effective and dynamic approaches is waste management and monitoring systems using robot [34]. Finally, artificial intelligence (AI) is the most recent and most effective addition to the smart waste management system. There are different fields of waste management like- waste categorizing, efficient sorting, automated identification, estimation of waste generation, etc. and a range of AI models have been deployed to address different issues in each of these fields.

3 Methodology

We followed a systematic literature review approach in order to evaluate and summarize the existing studies regarding this topic. Systematic literature review is meant to be done by following a predefined search strategy and rigorous manner [15]. It is a well-planned strategy to search, identify and evaluate the most relevant studies of any particular research area. By following this scientific method, we tend to understand the scope of the existing literature and map the limitations of them so that those gaps can be explored later on to develop a new agenda. The procedure used in this SLR followed the standard protocol which involves different phases in order to conduct the whole review process.

3.1 Identification of Literature

For conducting SLR, rigorous searching techniques should be followed.

Search Strategy

Firstly, the most relevant keywords which are the core of the research question, should be identified. Boolean operators AND and OR can be used to generate search strings and to use those keywords elaborately. The keywords that are used in this chapter include "Artificial intelligence", "waste management", "smart waste management", "Wastewater management", and "solid waste management".

The strings that we produced in order to perform the identification of the literatures are

- "Artificial intelligence" AND "waste management".
- "Smart waste management".
- "Artificial intelligence" AND "Wastewater management".
- "Artificial intelligence" AND "Solid waste management".

The studies were retrieved from the International digital database SCOPUS. This database was chosen because it offers us a range of facilities. It provides quality research articles; it is authorized and well-known in the research community and the extraction of the information regarding specific studies is easy as well. The searches were done within the article title, abstract, keywords field. The final search was executed on August 30, 2021.

3.2 Screening

Once the results are obtained following search strategy, they need to be measured for relevance. For this, inclusion and exclusion criteria are followed.

3.2.1 Inclusion and Exclusion Criteria

The preliminary search returned 774 results altogether. After that inclusion and exclusion criteria is used to limit them and identify the studies that best explains our research agenda.

Exclusion Criteria

1. Review, Conference review, Book chapter, Notes, Short surveys and Thesis were excluded.
2. Studies that are not entirely based on artificial intelligence techniques for waste management were excluded.
3. Publications other than the English language are excluded.

Inclusion Criteria

1. Articles published on journal and conference proceeding.
2. Full text available on digital database.
3. Articles that involve the subject areas like- Environmental Science, Computer Science, and Engineering.
4. For more precise results these inclusion keywords were identified and selected—"waste management", "artificial intelligence", "machine learning", "deep learning" and "artificial neural networks".
5. Studies published in the English language.

Screening of articles using all these criteria returned 406 articles in total. Quality assessment was performed on those articles next.

3.3 Quality Assessment

Here, in this phase, we evaluated each of the papers individually. After the inclusion–exclusion criteria, an excel sheet containing information on 406 articles was extracted. Therefore, 379 articles remained after removing the duplicates. Among them, 273 articles were found which did not match our research area. Some of them were out of our study scope and others were not entirely based on our research area. We analyzed them through the title and abstract field. We identified those papers where AI was used as the major tool for waste management. Each of them was reviewed and based on our research area 40 articles were selected finally.

Final Outcome

After the completion of all criteria, 40 articles were finalized for this systematic literature review. Figure 1 illustrates the whole process.

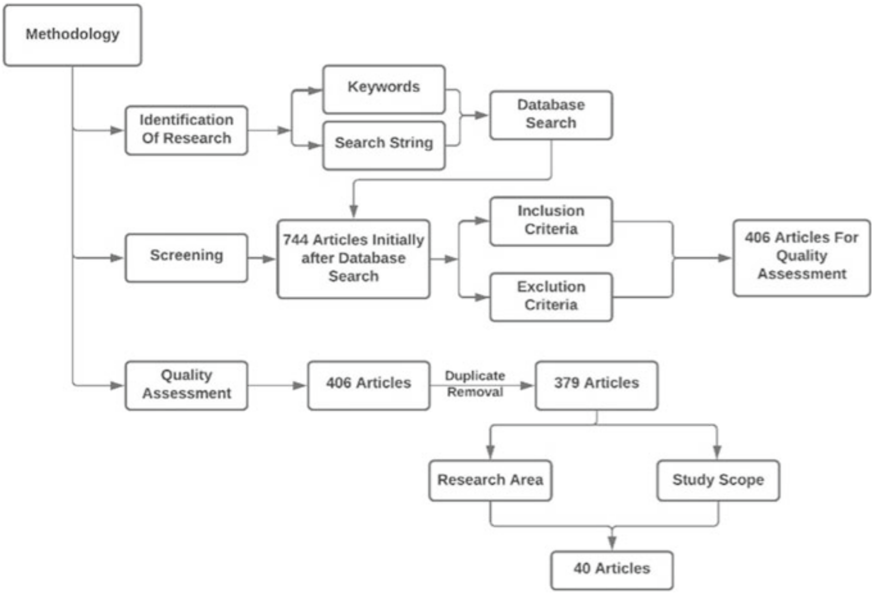

Fig. 1 Methodology of the SLR

4 Result and Discussion

4.1 Research Trend

Observing the research articles published throughout the years is an effective way to visualize research trends and their influence. From the literature search, we observe that articles regarding artificial intelligence first began in 2001. After 2016, the quantity of research increased, with the majority of the studies taking place between 2020 and 2021. Figure 2 depicts data on the number of articles published by various publishers during the previous two decades.

For this systematic literature review, we selected 40 papers. IEEE, Elsevier Ltd, and Springer published the majority of the works. IEEE published 13 papers, Elsevier Ltd published 11, and Springer published 5. Additionally, SAGE Publications Ltd published three articles and MDPI published two. Each of the following organizations published one paper: ACM, ASCE Library, Biomed Library, EDP Science, Frontiers Media S. A., and Hindawi Ltd.

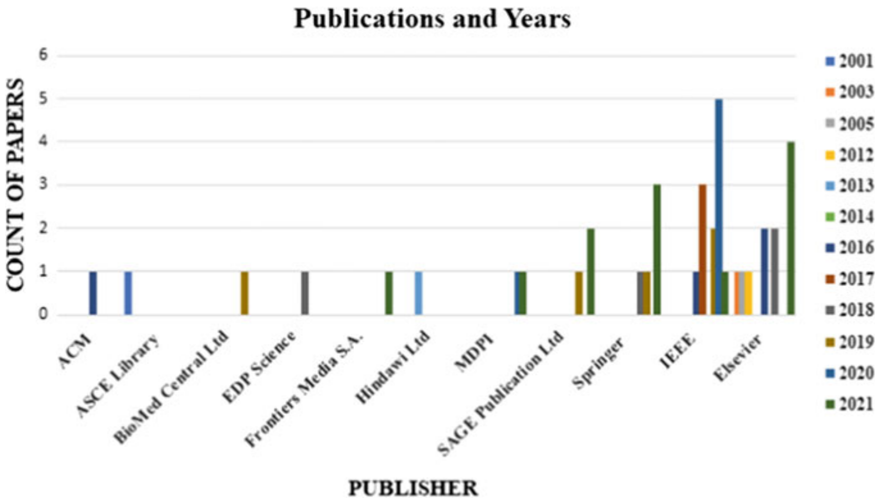

Fig. 2 Number of papers published

4.2 Addressing RQ1

The first research question considered for this study is—"What are the waste management fields that involve AI as a major tool?" Fig. 3 shows the number of published articles focusing on different waste management fields.

From Fig. 3, it is quite clear that most of the articles were published focused on the municipal solid waste management field. The least discussed fields were E-waste, construction, and industrial waste management. In order to facilitate the discussion,

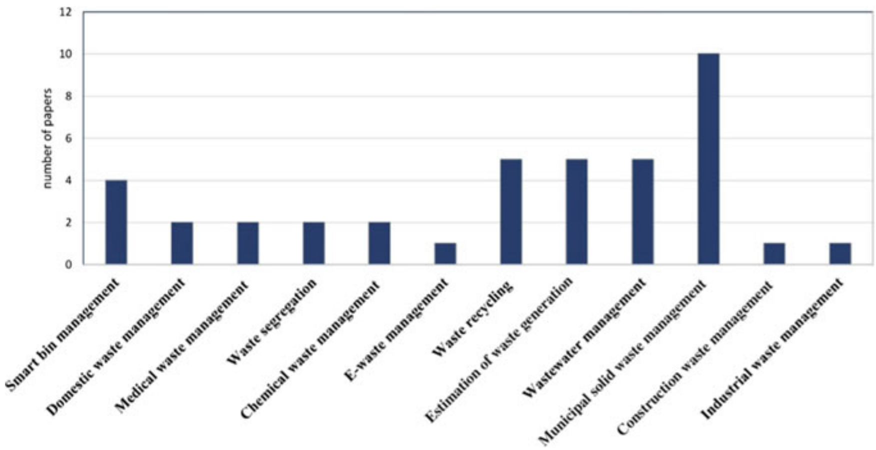

Fig. 3 Number of articles in different fields

the reviewed papers are classified under different waste management fields. The discussion regarding these fields are as follows –

4.2.1 Municipal Solid Waste Management

In this era of urbanization, solid waste management is a growing concern; which needs widespread attention. In developing countries, the challenges of solid waste management are increasing proportionally to the growth of urbanization [35]. One of the most important aspects of solid waste management is the collection and transportation process. In the municipal solid waste management budget, the collection cost takes almost 80–90% and 50–80% in low income and middle-income countries, respectively [36]. Manh Hua et al. discussed an optimized system for waste collection and transportation using K-means algorithm and by applying the vehicle routing problem. Here, K-means algorithm was used to cluster the waste collection centers and VRP was applied to generate an optimized path for the waste collector vehicles [37]. Similarly, Dordevic et al. has presented a model for efficient waste collection, which will eventually save resources. Neural network algorithm (NNA), genetic algorithm (GA) and MATLAB is used for the improvised system [44].

In addition to the transportation issue, unorganized waste dumping is a major concern in metropolitan areas. A mobile application-based smart system has been proposed to raise complaints about it by locals so that the authorities can take action immediately. However, in this case, fake complaints might be a source of concern that must be addressed. Machine learning algorithms like support vector machine (SVM) and convolutional neural network (CNN) have been used in this regard where CNN performed the best with 87% of accuracy [38].

To avoid reckless waste material dumping in urban areas, identifying trash dump yards is a useful approach. In light of this, Ramasami et al. proposed a system that utilizes artificial intelligence algorithms to identify acceptable zones for solid waste dump yards and genetic algorithm (GA) is used in this regard [39]. Detection of different solid waste items is important before conducting waste recycling and sorting. Patel et al. employed a garbage detection system using object detection models which can automatically locate garbage using real-world images as well as videos. EfficientDet-D1, SSD ResNet-50 VA, Faster RCNN ResNet-101 V1, CenterNet ResNet-101 V1, YOLOv5M is used here and YOLOv5M achieved the best result by achieving a mean average precision value of 0.613 [40]. Additionally, a convolutional neural network (CNN)-based prediction model has been proposed to identify waste items and waste mass [43].

Different types of waste can be exploited into energy. To accomplish this, it is necessary to determine the higher heating value (HHV) of municipal solid waste. Machine learning-based systems have been developed in order to forecast the higher heating value which can be used later to transform the waste materials into energy. Multiple regression and genetic programming is used for the implementation. However, genetic programming provides the most precise result [41]. Apart from these, a comparative study of two ML algorithms: Multi-layer perception artificial neural network (MLP-ANN) and support vector regression (SVR) is conducted to analyze performance and accuracy level of different models [42].

4.2.2 Smart Bin Management

AI-driven smart bins are a very innovative way to manage waste materials. Abeygunawardhana et al. proposed a smart bin for classifying waste materials, monitoring filled bins and generating optimal routes for the collectors. This study basically used image processing for the identification of waste materials and convolutional neural network (CNN) is trained to recognize individual trash items in order to facilitate further sorting. To eliminate the manual monitoring, the system used ultrasonic sensors to identify the filled beans and lastly a mobile application was developed for the whole system to produce optimal routes for the waste collectors [45].

Similarly, Jadli et al. offered an architecture in which artificial intelligence techniques are utilized to determine the current status of waste bins where automated surveillance cameras are used to take pictures which are then forwarded to the processing server to detect the fill level. Finally, the architecture produces optimized waste collection schedules for the facility system according to the retrieved data. It employed various algorithms including Inception V3 model for future extraction, then support vector machine (SVM), naive Bayes, and linear regression for classifying the waste materials and lastly convolutional neural network (CNN) for the fill level detection and solar powered cameras were used to take the pictures for the system [46].

In addition to those methods, Ji Sheng et al. demonstrated a smart bin capable of simultaneously detecting and segregating waste materials. The system is configured in such a way that waste products can be separated into distinct compartments within the bin. Tensorflow framework-based deep learning model is used here, which is then exported to the Raspberry Pi mobile microprocessor for waste detection. LoRa communication protocol is used to transmit sensor data, an RFID module is used for bin maintenance, and finally, servo motors controlled by the Raspberry Pi are used to open and close the lids of the bin's individual compartments [47].

On the contrary, M. A. Hannan et al. implemented a method for bin level detection-based on a gray level aura matrix (GLAM). This system can be used to classify the bin level and grade of the solid waste. Both of the information are important features for solid waste collection. A gray level aura matrix (GLAM) is implemented here in order to extract the bin image texture. Then, the extracted image is trained and tested using multi-layer Perceptions (MLP) and K-nearest neighbor classifiers which helps to evaluate the performance of the system. The MLP classifier demonstrated that the bin level and grade classification rates are 98.98 and 90.19%, similarly using K-nearest neighbor classifiers the rates were found 96.91% and 89.14%, respectively [48].

4.2.3 Medical Waste Management

Hospital solid-waste encompasses a variety of infectious, chemical, and radioactive wastes that are extremely hazardous to both humans and the environment. [49]. Golbaz S et al. focused on the development of predicting models using AI techniques in order to find out the HSW rate. Different methods were employed to analyze and forecast the waste generation rate and comparative measurement was also conducted in order to find out the most effective model. In the study multiple linear regression (MLR) and several neuron and kernel-based machine learning methods like ANN, ANFIS, LSSVM, SVM, and FSVM were used. Among all of them kernel-based ML models provided the most satisfactory result [50].

Considering the recent COVID outbreak Kumar N et al. precisely put emphasis on the current COVID situation and addressed an important issue which is COVID related medical waste sorting. During this outbreak a number of infectious medical waste mixed with usual waste types. To solve the problem, the study implemented an automated smart system using AI techniques to sort those wastes before recycling so that the infection can be prevented. For the waste type recognition artificial neural network (ANN), support vector machine (SVM) and K-nearest neighbor (KNN) classifiers are used. Among them, support vector machine performed the best with a 96.5% accuracy [51].

4.2.4 Domestic Waste Management

Nowadays, smart home management incorporates an intelligent approach to waste management. In light of this, Article 50 presents a concept for a smart house management system. Here, advanced technologies are employed to maximize the efficiency of all available resources. For instance, dynamically identifying and resolving issues, optimizing power consumption, and so forth. Machine learning algorithms are employed to reduce waste and carbon emissions. Waste items are categorized into dry, wet, plastic hazardous, etc. Image processing and machine learning techniques are primarily used in this system to ensure an automated home system [52].

Additionally, Papagiannis F. et al. presents an alternative system solution for the European household waste problem where it informs the policymakers on the ambiguous household behaviors. The implementation method is carried out using K-means clustering [53].

4.2.5 Waste-water Management

Gabriel Markovic et al. described the modeling of rainwater and graywater in a school building in Slovakia using artificial intelligence. Fuzzy cognitive maps were used for this management and MATLAB software for the implementation [54]. For wastewater treatment, Chen W. C. et al. stated that by incorporating rough set theory into the neural fuzzy controller, it is possible to achieve superior plant performance in terms of cost effectiveness, control stability, and response time. Neural network model and genetic algorithm was used to meet various control needs. Additionally, they used a hybrid fuzzy control system, which incorporated a variety of artificial intelligence techniques [55].

Similarly, Chen W. et al. presented a three-stage analytical method for advanced fuzzy control. The fuzzy neural controller worked effectively and it achieved required real time control objectives. It can be an efficient and cost effective tool to accommodate the quality control in terms of response time and stability control of the wastewater treatment process. They also utilized neural network model and genetic algorithm [56].

Matheri A. et al. described a model to solve the real-life problem of wastewater treatment using the artificial neural network model and MATLAB. They forecasted the demand for trace metals and chemical oxygen in wastewater treatment [57]. The chemical industry's rise has resulted in an increase of poisonous and dangerous components. Yanbo J. et al. deeply analyzed the wastewater quality and chemical wastewater's biodegradability in a chemical industry park. The time varying and unstable system in the treatment process of toxic and refractory organic wastewater was considered as the research subject. It was analyzed based on the fuzzy control theory of artificial intelligence [58].

4.2.6 Chemical Waste Management

Chemical wastes must be managed appropriately because it can cause severe damage to the environment. Moreover, it can also cause harm to people if they are released or dumped carelessly. Taking this into account, J. M. Aitken et al. developed a reconfigurable rational agent-based robotic system capable of simulating autonomous nuclear waste processing. In this project, random sample consensus algorithm (RANSAC), MSAC and robot operating system (ROS) has been used [59]. Similarly, Fawzy M. et al. conducted a batch biosorption experiment to determine the removal efficiency of Cd(II) ion from aqueous solution by Gossypium Barbadense waste. Artificial neural network (ANN) is used to predict the absorption efficiency of Cd(II) ion removal [60].

4.2.7 Waste Segregation

Along with waste collection and transportation, waste segregation or categorizing is also essential for further processing. Advancement in this sector can accelerate waste recycling. Considering this, few studies have developed. In article 60, an approach was taken in order to classify the waste items into biodegradable and non-biodegradable. This approach was basically developed using deep learning. It is an intelligent system which can learn an update by itself. Boundary algorithm and deep learning framework Caffe was used for the implementation [61].

Similarly in Article 61, a system based on object recognition method is proposed where the waste items are examined through weight sensors. Next a camera is used to capture the pictures and then image segmentation is done for the prediction process. After identifying the items, they were categorized into degradable and non-degradable using AI techniques. Here, TensorFlow library and Raspberry PI Microcontroller was used for the implementation [62].

4.2.8 Estimation of Waste Generation

Estimation of waste generation is an important factor for planning sustainable waste management strategies. In Article 62, four machine learning algorithms were evaluated for their ability to estimate the monthly municipal solid waste generation in Logan city. Support vector machine (SVM), artificial neural network (ANN), K-nearest neighbor (KNN), and adaptive neuro fuzzy inference system (ANFIS) were applied for the estimation process and among them ANFIS performed the best [63].

Another comparative study was done considering Delhi city to find out the monthly MSW generation. Six distinct models were evaluated in this study. There were also a few hybrid models among them. Those models are pure ANN, Pure ANFIS, GA-ANN, DWT-ANN, GA ANFIS, and DWT-ANFIS. Among them GA-ANN performed the best [64]. On the contrary, Coskuner et al. focused on the prediction of domestic, commercial, construction, and demolition waste generation. Here, multi-layer perception artificial neural network (MLP-ANN) is applied to predict the annual waste generation [65]. Similarly, Cha G. W. et al. proposed a RF model to forecast the generation of demolition waste. Here, a small dataset is used for multipurpose demolition waste management. This model is capable of predicting the amount of waste generation based on the type of wastes. In this study, RF-recursive feature elimination (RFE) was used for feature selection and lastly Leave-One-Out Cross-Validation (LOOCV) method was applied to verify the performance of RF models [66].

Finally in Article 66, a model capable of predicting the municipal solid waste generation and diversion of a given region using the demographic and social economic parameters at municipal level is proposed. For the implementation process decision tree and neural network were utilized. Between them neural network performed the best [67].

4.2.9 Waste Recycling

We have encountered the involvement of different machine learning algorithms in the waste recycling process. Ozdemir et al. described several machine learning algorithms along with their workflows, and contributions in the subject of recycling. They employed a variety of AI-based models and machine learning algorithms, including K-nearest neighbor, decision tree, artificial neural network, support vector machine, random forest, and convolutional neural network (CNN) [68].

Huang, Jueru and Dmitry D. Koroteev stated about the development of a machine learning driven predictive analytic framework (MLPAF) for energy and waste management planning. That framework attempted to improve the waste management process by considering energy conservation and material recycling [69]. For an automated recycling system, Nañez Alonso et al. took necessary measures using CNN and image identification to automatically recycle waste material like paper, glass, organic, and plastic. Therefore, (83% of detected paper, 76% of plastic, 97% organic material, 84% glass) using VGG-16 Network, (82% paper, 95% organic material, 60% plastic, 78% glass) using VGG-19 Network, and (88% paper, 98% organic material, 70% plastic, 83% glass) was found using ResNet15V2 Network [70].

D. Rutqvist el al. presented an accurate detection of emptying a recycling container using the measurements from the sensor mounted on the upper part of the container with the help of an automated machine learning approach. They used several machine learning models in this system. For instance, ANN, logistic regression, decision tree, random forest, etc. [71]. A multi-layer hybrid deep learning system was employed in order to automatically sort waste disposed by individuals in the urban public area. This system is constructed with a high-resolution camera for capturing waste image and requires a sensor to detect other necessary features. For extracting the image features this system used a CNN algorithm and MLP to consolidate image features and other related features to identify whether wastes are recyclable or not. Multi-layer hybrid deep learning system (MHS) showed the best result for identifying the recyclable wastes [72].

4.2.10 E-waste Management

Electrical and electronic waste WEEE, or electronic trash, is a top priority in waste management. It has become a significant issue in both developed and developing countries [73]. Król A et al. precisely focused on wastes generated from electrical equipment. To improve WEEE management, the waste transportation structure was developed along with the user interface using artificial intelligence techniques. The system aimed to optimize the route length and number of vehicles so that it results in cost reduction and time efficiency. Additionally, the use of websites and mobile applications was advised to make these services accessible to locals. This concept was primarily articulated in order to facilitate the work of garbage collecting authority. Genetic algorithms (GA) and fuzzy logic were employed in this regard [74].

4.2.11 Industrial Waste Management

According to a study, China produces almost 3.3 billion tons of industrial waste every year. Industrial wastes create a huge problem in the environment, if these wastes are not disposed of within a certain time, it not only hampers the land resource and money but also it affects the ecosystem [75–77]. Liao B. et al. developed an intelligent model for industrial waste planning. They tried to overcome the limitations of traditional ways of industrial waste management and proposed a smart model to upgrade the system. By using the industrial waste images and appropriate detection model, it identifies the target objects and then proceeds for the further recycling process with the help of BP-network prediction model. Here, the faster RCNN algorithm was used for the target detection [78].

4.2.12 Construction Waste Management

The construction industry is likewise experiencing significant difficulties as a result of waste. Construction wastes require huge financial resources to be tackled along with the fact that this waste is a severe threat for the environment. It is estimated in a study that the construction industry produces almost 35% of the overall wastes [78]. The percentage of construction waste in the UK, USA, Australia, Canada, Hong Kong is, respectively, 50%, 33%, 30%, 35%, and 65%. [79, 80]. Application of artificial intelligence is discussed and reviewed through a conceptual framework for an effective waste management system. There T. H. Ali el al. developed an idea of an effective construction waste management system (EMS) by the involvement of AI. Through the EMS the construction practitioners can identify the most effective and economical waste management techniques [81].

4.3 Addressing RQ2

Our second research question is—"What are the AI techniques that are used as a solution for those?" Table 1 represents the usage of different AI models in different papers.

There are 16 AI models that have been identified from our selected research articles. Among them artificial neural network (ANN) was the most used model. This model has been extensively used for estimating the waste generation rates, constructing predictive analytical frameworks and waste type recognition. Apart from that the contribution of support vector machine (SVM), convolutional neural network (CNN), genetic algorithm (GA) were also frequent. Among them CNN is mostly used for categorizing waste items, waste bin fill level detection and object recognition.

Although SVM is another most frequently used model for detection and classifying of waste materials. Usage of GA and fuzzy logic have been found commonly in wastewater treatment and E-waste management. For the waste recycling process, a sheer involvement of KNN is noticed. Few hybrid models for instance; GA-ANN, DWT-ANN, MLP-ANN, DWT-ANN, DWT-ANFIS were mentioned in few studies too. In essence, these models were employed to determine the rates of municipal solid waste generation and they performed comparatively better than the pure machine learning models. The remaining models have also made significant contributions to

Table 1 Percentage of AI technique used in number of papers

AI techniques	Used in no. of papers	Percentage (%)
ANN	9	22.5
CNN	7	17.5
SVM	7	17.5
GA	6	15
KNN	4	10
Fuzzy logic	4	10
ANFIS	3	7.5
Decision tree	3	7.5
Hybrid model	3	7.5
K-means	2	5
RF	2	5
MLR	2	5
Naive Bayes	1	2.5
Linear regression	1	2.5
Logistic regression	1	2.5
BP-network	1	2.5

many domains of smart waste management. Nevertheless, Table 2 outlines the use of many AI models and their contribution to various studies.

4.4 Addressing RQ3

Our third research question is "What are the research gaps in the artificial intelligence and smart waste management domain? In previous sections we provided a categorical representation about the involvement of artificial intelligence in different waste management fields. We reviewed the applications of artificial intelligence, frameworks, and proposed infrastructures for resolving various difficulties in those domains. Following these analytical discoveries, we identified many significant research gaps that can be studied further in the future. The research gaps are as follows:

1. From previous analysis, it is apparent that AI is used frequently in smart waste management systems, and its reach is expanding daily in this sector. The majority of the research we discovered was done on municipal solid waste management (MSW). Apart from these, additional areas of waste management where AI has been extensively applied include- smart bin management, wastewater management, and recycling. However, the rate of studies conducted in these areas is half as compared to the MSW. But wastewater management is a critical component of smart waste management. Due to urbanization, enormous amounts of

Table 2 Usage of different AI models and their contribution

AI models	Articles and references	Applications
ANN	[50, 51, 57, 60], [63, 64, 68, 69], [71]	• MSW generation rate • Hospital solid waste generation rate • Predictive analytical framework • Waste recycling • Wastewater treatment • Waste type recognition
SVM/SVR	[38, 45, 50, 71], [42, 51]	• Classifying waste materials • Identifying spurious complaints about uncollected garbage • Hospital solid waste generation rate
CNN/faster RCNN	[38, 40, 45, 46, 72, 78, 82]	• Waste item recognition • Waste bin fill level detection • Identifying spurious complaints about uncollected garbage • Target object detection • Predicting waste and waste mass
Naive Bayes	[46]	• Classifying waste materials
Linear regression	[46]	• Classifying waste materials
K-means algorithm	[37, 53]	• To group waste collection centers into small clusters
ANFIS	[50, 63, 64]	• Estimating waste generation
RF	[66, 71]	• Waste recycling • Generation of demolition waste
Fuzzy logic	[54–56, 73]	• Cost effective wastewater management • Improved infrastructure for WEEE management
Decision tree	[67, 68, 71]	• Waste recycling • MSW generation
BP-network	[66]	• Industrial waste planning
KNN	[51, 63, 68, 71]	• Estimation of waste generation • Waste type recognition • Waste recycling
MLR	[41, 50]	• Higher heating value prediction of waste materials • HSW generation rate
Logistic regression	[71]	• Waste recycling
GA	[39, 41, 56, 74], [55]	• WEEE management • Location prediction for waste dump yard • Higher heating value prediction of waste materials • Wastewater treatment • Optimizing waste collection

(continued)

Table 2 (continued)

AI models	Articles and references	Applications
Hybrid model	[42, 64, 65]	• Estimation of waste generation

wastewater are generated every day, and the majority of it is just discharged carelessly into surrounding canals and rivers, causing severe environmental harm, yet only five studies [54–58] on wastewater treatment and processing were identified. As a result, wastewater management could be a promising field of research for further developing the notion of smart waste management.

2. Second, we observed that there is very limited research on E-waste management. Due to urbanization, electrical and electronic equipment-related wastes are also increasing at an alarming rate, yet relatively few research have examined this topic. The involvement of artificial intelligence in this area is remarkably less than other fields despite the fact that this is a critical issue in the modern era. Only one article [74] was found regarding AI-based WEEE management which aimed to optimize the transportation of E-wastes so that cost efficiency can be achieved. Extensive research and effective frameworks should be very impactful and highly recommended.
3. Another comparatively least discussed topic is industrial and construction waste management. We can notice an emerging industrial revolution in our world. As a result, a large number of wastes are generated on a daily basis in the sector. Most importantly, the waste generated in this industry can be extremely dangerous due to the fact that the majority of it is chemical waste, which is extremely detrimental to the environment. But we found only one study regarding this topic where a smart model for object detection was proposed. However, sophisticated frameworks can be established to mitigate the risks associated with this subject. On the other hand, in construction and demolition waste management AI has been rarely discussed. Further research in this area can be very helpful to come up with advanced solutions for construction waste management systems.
4. We have noticed the existence of a good number of papers for smart bin management [45–48]; where the bins are monitored through surveillance cameras and weight sensors and the waste materials are also identified automatically once they are dumped into the bin. However, in addition to identifying waste items, efficient sorting is required. Automated systems are required for this. We discovered only one publication in which waste items were automatically detected and sorted [48], implying that such a smart device was installed to enable waste products to be segregated without human intervention. This is a very novel concept, but this concept needs to be explored more so that more efficient and reliable automated systems can be accomplished. Therefore, it can be a potential research area for the future.
5. Finally, the efficiency and accuracy level of AI models needs to be increased. Different kinds of machine learning and deep learning algorithms were used in different studies to train the model. Additionally, few comparative studies

[38, 40, 42, 50, 63, 64] were also done to find out the most efficient models. Therefore, further research for improving these models is highly recommended.

However, we have noticed that different models have different accuracy levels under different circumstances. Table 3 summarizes the comparative studies of different models.

5 Contribution

We have identified the following implication after analyzing the selected articles. The implications are outlined as follows:

1. The first and foremost contribution of this work is to the best of our knowledge there is no previous systematic literature review on artificial intelligence and smart waste management. Although there are a few research studies that concentrated on a specific field of waste management and conducted a systematic review of the literature. [12–14] However, this literature review considers several fields of waste management. We have discussed about a number of waste management fields in this chapter, where AI techniques have been used extensively. Additionally, we offered an overview of the rate of work in each field. This literature review will aid the researchers in identifying the less discussed fields. In this way they will be able to contribute to those fields.
2. Secondly, this chapter provides a comprehensive summary of the AI models that have been used for solving different problems at one place. Researchers can gain a thorough understanding of the most often addressed issues in this field. Additionally, they can visualize current issues that require additional attention.
3. Thirdly, we have discussed the most frequently used machine learning and deep learning algorithms along with their applications. Moreover, we have provided the findings about the comparative studies of different models. We have summarized the findings in such a way so that the researchers can have a clear conception about the accuracy level and functionality of each model.
4. We have analyzed and provided a very detailed overview of different research fields of waste management that have been taken into consideration until now. For example, municipal solid waste management, wastewater management, smart bin management are the most explored domains. A few other areas, for instance, E-waste management, hazardous waste management, construction, and industrial waste management are the less discussed areas. Our observation from this analysis will help the potential researchers to gaze their site onto those areas. As a result, those unexplored areas will be developed.
5. Finally, the article can be a guideline for learning more about artificial intelligence and its application to smart waste management. Our analysis revealed that waste management is a wide topic with numerous potential areas for progress and innovative tactics to be implemented. Artificial intelligence may be a viable option in this instance. The findings from this study can assist

Table 3 Comparative studies of different models

Articles	Objective	Key findings
[63]	Comparison of different AI techniques for estimating monthly Municipal waste generation to find out the most reliable method	R2 = coefficient of determination • ANFIS performed better where train value of R2 was 0.98 • SVM, ANN, KNN were performed, respectively, with train value of R2 0.71, 0.46 and 0.51, respectively
[64]	Comparison of different AI techniques for estimating monthly municipal waste generation to find out the most reliable method	• Pure ANN models performed with a R2 value of 0.72 • DWT-ANN performed with a R2 value of 0.67 • GA-ANN, Pure ANFIS, DWT-ANFIS, GA-ANSIS showed R2 value of 0.87, 0.36, 0.73, 0.56, respectively. Therefore, GA-ANN was considered as the most effective model
[38]	Identification of uncollected garbage in urban areas so that necessary steps can be taken immediately for processing the waste items	• Accuracy of CNN hit a peak of 83% to 85% and the intermittent spikes was up to 87%
[40]	The main objective of this research is to conduct a comparative study between different object detection model based on their performance on their dataset	mAP@0.5 = mean average precision is calculated by thresholding intersection over union (IoU) at 0.5 • The mAP@0.5 value for EfficientDet-D1 was 0.360 • SSD ResNet-50 FPN (RetinaNet50), Faster RCNN ResNet-101, CenterNet ResNet-101 FPN and YOLOv5M's mAP@0.5 value were, respectively, 0.511, 0.586, 0.595, and 0.613 • YOLOv5M performed better result in mAP@0.5
[42]	This chapter compared two machine learning techniques one was multi-layer perceptron artificial neural network (MLP-ANN) and another one was SVR to predict annual municipal solid waste in Bahrain using MSW dataset (1997–2019)	• Test data of R2 value of ZSN was 0.98 and MMN was 0.99 • Entire data value of R2 of ZSN was 0.93 and MMN was 0.94
[50]	Development of predicting models for hospital solid waste (HSW) management system	• In ANN modeling the testing value of R2 was 0.73, 0.65 and 0.70, respectively • Same as for ANFIS the value of R2 was 0.66, 0.71, and 0.59, respectively • For SVM the value of R2 was 0.79, 0.98, and 0.90, respectively • For LSSVM the value of R2 was from 0.70 to 0.77 • In FSVM model it was 0.79–0.92 Hence, kernel-based models provided the most satisfactory result

researchers, enthusiasts, and other stakeholders to evolve the concept of smart waste management.

6 Conclusion

The purpose of this systematic literature review is to assess prior research on artificial intelligence smart waste management. We acquired the relevant studies from Scopus which is a well-known database and conducted a thorough analysis of each one. We examined the number of publications published each year on this subject and discovered that the scope of this field of study has expanded in recent years. This systematic review examined the role of various AI models in the waste management system by examining 40 publications published between 2001 and 2021. A comprehensive analysis was conducted on several AI models and their applications in the waste management industry. According to the findings of this SLR study, different types of AI models have been used to anticipate, simulate, and enhance waste management systems, including pure machine learning and deep learning models, as well as hybrid AI models. Despite increased study in this field, AI systems are still mostly in the research and development phase. This SLR demonstrates unequivocally which domains have received the greatest attention and which domains have received the least. The most significant drawback of this SLR is that we only searched one database, Scopus. To discover other publications, we employed citation chaining. Despite this, we may have overlooked some essential articles that should have been included in this SLR. This constraint can be alleviated in the future by increasing the number of databases accessible for article searching.

References

1. Low, N., Gleeson, B., Green, R., Radovic, D.: The Green City: Sustainable Homes, Sustainable Suburbs. Routledge (2016)
2. Roo, M.D., Kuypers, V.H.M., Lenzholzer, S.: The Green City Guidelines: Techniques For a Healthy Liveable City. The Green City (2011)
3. Hoornweg, D., Bhada-Tata, P., Kennedy, C.: Environment: waste production must peak this century. https://doi.org/10.1038/502615a
4. Besen, G., Fracalanza, A.: Challenges for the sustainable management of municipal solid waste in Brazil. disP—Plan. Rev. **52**(2), 45–52 (2016)
5. World Bank. What a waste 2.0: a global snapshot of solid waste management to 2050. Int. Bank Reconstr. Develop. (2018)
6. Triassi, M., Alfano, R., Illario, M., Nardone, A., Caporale, O., Montuori, P.: Environmental pollution from illegal waste disposal and health effects: a review on the "triangle of death". Int. J. Environ. Res. Public Health **12**, 1216–1236 (2015)
7. Pardini, K., Rodrigues, J.J.P.C., Kozlov, S.A., Kumar, N., Furtado, V.: IoT-based solid waste management solutions: a survey. J. Sens. Actuator Netw. **8**, 5 (2019)
8. Vijay, S., Raju, S., Nitish Kuma, P., S, V.: Smart waste management system using ARDUINO. Int. J. Eng. Res. Technol. (IJERT) (2019). Available at: https://www.ijert.org/>. Accessed 8 Dec 2020

9. Islam, M., Arebey, M., Hannan, M., Basri, H.: Overview for solid waste bin monitoring and collection system. In: 2012 International Conference on Innovation Management and Technology Research (2012)
10. Abdulla Al Mamun, M., Hannan, M., Hussain, A., Basri, H.: Integrated sensing systems and algorithms for solid waste bin state management automation. IEEE Sens. J. **15**(1), 561–567 (2015)
11. Yetilmezsoy, K., Ozkaya, B., Cakmakci, M.: Artificial intelligence-based prediction models for environmental engineering. Neural Netw. World. **21**(3), 193–218 (2011)
12. Basri, H., Stentiford, E.: Expert systems in solid waste management. Waste Manag. Res. J. Sustain. Circular Econ. **13**(1), 67–89 (1995)
13. Jayawardhana, L., de Alwis, A., Pilapitiya, S., Ransinghe, M.: Bestcity: developing clean cities. In: Li, D., Wang, B. (eds) Artificial Intelligence Applications and Innovations. AIAI 2005. IFIP—The International Federation for Information Processing, vol. 187. Springer, Boston. https://doi.org/10.1007/0-387-29295-0_6(2005)
14. Xia, W., Jiang, Y., Chen, X., Zhao, R.: Application of machine learning algorithms in municipal solid waste management: a mini review. Waste Manag. Res. J. Sustain. Circular Econ. 0734242X2110337 (2021)
15. Agarwal, V., Goyal, S., Goel, S.: Artificial intelligence in waste electronic and electrical equipment treatment: opportunities and challenges. Int. Conf. Intell. Eng. Manage. (ICIEM) **2020**, 526–529 (2020). https://doi.org/10.1109/ICIEM48762.2020.9160065
16. Abdallah, M., Abu Talib, M., Feroz, S., Nasir, Q., Abdalla, H., Mahfood, B.: Artificial intelligence applications in solid waste management: a systematic research review. Waste Manag. **109**, 231–246 (2020)
17. Kitchenham, B., Charters, S.: Guidelines for Performing Systematic Literature Reviews in Software Engineering. Accessed 27 Dec 2020. Available: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.117.471
18. Haenlein, M., Kaplan, A.: A brief history of artificial intelligence: on the past, present, and future of artificial intelligence. Calif. Manag. Rev. **61**(4), 5–14 (2019)
19. McCarthy, J.: What is AI? [Internet]. Jmc.stanford.edu. 2021 [cited 22 October 2021]. Available from: http://jmc.stanford.edu/articles/whatisai.html
20. Ning, S., Yan, M.: Discussion on research and development of artificial intelligence. In: 2010 IEEE International Conference on Advanced Management Science (ICAMS 2010), pp. 110–112. doi:https://doi.org/10.1109/ICAMS.2010.5553039 (2010)
21. Wirtz, B., Weyerer, J., Geyer, C.: Artificial intelligence and the public sector—applications and challenges. Int. J. Public Adm. **42**(7), 596–615 (2018)
22. European Commission, "Waste": http://ec.europa.eu/environment/waste/. Accessed 23 May 2018
23. The World Counts: Theworldcounts.com. Available: https://www.theworldcounts.com/challenges/planet-earth/state-of-the-planet/world-waste-facts/story (2021)
24. "Wang, Z., Zhang, B., Guan, D.: Take responsibility for electronic-waste disposal. Nat. Cell Biol. **536**, 23–25 (2016)
25. Trends in Solid Waste Management: Datatopics.worldbank.org. Available: https://datatopics.worldbank.org/what-a-waste/trends_in_solid_waste_management.html (2021)
26. The World Counts: Theworldcounts.com. Available: https://www.theworldcounts.com/challenges/planet-earth/waste/hazardous-waste-statistics/story (2021)
27. Liao, B., Wang, T.: Research on industrial waste recovery network optimization: opportunities brought by artificial intelligence. Math. Prob. Eng. **2020**, 1–11. Available: https://doi.org/10.1155/2020/3618424 (2020)
28. Yang, H., Xia, J., Thompson, J., Flower, R.: Urban construction and demolition waste and landfill failure in Shenzhen, China. Waste Manag. **63**, 393–396 (2017). Available: https://doi.org/10.1016/j.wasman.2017.01.026
29. Malinauskaite, J., et al.: Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. Energy, **141**, 2013–2044 (2017). Available: https://doi.org/10.1016/j.energy.2017.11.128

30. Smart Waste Management by Sensoneo: Sensoneo. Available: https://sensoneo.com/ (2021)
31. What is Smart Waste Management?: IoT For All. Available: https://www.iotforall.com/smart-waste-management (2021)
32. Big belly-Smart city solution: http://bigbelly.com/. Accessed 27 May 2018. Available :http://bigbelly.com/
33. Commscope.com: https://www.commscope.com/globalassets/digizuite/1440-1270-sb-bigbelly.pdf?utm_source=ruckus&utm_medium=redirect (2021)
34. Chowdhury, B., Chowdhury, M.U.: RFID based real-time smart waste management system. In: 2007 Australasian Telecommunication Networks and Application Conference, pp.175–180 (2007)
35. Sharmin, S., Al-Amin, S.T.: Cloud-based dynamic waste management system for smart cities. In: Proceeding of the 7th Annual Symposium on Computing for Development, ser. ACM DEC 16
36. Purushotham Vijay Naidu, V., Dhikhi, T.: Smart Garbage Management Systems. Int. J. Pharm. Technol. **8**(4) (2016)
37. Ahmed, S., Ali, M.: Partnerships for solid waste management in developing countries: linking theories to realities. Habitat Int. **28**(3), 467–479 (2004)
38. Aremu, A.: In-town tour optimization of conventional mode for municipal solid waste collection. Ajol.info. 2021 [cited 22 October 2021]. Available from: https://www.ajol.info/index.php/njt/article/view/123619
39. Towards a decision support system for municipal waste collection by integrating geographical information system map, smart devices and agent-based model. In: Proceedings of the Seventh Symposium on Information and Communication Technology [Internet]. Dl.acm.org. 2021 [cited 22 October 2021]. Available from: https://dl.acm.org/doi/https://doi.org/10.1145/3011077.3011129
40. Identifying uncollected garbage in urban areas using crowdsourcing and machine learning [Internet]. Ieeexplore.ieee.org. 2021 [cited 22 October 2021]. Available from: https://ieeexplore.ieee.org/document/8070078
41. Location prediction for solid waste management—A Genetic algorithmic approach [Internet]. Ieeexplore.ieee.org. 2021 [cited 22 October 2021]. Available from: https://ieeexplore.ieee.org/abstract/document/7919609
42. Garbage Detection using Advanced Object Detection Techniques [Internet]. Ieeexplore.ieee.org. 2021 [cited 22 October 2021]. Available from: https://ieeexplore.ieee.org/abstract/document/9395916
43. Boumanchar, I., Chhiti, Y., M'hamdi Alaoui, F.E., et al.: Municipal solid waste higher heating value prediction from ultimate analysis using multiple regression and genetic programming techniques. Waste Manag. Res. 2019;37(6):578–589. doi:https://doi.org/10.1177/0734242X18816797
44. Jassim, M.S., Coskuner, G., Zontul, M.: Comparative performance analysis of support vector regression and artificial neural network for prediction of municipal solid waste generation. Waste Manag. Res. Apr 4:734242X211008526. doi:https://doi.org/10.1177/0734242X211008526. Epub ahead of print. PMID: 33818220 (2021)
45. Rutqvist, D.K., Blomstedt, F.: An Automated Machine Learning Approach for Smart Waste Management Systems. In: IEEE Transactions on Industrial Informatics, vol. 16, no. 1, pp. 384–392 (2020). doi:https://doi.org/10.1109/TII.2019.2915572
46. Mi϶ić, M.., Dordevic, A., Arsić, A.K.: The optimization of vehicle routing of communal waste in an urban environment using a nearest neighbirs' algorithm and genetic algorithm: Communal waste vehicle routing optimization in urban areas. In: 2017 Ninth International Conference on Advanced Computational Intelligence (ICACI), pp. 264–271 (2017). doi:https://doi.org/10.1109/ICACI.2017.7974519
47. Abeygunawardhana, A.G.D.T., Shalinda, R.M.M.M., Bandara, W.H.M.D., Anesta, W.D.S., Kasthurirathna, D., Abeysiri, L.: AI—driven smart bin for waste management. In: 2020 2nd International Conference on Advancements in Computing (ICAC), 2020, pp. 482–487, doi: https://doi.org/10.1109/ICAC51239.2020.9357151.

48. Jadli, A., Hain, M.: Toward a deep smart waste management system based on pattern recognition and transfer learning. In: 2020 3rd International Conference on Advanced Communication Technologies and Networking (CommNet), pp. 1–5 (2020). doi: https://doi.org/10.1109/CommNet49926.2020.9199615
49. Sheng, T.J., et al.: An internet of things based smart waste management system using LoRa and tensorflow deep learning model. IEEE Access **8**, 148793–148811 (2020). https://doi.org/10.1109/ACCESS.2020.3016255
50. Hannan, M., Arebey, M., Begum, R., Basri, H.: An automated solid waste bin level detection system using a gray level aura matrix. Waste Manag. **32**(12), 2229–2238 (2012)
51. Sabour, M.R., Mohamedifard, A., Kamalan, H.: A mathematical model to predict the composition and generation of hospital wastes in Iran. Waste Manag. **27**(4), 584–587 (2007). https://doi.org/10.1016/j.wasman.2006.05.010. Epub 2007 Jan 18 PMID: 17239577
52. Golbaz, S., Nabizadeh, R., Sajadi, H.S.: Comparative study of predicting hospital solid waste generation using multiple linear regression and artificial intelligence. J. Environ. Health Sci. Eng. **17**(1), 41–51 (2019). https://doi.org/10.1007/s40201-018-00324-z.PMID:31297201;PMCID:PMC6582046
53. Kumar, N., Mohammed, M., Abdulkareem, K., Damasevicius, R., Mostafa, S., Maashi, M., et al.: Artificial intelligence-based solution for sorting COVID related medical waste streams and supporting data-driven decisions for smart circular economy practice (2021)
54. Naveen Ananda Kumar, J., Chimmani, S.: Proposal of smart home resource management for waste reduction and sustainability using AI and ML. In: 2019 International Conference on Communication and Electronics Systems (ICCES), pp. 992–998 (2019). doi:https://doi.org/10.1109/ICCES45898.2019.9002031
55. Papagiannis, F., Gazzola, P., Burak, O., Pokutsa, I.: A European household waste management approach: Intelligently clean Ukraine. J. Environ. Manag. **294**, 113015 (2021). doi:https://doi.org/10.1016/j.jenvman.2021.113015. Epub 2021 Jun 10. PMID: 34119987
56. Wastewater management using artificial intelligence. Wastewater management using artificial intelligence [Internet]. 2018 [cited 22 October 2021]. p. 8. Available from: https://doi.org/10.1051/e3sconf/20184500050
57. Chen, W.C., Chang, N.B., Chen, J.C.: Rough set-based hybrid fuzzy-neural controller design for industrial wastewater treatment. Water Res. **37**(1), 95–107 (2003). https://doi.org/10.1016/s0043-1354(02)00255-5. PMID: 12465791
58. Chen, W., Chang, N., Shieh, W.: Advanced hybrid fuzzy-neural controller for industrial wastewater treatment. J. Environ. Eng. **127**(11), 1048–1059 (2001)
59. Matheri, A., Ntuli, F., Ngila, J., Seodigeng, T., Zvinowanda, C.: Performance prediction of trace metals and cod in wastewater treatment using artificial neural network. Com. Chem. Eng. **149**, 107308 (2021)
60. Yanbo, J., Jianyi, J., Xiandong, W., Wei, L., Lincheng, J.: Bioaugmentation technology for treatment of toxic and refractory organic waste water based on artificial intelligence. Front Bioeng Biotechnol, **9**, 696166 (2021). Published 2 July 2021. doi:https://doi.org/10.3389/fbioe.2021.696166
61. Aitken, J.M., et al.: Autonomous nuclear waste management. IEEE Intell. Syst. **33**(6), 47–55 (2018). doi:https://doi.org/10.1109/MIS.2018.111144814
62. Fawzy, M., Nasr, M., Nagy, H., Helmi, S.: Artificial intelligence and regression analysis for Cd(II) ion biosorption from aqueous solution by Gossypium barbadense waste. Environ. Sci. Pollut. Res. Int. **25**(6), 5875–5888 (2018). https://doi.org/10.1007/s11356-017-0922-1. Epub 2017 Dec 12 PMID: 29235028
63. Sudha, S., Vidhyalakshmi, M., Pavithra, K., Sangeetha, K., Swaathi, V.: An automatic classification method for environment: friendly waste segregation using deep learning. IEEE Technological Innovations in ICT for Agriculture and Rural Development (TIAR) **2016**, 65–70 (2016). https://doi.org/10.1109/TIAR.2016.7801215
64. A. R., R. B. A. R.: An improvised smart bin management system using an object recognition method. In: 2020 International Conference on System, Computation, Automation and Networking (ICSCAN), pp. 1–6. doi: https://doi.org/10.1109/ICSCAN49426.2020.9262333 (2020)

65. Abbasi, M., El Hanandeh, A.: Forecasting Municipal Solid Waste Generation Using Artificial Intelligence Modelling Approaches (2021)
66. Soni, U., Roy, A., Verma, A., Jain, V.: Forecasting Municipal Solid Waste Generation Using Artificial Intelligence Models—A Case Study In India (2021)
67. Coskuner, G., et al.: Application of artificial intelligence neural network modeling to predict the generation of domestic, commercial and construction wastes. Waste Manag. Res. **39**, 499–507 (2020)
68. Cha, G.-W., Moon, H.J., Kim, Y.-M., Hong, W.-H., Hwang, J.-H., Park, W.-J., Kim, Y.-C.: Development of a prediction model for demolition waste generation using a random forest algorithm based on small datasets. Int. J. Environ. Res. Public Health. **17**(19), 6997 (2020). https://doi.org/10.3390/ijerph17196997
69. Kannangara, M., Dua, R., Ahmadi, L., Bensebaa, F.: Modeling and prediction of regional municipal solid waste generation and diversion in Canada using machine learning approaches. Waste Manag. **74**, 3–15 (2018)
70. Erkinay Ozdemir, M., Ali, Z., Subeshan, B. et al.: Applying machine learning approach in recycling. J. Mater. Cycles. Waste. Manag. **23**, 855–871 (2021). https://doi.org/10.1007/s10163-021-01182-y
71. Huang, J., Dmitry D.K.: Artificial intelligence for planning of energy and waste management. Sustain. Energy Technol. Assess. **47**, 101426 (2021)
72. Nañez Alonso, S.L., Reier Forradellas, R.F., Pi Morell, O., Jorge-Vazquez, J.: Digitalization, circular economy and environmental sustainability: the application of artificial intelligence in the efficient self-management of waste. Sustainability **13**, 2092 (2021). https://doi.org/10.3390/su13042092
73. Rutqvist, D., Kleyko, D., Blomstedt, F.: An automated machine learning approach for smart waste management systems. IEEE Trans. Industr. Inf. **16**(1), 384–392 (2020). https://doi.org/10.1109/TII.2019.2915572
74. Chu, Y., Huang, C., Xie, X., Tan, B., Kamal, S., Xiong, X.: Multilayer Hybrid Deep-Learning Method for Waste Classification And Recycling (2021)
75. Ongondo, F.O., Williams, I.D., Cherrett, T.J.: How are WEEE doing? A global review of the management of electrical and electronic wastes. Waste Manag. **31**(4), 714–730 (2011). https://doi.org/10.1016/j.wasman.2010.10.023. Epub 2010 Dec 13 PMID: 21146974
76. Król, A., Nowakowski, P., Mrówczyńska, B.: How to improve WEEE management? Novel approach in mobile collection with application of artificial intelligence. Waste Manag. **50**, 222–233 (2016). https://doi.org/10.1016/j.wasman.2016.02.033. Epub 2016 Mar 2 PMID: 26944864
77. Lu, Z., Zhang, J., Lu, S., et al.: Pollution characteristics and evaluation of heavy metal elements in the soil around the municipal solid waste incineration power plant and in the plant area. Environ. Sci. **40**(5), 483–2492 (2019)
78. Peng, Y., Lei, L., Peng, X., Yang, P., Zhao, X., Ma, W.: /edevelopment of domestic waste classification in China? Obstacles and countermeasures. China Environ. Sci. **38**(10), 3874–3879 (2018)
79. Dan, L., Chen, G., Ma, W., Duan, N.: Characteristics and treatment status of domestic garbage in villages and towns in China. China Environ. Sci. **38**(11), 4187–4197 (2018)
80. Liao, B., Wang, T.: Research on Industrial Waste Recovery Network Optimization: Opportunities Brought by Artificial Intelligence (2021)
81. Huang, X.S., Xu, X.: Legal regulation perspective of eco efficiency construction waste reduction and utilization. Urban Dev. Stud. **9**, 90–94 (2011)

82. Malinauskaite, J., Jouhara, H., Czajczynska, D., Stanchev, P., Katsou, E., Rostkowski, P., Thorne, R.J., Colón, J., Ponsá, S., Al-Mansour, F., Anguilano, L.: Municipal solid waste management and waste-toenergy in the context of a circular economy and energy recycling in Europe. Energy **141**, 2013–2044 (2017). https://doi.org/10.1016/j.energy.2017.11.128
83. Ali, T.H., Akhund, M.A., Memon, N.A., Memon, A.H., Imad, H.U., Khahro, S.H.: Application of artifical intelligence in construction waste management. In: 2019 8th International Conference on Industrial Technology and Management (ICITM), pp. 50–55. doi:https://doi.org/10.1109/ICITM.2019.8710680 (2019)
84. Jude, A.B., Singh, D., Islam, S., et al.: An artificial intelligence based predictive approach for smart waste management. Wireless Pers. Commun. (2021). https://doi.org/10.1007/s11277-021-08803-7