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Review article

A review of clustering techniques for waste management

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HIGHLIGHTS

- A methodological approach focusing on algorithms and applications used by waste management researchers.
- Waste management problems can be categorized into nine types of applications.
- Waste collection problems are the most influential research in this niche of work.
- Heuristics algorithms are the most frequently used class of methods in the selected papers.
- The k-means algorithm is the most commonly used clustering technique in waste management applications.

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ABSTRACT

A variety of problems related to waste management systems can be found in the literature, as they have become tougher to solve over the years. With this in mind, a report of the most influential research concerns in this field could help develop innovative works for solving waste management applications. Literature reviews appear in most introductions and discussion sections of research reports, case reports, and expert opinion papers. It was immediately observed that Cluster Analysis, a multivariate data mining technique, has been used in various applications for sustainability issues. For this reason, this paper shows the results of a Systematic Literature Review on Cluster Analysis techniques applied to waste management. This paper's primary goal is to detect what is happening with the applications and techniques in clustering techniques for waste management and, in this way, define possible gaps in this research field. The 61 analyzed papers were categorized into nine application types within the field of waste management (logistics/business; landfill research; theoretical/consequential; waste collection problems; location/selection; monitoring/decision support systems; leachate/water contamination; waste incineration/energy production and, waste forecast/waste production behavior). Following an analysis of their content, gaps were found related to exploring the complex situations in each problem. Instead of using general rules and constraints for their methodologies to solve real-world problems, they resorted to theoretical orientation solutions. Furthermore, suggestions from specialists in the field and more fitting constraints related to the data evaluated could make the works seem less theoretical and more visually applicable.

1. Introduction

Different issues related to waste management have become tougher to solve in recent decades. Achillas et al. (2013) affirm that the increase of waste volume and social, environmental awareness could lead to drivers that would help accomplish a sustainable and practical waste management framework or system.

According to IBRD/IDA (2019), the rates of waste generation rise every year. By 2016, cities around the globe were generating 2.01 billion tons of solid waste. Factors such as fast population growth and urbanization spur an annual waste generation increase of 70%, meaning that the 2.01 billion tons in 2016 could rise to 3.40 billion tons in 2050. Therefore, different problems related to this area arise from collection services, landfill location, and reverse logistic applications. However, when such an array of issues can be found on a single subject, it is difficult to determine which aspects one should focus on to reduce waste management problems. Therefore, a report of what is happening in this research field is necessary to discern the best course of action regarding original research.

Cluster Analysis is a multivariate data mining technique that, based on the use of numerical methods and information on the variables in each

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case, is used to group through n unsupervised learning the n cases of the database in a certain number k of groups, known as clusters or groupings (Cassiano, 2015). There is a large variety of applications in sustainability issues using clustering algorithms, like energy consumption problems (Chui et al., 2013; Smith, 2014; and Costa and Santos, 2015), sustainable supply networks (Ross et al., 2012; Tan et al., 2016), urban sustainability (Kazimee, 2003; Reeve et al., 2015; Qu and Lu, 2018; and Xun and Hu, 2019), and even waste disposal applications (Oribe-Garcia et al., 2015; Cha and Park, 2019).

Considering the theme of waste disposal applications, this work's focus is to observe different clustering approaches. For instance, Cha and Park (2019) considered a marketing approach using the 4 P's of marketing (product, price, promotion, and place) to assess the applied survey. In contrast, Oribe-Garcia et al. (2015) tested two different clustering techniques, HCM (Hierarchical Clustering Method) and WMCD (Ward's Method Clustering Distance), to identify relevant socio-economic features of municipalities regarding Household Waste (HW) generation. The first challenge concerning these documents is related to how one defines the clustering application in waste management and which technique is more efficient or preferable to another.

An essential skill for any researcher to develop is conducting a full systematic review of the literature. Although first applied in the medical sciences in the 1970s, systematic reviews have been recently and increasingly used in any research field to examine and study a wide variety of research questions (Mallett et al., 2012). This method can allow the identification of every aspect in the current literature, where there are limitations (Piper, 2013). The main intention of systematic reviews is to identify all the available research addressing a series of specific research questions to give a fair and unbiased summary of the literature (Nightingale, 2009).

According to Mallett et al. (2012), by adopting broad search strategies, using predefined search terms, and developing concise inclusion and exclusion criteria, systematic reviews can stimulate researchers to explore studies beyond their subject areas and networks. In theory, this improves the likelihood of generating a more transparent and more objective answer to the proposed research question.

Considering these points, the main goal of this study is to conduct a Systematic Literature Review (SLR) on the subject of Waste Management and clustering strategies to evaluate which Waste Management issues and research efforts are considered more influential in this field of research and identify possible existing gaps in this literature.

For this purpose, the research database chosen for document selection was Scopus. It was chosen because Scopus is considered the most significant paper database with peer-reviewed publications, offering a comprehensive overview of the world's research in the most diverse fields of study (Elsevier, 2017).

Our contribution is focused on describing what is happening in this research topic, the primary applications, clustering methodologies, and the research focus on each application. To make this contribution, we adapted our review process to the objective of returning not the results of each selected paper, but instead, specifics surrounding their methodologies. Therefore, this work is of great use in aiding researchers to recognize the most influential fields within waste management, what kind of clustering algorithms are mostly applied, and the researchers' intentions considering their application's objective and restrictions.

This research is divided into six main sections, the first being this brief introduction of the leading research subject and the method and reasoning behind it that will be applied further in this paper. Section 2 presents the methodological considerations surrounding this research and everything related to the planning of this study. Section 3 contains the initial results, presenting an overview of what was found through the methodological approach presented in Section 2. Section 4 focuses on the content of the papers in a comparative way. Section 5 presents a research agenda proposal on the theme in question. Finally, the conclusions and some suggestions for future studies are presented in Section 6.

2. Research design

This section focuses solely on presenting every parameter and premise the authors took when planning this review. Therefore, the authors will present the parameters used for paper selection, the exclusion criteria for filtering the documents, and their objectives for the content analysis portion of this Systematic Literature Review (SLR).

The initial step, as mentioned above, is selecting the keywords for the paper collection. Figure 1 demonstrates how the initial filters for paper selection were applied to the chosen database.

With this initial filtering process, a total of 428 documents were found, forming the initial base for this research. All these papers were initially included for content analysis. After that, a series of exclusion criteria were developed (Table 1).

After observing the review parameters presented above, we developed a process for excluding papers from the initial database in keeping with the criteria presented in Table 1. This process is shown in Figure 2.

Finally, the last portion of our SLR was the content analysis of every single paper from the 61 selected studies filtered through the process in Figure 2.

The conduction of the content analysis for this research was developed focusing on answering the research question on the type of application that each paper dealt with and which methodologies/considerations appeared in the papers and considerations on objective functions – if applicable – and any constraints that were used.

Nine different applications were found: (i) Logistics/Business; (ii) Landfill Research; (iii) Theoretical/Consequential; (iv) Waste Collection Problem; (v) Location/Selection; (vi) Monitoring/Decision Support Systems; (vii) Leachate/Water Contamination; (viii) Waste Incineration/Energy Production; (ix) Waste Forecast/Waste Production Behavior. These classifications will be discussed in more detail in section four, focusing on answering the research question.

3. Clustering in waste management – an overview

For this section, we provide an overview of selected papers, assessing them in terms of year of publication, the amount of citation throughout

Initial Search

The preliminary search used the following keywords on Scopus database:

(Waste OR Trash OR Garbage) AND (Disposal OR Management OR Strategy) AND (Clustering)

Initial Results: 502 documents

First Filter: Type of Document – Journal papers and Conference Proceedings: 441 documents

Second Filter: Language – English: 417 Documents

Complementary Search

To complement the previous search it was decided to look for papers including Landfill as main keyword, therefore using:

(Landfill) AND (Clustering)

Initial Results: 25 Documents

First Filter: Type of Document – Journal papers and Conference Proceedings: 17 documents

Second Filter: Language – English: 11 Documents

Figure 1. Keywords and initial filters.

Table 1. Exclusion criteria.

Analysis	Criteria
Title	• The title must contain a reference related to waste management research.
	• Many documents focused on bodies of water that were polluted due to improper waste disposal.
Abstract	• The abstract must reference a waste-related problem.
	• Some studies were excluded because they focused on soil assessment rather than managerial issues on this research theme.
Found Paper	• If the paper was not found for full-text analysis, it was excluded from the selection.
Full Text	• The application must be related to waste management.

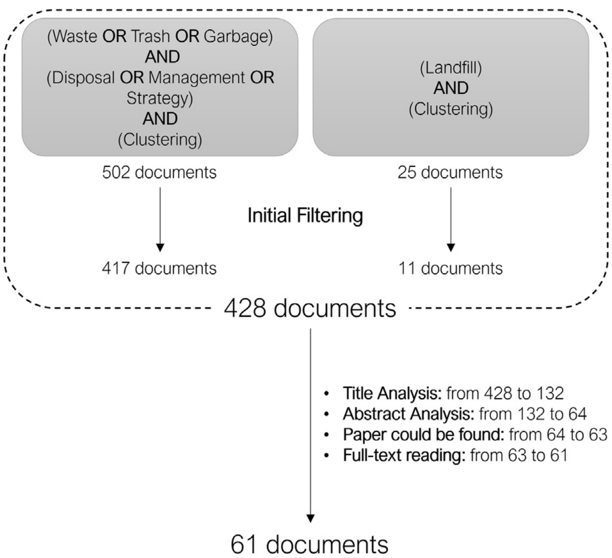


Figure 2. Exclusion process.

the years, the appearance of primary keywords, and the relevance of journals in which they were published. This bibliometric assessment aims first to evaluate whether the selected documents are relevant in terms of the number of publications for each year and the number of citations for each paper. Furthermore, we attempted to evaluate the means of publication (conference or journal; SJR for the prominent journals).

Considering the type of document analysis, most papers from the 61 selected papers for this review are journal published documents, accounting for 68% of the total. This shows that the majority of the selected documents underwent a robust review process.

The amounts of citations and the type of publication are shown in Figure 3. Each journal or conference found amongst the documents is listed on the horizontal axis, and vertically we observe a Pareto graph with the number of citations per journal and its influence in percentages related to the total number of citations.

In Table 2, the presented journals correspond to 80% of the citations found among the papers. We chose to present only the 80% of citations due to the Pareto Principle, 80% of citations corresponded to 20% of the journals and conferences that were found. The same table is used to analyze the journals and conference's ranking that received the number of citations.

For the next analysis, we present a comparison between the year of publication versus the number of citations throughout the year. In Figure 4, the column graphic presents the number of publications per year, and this is related to the primary axis on the right, as, for the area graph, it corresponds to the secondary axis and shows the number of citations for the year.

For citation analysis, the peak occurred in 2006, specifically where two papers were found: Kim et al. (2006) with 434 citations and Matani (2006) with 14. The research conducted by Kim et al. (2006), which focused on the waste collection problem with time window constraints, was highly influential on future research.

The following assessment in this study is related to the country of publication, collected by the authors' institution registered in the paper. This evaluation is shown in Figure 5.

From countries such as China and India, we observed initiatives that could justify the high number of papers published.

In China and urbanization, population growth, and industrialization, the quantity of municipal solid waste (MSW) generation has increased rapidly. According to Wong (2019), from 1990 to 2018, garbage disposal in the country rose from 67.67 to 228.02 million tons. In Wang and Jiang (2020), it is mentioned that to address rising mountains of domestic wastes, in March 2017, China issued a more ambitious national plan, requiring 46 pilot cities, including Shanghai, to pass local decrees or local rules on adopting mandatory waste classification by the end of 2020.

As for India, the Indian government, recognizing the challenges that come with growing urbanization growth (e.g., low collection, transportation, treatment, and safe disposal of solid waste), deliberated upon mechanisms and arrangements to facilitate the requirements for the treatment and safe disposal of solid waste (Mani and Singh, 2016).

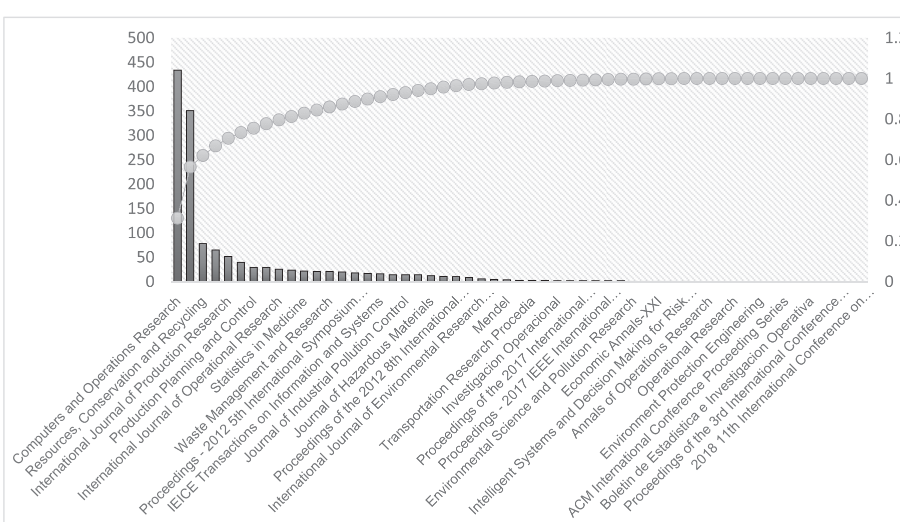


Figure 3. Journals published and amount of citation per journal.

Table 2. Journals that represent 80% of citations.

Journal	Type	SJR	H Index	Citation	%	%Acc
Computers and Operations Research	Journal	1.663	143	434	0.312455	0.312455
Waste Management	Journal	1.634	145	351	0.2527	0.565155
Resources, Conservation and Recycling	Journal	2.215	119	78	0.056156	0.62131
Proceedings of the 3rd IASTED International Conference on Computational Intelligence, CI 2007	Conference	0.133	3	65	0.046796	0.668107
International Journal of Production Research	Journal	1.776	125	52	0.037437	0.705544
Journal of Environmental Management	Journal	1.321	161	40	0.028798	0.734341
Production Planning and Control	Journal	1.394	70	30	0.021598	0.75594
Journal of Applied Geophysics	Journal	0.781	77	30	0.021598	0.777538
International Journal of Operational Research	Journal	0.321	24	26	0.018719	0.796256
Applied Artificial Intelligence	Journal	0.317	54	24	0.017279	0.813535

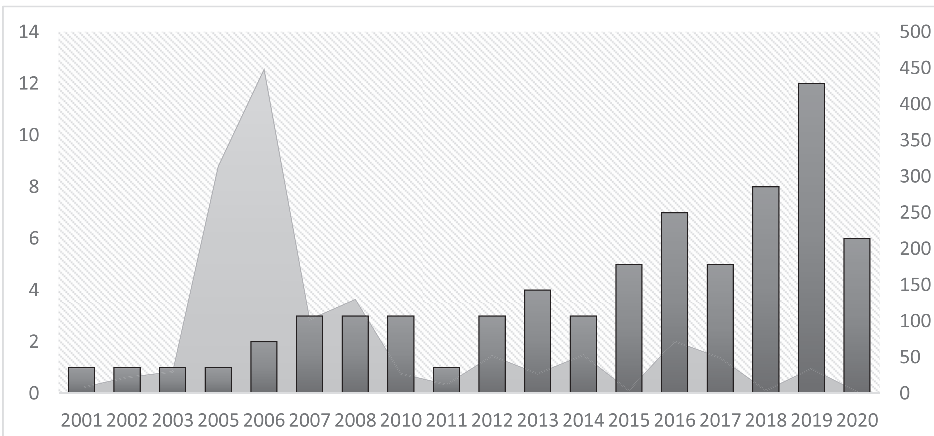


Figure 4. Evolution of the number of papers through the years.

Lastly, we present a keyword assessment made using VOSviewer – a software tool for constructing and visualizing bibliometric networks (VOSviewer, 2020). We chose to analyze the keywords that appeared at least five times among the documents. The results of this process are shown in Figure 6 and Figure 7.

In Figure 6, we can see the formation of two clusters of keywords (red and green) where the most significant node is presented in the middle with the combination "waste disposal." This division of clusters in two colors helps verify the significant relationship between keywords, which means waste disposal is more commonly related to recycling research and landfills and decision making. In contrast, waste collection problems are usually found in optimization-themed research, combining keywords such as vehicle routing problems and algorithms. This division also raised the hypothesis that Waste Collection is an influential type of problem considering the assessment in Figure 4. There we argued about the peak of citations attributed to the work of

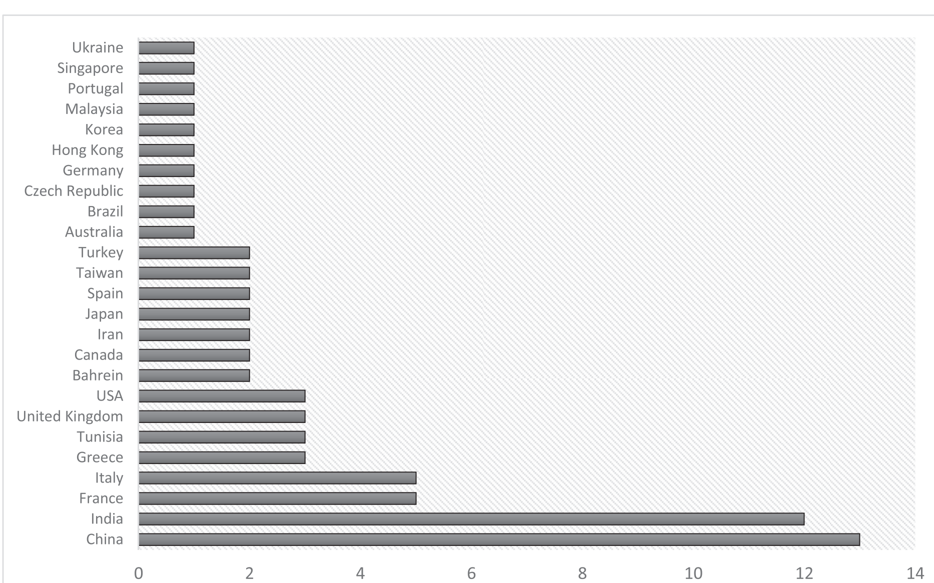


Figure 5. Number of publications per country.

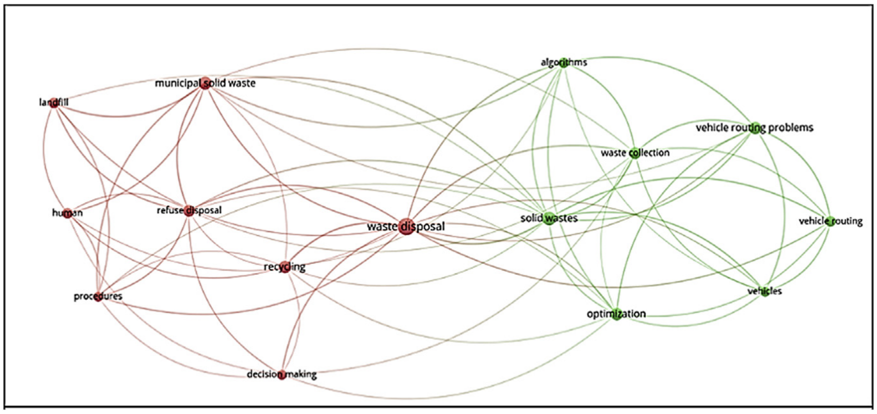


Figure 6. Keyword network.

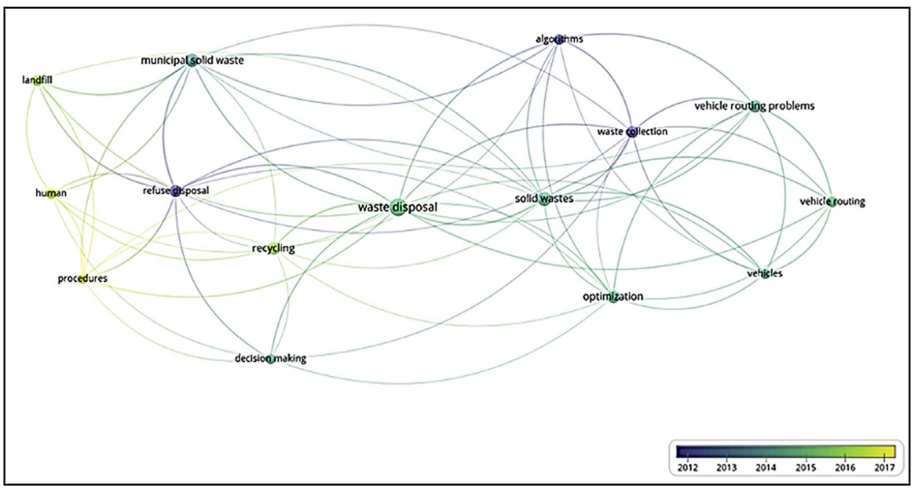


Figure 7. Keyword usage through the years.

Table 3. Methodologies found for Logistics/Business.

#	Authors	Method	Application
1	Argoubi et al., (2020)	Literature Review; **MINLP**	Literature review on waste management in industries
2	Mashhadi and Behdad (2020)	**MIBLP**; **ABS**	End-of-life products
3	Panjeh Fouladgaran and Lim (2020)	Questionnaire; **SOM**; **ANOVA**	Reverse Logistics Implementation
4	Wang et al., (2020)	Framework	E-waste Recycling
5	Kır et al., (2019)	**MINP**	End-of-life products
6	Mohamed Sultan and Mativenga (2019)	Mathematical Modelling; **k-Means**	Supply chain recycling center location
7	Shi et al., (2019)	**GA**; **MOO**; PRO	Supply chain recycling center location
8	Fancello et al., (2017)	**MIBLP**	Reverse Logistics Implementation
9	Lozano et al., (2010)	**SOFM**; Survey	E-waste Recycling
10	Li et al., (2008)	**Fuzzy Graph**; DfE; **AHP**	Reverse Logistics Implementation
11	Matani (2006)	Literature Review	Literature review on waste management in industries

Acronyms (Alphabetical): ABS (Agent-Based Simulation); AHP (Analytic Hierarchy Process); ANOVA (Analysis of Variance); DfE (Design for Environment); GA (Genetic Algorithm); MIBLP (Mixed Integer Binary Linear Programming); MINLP (Mixed Integer Non-Linear Programming); MINP (Mixed-Integer Nonlinear Programming); MOO (Multi-Objective Optimization); PRO (Probabilistic Robust Optimization); SOFM (Self Organizing Feature Map); SOM (Self Organizing Maps).

Kim et al. (2006), in which the authors' application was indeed a waste collection problem.

In Figure 7, we can observe the tendencies of keyword choice through the years, and, most recently, researchers are using words related to landfill, human, and procedures. We can see that the cluster before shown in green has deeper tones indicating older research. The color red previously presented the most recent ones (Figure 6). This may be interpreted as the older documents that were more influential in this research field being related to optimization, especially in vehicle routing problems for waste collection. In contrast, the most recent ones are related to landfill research, especially concerning recycling and procedures related to these points.

4. Clustering in waste management

This section is divided into two parts. Initially, we present the analysis of each research effort found amongst the papers regarding areas of the applications and algorithms used. We then focus on analyzing types of algorithms, objective functions, and constraints.

Table 4. Methodologies found for Landfill Problems.

#	Author	Method	Application
1	Eghtesadifard et al., (2020)	GIS; **MCDA**; **Fuzzy Logic**; **k-Means**; Delphi	Selection of Landfills
2	Audebert et al., (2016a)	**MICS**	Leachate monitoring
3	Audebert et al., (2016b)	**MICS**	Leachate monitoring
4	Audebert et al., (2014)	**MICS**	Leachate monitoring
5	Kanoun et al., (2013)	**k-Means**	Selection of Landfills
6	Liu et al., (2011)	**k-Means**; **2-opt**	Selection of Landfills
7	Kontos et al., (2005)	**AWM**; **SCA**; **AHP**	Selection of Landfills

Acronyms (Alphabetical): AHP (Analytic Hierarchical Process); AWM (Additive Weighting Method); GIS (Geographic Information System); MCDA (Multi-criteria Decision Analysis); MICS (Multiple Inversions and Clustering Strategy); SCA (Spatial Clustering Analysis).

As mentioned before in this study, nine types of the application were found among the researched papers. Their classification is defined as follows:

a. Logistics/Business: Papers in which the methodology was applied to a company or its supply chain;
b. Landfill Research: Documents in which the methodology was applied to landfill-related issues;
c. Theoretical/Consequential: This classification is for the papers that presented a literature review or framework development or that could be used as a secondary type for consequential issues due to waste management;
d. Waste Collection Problem: Researches in this group focused their efforts on routing the waste collection in their database;
e. Location/Selection: Papers in this group focused on techniques for finding the best location for a decision related to Waste Management;
f. Monitoring/Decision Support Systems: The researches in this group developed some sort of system for Waste Management;
g. Leachate/Water Contamination: Documents in which the main issue was related to water contamination due to Waste Management practices;
h. Waste Incineration/Energy Production: Researches in this group assessed issues with waste incineration or the production of energy using waste and residues;
i. Waste Forecast/Waste Production Behavior: This last application dealt with forecasting or analyzing waste production in regions.

In the following tables (Tables 3, 4, 5, and 6 and subsequent paragraphs), we proposed dividing the papers into these types and considered the possibility of a single paper being classified into two groups. Moreover, at the same table, we present the methods used for solving the proposed problem by each author. In bold, we highlighted the clustering method or methodology that the authors applied.

Table 6. Methodologies found for Waste Collection Applications.

#	Author (Citation)	Method	Application
1	Chen et al., (2019)	**SMV**; **LR**; **ANN**; **RNN**; AE; **LSTM**	Travel time prediction
2	Chun-Lin et al., (2019)	LP; **Weighted K-Means**	Facility location
3	Jammeli et al., (2019)	**MOSP**; **k-Means**	Facility location
4	Jain et al., (2018)	**k-Means**; **Heuristics**	Travel time/length
5	Ray et al., (2018)	**k-Means**	Monitoring System
6	Parchitelli et al., (2017)	**HCA**; **SBGA**	Monitoring System
7	Sackmann et al., (2017)	**CKM**; **CSA**	Travel time/length
8	Sreelekshmi and Nair (2017)	**MCKM**; **VNS**	Minimize route risk
9	Abbatecola et al., (2016)	**MILP**; **CA**	Travel time/length
10	Fanti et al., (2016)	**MILP**; **CA**	Travel time/length
11	Perea et al., (2016)	**Helsgaun Heuristic**; **Greedy**	Travel time/length
12	Wang et al., (2015)	DIG	Travel time prediction
13	Da Guabiroba et al., (2014)	Not specified	Facility location
14	Nambiar and Idicula (2014)	**k-Means**; **ACO**	Travel time/length
15	Geetha et al., (2013)	**HPSO**; **k-Means**	Travel time/length
16	Geetha et al., (2012)	**GA**; **PSO**; **NNH**; **k-Means**	Travel time/length
17	Liu and He (2012a)	**ACS**	Travel time/length
18	Liu and He (2012b)	**ACS**	Travel time/length
19	Ombuki-Berman et al., (2007)	**GA**; MOP	Travel time/length
20	Kim et al., (2006)	**ESIA**; **k-Means**	Travel time/length

Acronyms (Alphabetical): ACO (Ant Colony Optimization); ACS (Ant Colony System); AE (Auto-Encoder); ANN (Artificial Neural Networks); CA (Cluster Analysis); CKM (Capacitated k-Means); CSA (Capacitated Savings Algorithm); DIG (Data-CentrIc Garbage Collection); ESIA (Extended Solomon Insertion Algorithm); GA (Genetic Algorithm); HCA (Hierarchical Cluster Analysis); HPSO (Hybrid Particle Swarm Optimization); LP (Linear Programming); LR (Logistic Regression); LSTM (Long Short Term Memory Networks); MCKM (Modified Capacitated k-Means); MILP (Mixed Integer Linear Programming); MOP (Multi-Objective Problem); MOSP (Multi-Objective Stochastic Programming); NNH (Nearest Neighbor Heuristic); PSO (Particle Swarm Optimization); RNN (Recurrent Neural Networks); SBGA (Spectrum-Based Graph Analysis); SMV (Statistical Mean Value); VNS (Variable Neighborhood Search).

Table 5. Methodologies found for Theoretical/Consequential works.

#	Author (Citation)	Method	Application
1	Sabour et al., (2020)	Bibliometric Assessment; **SNA**	Landfill Consequences
2	Kokkinos et al., (2019)	**SOM**	Public acceptance of waste management
3	Liu et al., (2019a)	**FCM**	Public acceptance of waste management
4	Liu et al., (2019b)	**MLR**; **GM**	Literature Review on Waste generation
5	Wang et al., (2019)	Framework	Literature review on waste management
6	Istvan et al., (2019)	**SP**	Landfill Consequences
7	Nathan et al., (2018)	**HCA**; **DA**	Landfill Consequences
8	Kryvenko (2015)	Theoretical Paper	Literature review on waste management
9	Singh et al., (2010)	**ScA**	Landfill Consequences
10	Dimitrova et al., (2007)	Framework	Eco-Clustering
11	Rong et al., (2003)	**AHP**; **FCE**	Literature review on waste management

Acronyms (Alphabetical): AHP (Analytical Hierarchical Process); DA (Discriminant Analysis); FCE (Fuzzy Comprehensive Evaluation); FCM (Fuzzy C-Means); GM (Grey Model); HCA (Hierarchical Cluster Analysis); MLR (Multiple Linear Regression); ScA (Scoring Algorithm); SNA (Social Network Analysis); SOM (Self Organizing Maps); SP (Spatial Clustering).

Following the tables and content analysis, we present a brief content analysis of each paper regarding application and technique.

For the subjects of Location/Selection, Monitoring Systems; Leachate Contamination; and Waste Forecast, there were no more than three documents per field, and it was not necessary to use tables. For studies dealing with Facility Location or Selection, more recently, Anitha et al. (2018) used the algorithm named LEACH (Low-Energy Adaptive Clustering Hierarchy) to develop a maintenance system to help select facilities for waste disposal. In Gergin and Esnaf (2013), the authors used three clustering techniques FCM (Fuzzy C-Means), SOM (Self-Organizing Maps), COG (Center of Gravity) to choose the best waste disposal location. Finally, Gomes et al. (2007) also specified a waste disposal center's location, used as clustering techniques, both the k-means algorithm and SOM.

In Monitoring Systems/DSS applications, two works were found. In Chen and Zhu (2018), the authors chose both LEACH and WSN (Wireless Sensor Networks) to develop a Sanitation Monitoring System for their specifics. Furthermore, in Paulraj et al. (2016), the authors chose SVM (Support Vector Machines) as their clustering technique for image recognition applications. They used thermal image analysis of the garbage to identify better the type of waste the facility was dealing with.

For water or leachate contamination as the main subject, only one paper was found, written by Deepa and Roka (2018), where the authors used the k-means technique as their primary method. Their application consisted of focusing on designing a computer-automated garbage monitoring system in water terrain.

There were three applications for Waste Incineration or Energy Production Research, the most recent being De Clercq et al. (2017), which used a MCDA (Multi-Criteria Decision Analysis) to evaluate the energy performance production of a biogas plant. In Tango (2002), the author chose MLRA (Maximum Likelihood Ratio Analysis) to identify illegal waste incinerators in a specific region and, finally, Samaras et al. (2001), similar to De Clercq et al. (2017), also evaluated the performance of an energy production facility, this time using both statistical analysis (not specifying) and FCA (Fuzzy Clustering Analysis).

The last set of applications considered the subjects of Waste Forecast and Waste Production Behavior. Here, three works were found. Nevrlý et al. (2016) used linear programming – specifically MIBLP (Mixed Integer Binary Linear Programming) – for waste production forecast of a region of interest. Similarly, Wu et al. (2010) had the same objective, but instead, the authors chose heuristic techniques as their clustering methodologies. Therefore, algorithms such as HCA (Hierarchical Clustering Analysis), DCA (Dynamic Clustering Analysis), FCA (Fuzzy Clustering Analysis), and GCA (Grey Clustering Analysis) were used. Finally, the last application was developed by Shaw (2008), in which a NN (Nearest Neighbor) technique was used to evaluate the recycling behavior of a dataset.

The main identified methods were divided into seven categories for analysis: non-linear programming, linear programming, multi-criteria analysis, heuristics, metaheuristics, simulations/statistics, and machine learning. The methods and their categories are shown in Figure 8. We can observe how varied the methodology types are, mainly for the heuristics set with 23 different methods and, in second place, the machine learning methods with only eight techniques. It is worth noting here that only the clustering techniques were considered when dividing these methods.

Dividing these main types of methods presented in Figure 8 amongst the groups identified when assessing the different applications found, we observed the preference for the techniques within each group (Figure 9).

Figure 9 shows that the most researched application for the waste collection was researched in 20 papers from this portfolio. In three of them, the authors used Linear Programming, while in 18 cases, heuristic algorithms served as the central methodology. Metaheuristic procedures were used in nine, whereas in one, either simulation or statistical approaches were used, and Machine Learning in four.

Having finished evaluating the techniques employed in each document, we then moved to the second part of assessing the research efforts.

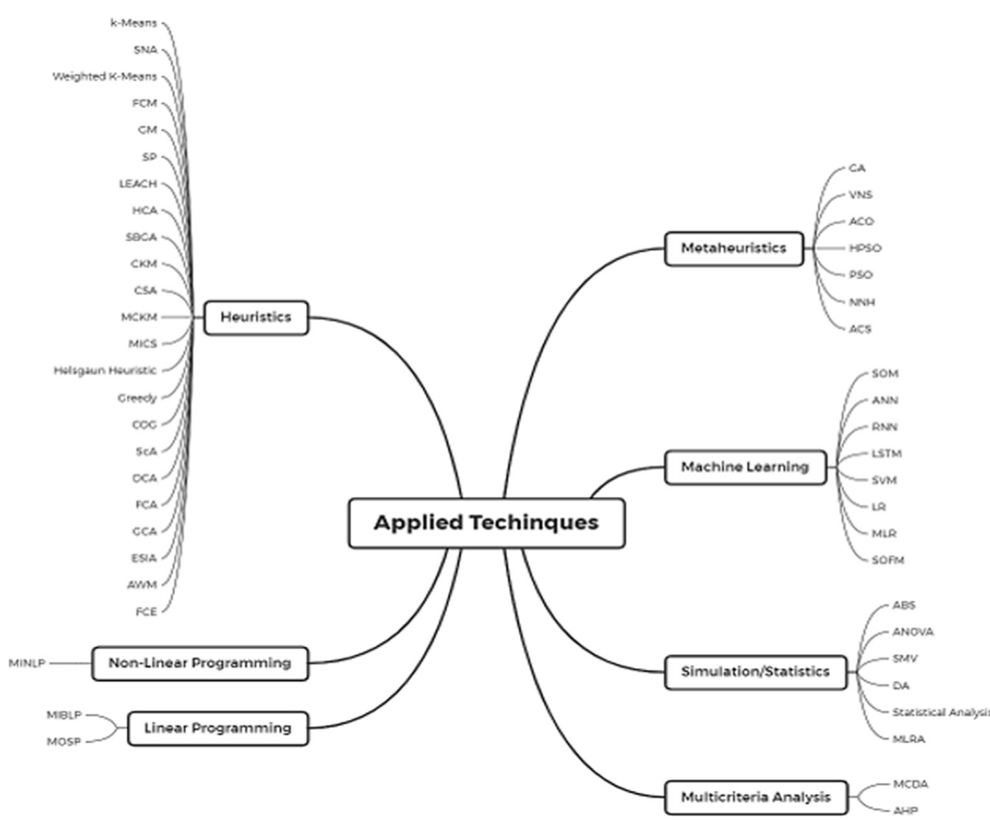
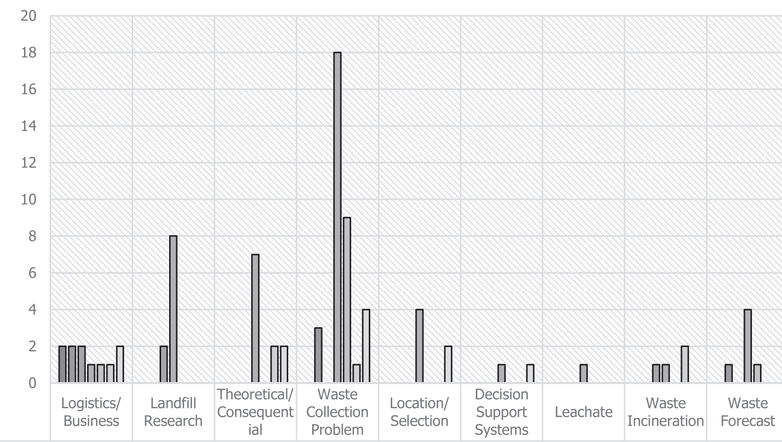


Figure 8. Applied Techniques. Acronyms (Alphabetical): as already presented.



	Logistics/ Business	Landfill Research	Theoretical/ Consequential	Waste Collection Problem	Location/ Selection	Decision Support Systems	Leachate	Waste Incineration	Waste Forecast
Non-Linear Programming	2	0	0	0	0	0	0	0	0
Linear Programming	2	0	0	3	0	0	0	0	1
Multicriteria Analysis	2	2	0	0	0	0	0	1	0
Heuristics	1	8	7	18	4	1	1	1	4
Metaheuristics	1	0	0	9	0	0	0	0	1
Simulation/Statistics	1	0	2	1	0	0	0	2	0
Machine Learning	2	0	2	4	2	1	0	0	0

Figure 9. Applications and types of methodologies.

Observing the methods themselves in both Figure 8 and Figure 9, we moved on to what the authors considered as the constraints on their problems and which restrictions were used, as shown in Table 7.

Not every single work that was identified contained an explanation of their constraints regarding which information was considered during their methodology development. Only 22 of the 61 papers presented explanations in this regard. Table 7 below presents the constraints that each author considered during the application.

In general, observing Table 7, we can see many similarities between each paper's constraints. For instance, the works of Abbatecola et al. (2016) and Fanti et al. (2016), as well as Geetha et al. (2012) and Geetha et al. (2013) and even Kim et al. (2006) and Ombuki-Berman et al. (2007) had very similar considerations regarding their methodologies, if not the same set of constraints in some cases. Nevertheless, seven of them shown variations in constraints and problem considerations. Eghtesadifard et al. (2020), unlike many other authors, used five considerations when building their methods, namely: (1) Economic (Distance from roads, Land Price); (2) Environmental (Distance from rivers, Distance from lakes, Distance from grassland, distance from forest regions, Distance from agricultural lands); (3) Climatic (Climate conditions, distance from flood-prone areas); (4) Geological (Slope of land; Terrain; AMSL - Above mean Sea level); (5) Social (Distance from residential areas).

Jammeli et al. (2019) considered two constraints that set their work apart from other waste collection applications. They considered that the number of bins per region is calculated according to the number of residents in the region and the collection time depends on the quantity of waste. De Clercq et al. (2017) observed seven criteria when creating their model that highlighted their work compared with others in energy production and waste generation: (1) Carbon emission reduction; (2) Probability of a project to lose money; (3) Capital investment per ton of treatment capacity; (4) Diversification of final output produced by the project; (5) Specific fermenter productivity; (6) Biogas production per ton of substrate; and (7) Co-digestion of different feedstocks.

Nevrlý et al. (2016), when constructing their MIBLP (Mixed Integer Binary Linear Programming), used a different constraint from similar works. They considered that each territory of a specific type could be a part of a bigger one. Two papers with a very similar set of constraints considered the driver's lunch break in their problem, both Kim et al. (2006) and Ombuki-Berman et al. (2007). The difference was that Kim et al. (2006) also included the time windows for stops and the depot in their problem.

Finally, from these works that used sets of constraints other than those usually considered, Kontos et al. (2005) included four criteria for their methodology to obey, namely: (1) Hydrological/hydrogeological (Distance from water sources; Water permeability); (2) Environmental; (Land Cover; Sensitive Ecosystems; Surface waters); (3) Social (Visibility; Land Uses; Cultural Areas; Urban Areas); and (4) Technical (Wind orientation; morphology).

With that, we observed 20 documents that presented their objective functions, of which ten used a multi-objective approach, considering multiple areas to cover using their model. As for the considered constraints, many similarities between the constraints in each paper were observed. Seven documents stood out for considering a more diverse type of considerations than solely using the original constraints for the mathematical model.

5. Research agenda

Combining what has been presented so far, mainly in Section 4, within the Waste Disposal Applications (left side of Figure 6), there are 41 documents. As shown in Figure 9, a preference in either theoretical/consequential research and logistics/business applications can be seen from those selected documents. Therefore, one possible suggestion for gaps in this research field could be the lower amount of publications, especially those related to the forecast of waste production behavior, prediction of energy production from waste, waste incineration research, location or selection of waste-related facilities, and even more so for both monitoring systems and water contamination due to improper waste disposal. These six applications present opportunities for researchers to propose viable methodologies and are extensive topics that could be further explored and used to achieve better waste management solutions.

Furthermore, of the techniques used herein, only five (Nevrlý et al., 2016; Fancello et al., 2017; Kır et al., 2019; Argoubi et al., 2020; Mashhadi and Behdad, 2020) used a methodology that will provide the optimal result – being either linear or non-linear programming.

Even with the optimal solution that these methods can provide, it is not certain that improvements cannot be made. For instance, reducing computational complexity is a significant concern for both linear and

Table 7. Constraints and information considered during method application.

Author (Citation)	Constraints/Information considered
Eghtesadifard et al., (2020)	Five dimensions of criteria were used for analysis:
	(1) Economic (Distance from roads, Land Price);
	(2) Environmental (Distance from rivers, distance from lakes, distance from grassland, distance from forest regions, Distance from agricultural lands);
	(3) Climatic (Climate conditions, distance from flood-prone areas);
	(4) Geological (Slope of land; Terrain; AMSL - Above mean Sea level);
	(5) Social (Distance from residential areas)
Mashhadi and Behdad, (2020)	**(1)** If the product comes back to the industry, a decision is made: recycle, refurbished, or remanufactured
	(2) If there is a replacement, the product is considered to be remanufactured
	(3) Total cost is: remanufacturing costs, refurbishing costs, and inventory
Chun-Lin et al., (2019)	**(1)** Garbage bins only should be transported to one garbage collection center
	(2) The capacity of the garbage collection center cannot be less than the minimum capacity or more significant than the maximum capacity
	(3) The collection capacity of the garbage center meets the need for garbage bins
	(4) The amount of garbage and garbage centers must be positive
Jammeli et al., (2019)	**(1)** The amount of bins per region is calculated according to the number of residents in the region;
	(2) The capacity of bins should be greater than the amount of household waste;
	(3) For each vehicle, the amount of waste collected does not exceed the vehicle's capacity;
	(4) The collection time depends on the quantity of waste;
	(5) The total time should not exceed a limit;
	(6) Each sector will be covered by one vehicle;
	(7) The incoming flow at each bin is equal to the outgoing flow;
	(8) Each route should include the depot;
	(9) The vehicle must visit bins before reaching the transfer center;
	(10) All trucks must go to the depot after visiting the transfer center;
	(11) Sub-tour elimination constraints
Kır et al., (2019)	**(1)** The capacity of toll centers must be following the demand for capacity of the nodes;
	(2) Equations provide the relationship between the nodes to the established toll center, and the Recycling Plant (RP) serviced;
	(3) Maximum of one toll center in all nodes;
	(4) The toll center should be serviced where it is established;
	(5) Each toll center can work with at most one RP;
	(6) Each node collects waste rubber only at one toll center;
	(7) The ELT (End-of-Life Tire) to be transported to the RPs from the toll centers to be installed in the node does not exceed the demand or capacity of the installation
Mohamed Sultan and Mativenga, (2019)	The authors considered the center-of-gravity method to evaluate the center of gravity location for waste in the UK (Where this study was applied)
Jain et al., (2018)	The model needs to respect that:
	(1) Each house should be visited exactly once by a single waste collection vehicle;
	(2) The total garbage load on any truck associated with a given route is following the maximum capacity of the dumpsite
De Clercq et al., (2017)	Seven Criteria to observe:
	(1) Carbon emission reduction
	(2) Probability of a project to lose money
	(3) Capital investment per ton of treatment capacity
	(4) Diversification of final output produced by the project
	(5) Specific fermenter productivity
	(6) Biogas production per ton of substrate
	(7) Co-Digestion of different feedstocks
Fancello et al., (2017)	The proposed modal has a total of 22 constraints, namely:
	(1) ensures that each pick-up point is assigned to a vehicle
	(2) Implies that a pick-up point can be assigned to a vehicle only if the vehicle is used
	(3) Requires that any vehicle used comes from a depot
	(4) Guarantees the continuity of the route
	(5) and **(6)** imply that a pick-up point can be visited by a vehicle only if it has been assigned to that vehicle
	(7) and **(8)** ensure that each pick-up point is visited only once
	(9) allows calculating the number of goods loaded into a vehicle after each visit to a node
	When the vehicle reaches a collection point, it is completely emptied, and the quantity of goods on board is reset to zero by the constraint **(10)**
	(11) ensures that the capacity limit of the vehicles is observed
	The first node visited by a route must be a pick-up point, while the last node is a collection point. These conditions are fulfilled thanks to constraints **(12)** and **(13)**, respectively
	(14) and **(15)** prevent movements between two depots and between two collection centers

(*continued on next page*)

Table 7 (*continued*)

Author (Citation)	Constraints/Information considered
	(16) allows calculating the total amount of goods delivered to a collection point, which must not exceed its capacity **(17)**
	The total time (travel + loading/unloading) of a route is calculated in **(18)** and must not exceed the maximum permissible **(19)**
	(20) implies that each vehicle can exit the depot at most once, ensuring at the same time connectivity of the routes
	(21) to **(22)** Specify the domain of the variables
Sackmann et al., (2017)	Considerations made by the authors:
	(1) multiple dumping sites
	(2) one depot
	(3) a given shift duration
	(4) a given uniform vehicle capacity
	(5) given time windows for the requestors.
Abbatecola et al., (2016)	**(1)** imposes that each node has to be served precisely once;
	(2)-(4) guarantees that every vehicle starts the first route at the garage, while the other routes begin from the disposal site;
	(5) states that each vehicle ends its route at the landfill site;
	(6) ensures the flow conservation avoiding the vehicles returning to the garage after having served a node;
	(7) Connects the end of a route to the start of the following one;
	(8) Imposes that the last route of the shift has to be from the disposal site to the garage;
	(9) - (10) Determine the arrival time at the node; **Non-linear**
	(11) - (12) updates the load collected by the vehicle; **Non-Linear**
	(13) - (16) Impose the time and capacity constraints
Fanti et al., (2016)	**(1)** imposes that each node has to be served precisely once;
	(2) - (4) guarantee that every vehicle starts the first route at the garage while the other routes, if necessary, begin from the disposal site;
	(5) states that each vehicle ends its route at the landfill site;
	(6) avoids the vehicles returning to the garage after having served a node;
	(7) connects the end of one route to the start of the following one;
	(8) imposes that the last route of the shift has to be from the disposal site to the garage;
	(9) - (10) update the starting time of service at the node; **Non-linear**
	(11) - (12) update the cargo collected by the vehicle; **Non-linear**
	(13) - (16) impose time and capacity constraints.
Nevrlý et al., (2016)	**(1)** connects some types in such a way that one or more might be composed of several others. In practice, this means that the sum of values in cities is equal to district value;
	(2) follows the idea that each territory j of an individual type H is part of some more significant territory named i;
	(3) which connects the input data with the modeled variable and its error;
	(4) describes the separation of errors into the positive and negative part;
	(5) - (6) where these variables are stated as non-negative.
Perea et al., (2016)	**(1)** Exactly one pattern is assigned to each collection site;
	(2) - (4) Force the number of service days in which fraction k is collected;
	(5) - (6) The company wants the amount of waste collected to be relatively constant (These two sets of constraints force the amount of collected waste on a service day to be within the interval of the premise)
	(7) - (10) maintain the linearity of the problem
Geetha et al., (2013)	**(1)** A load of each vehicle should not exceed the given vehicle capacity.
	(2) Each customer is serviced precisely once.
	(3) Each vehicle route starts and ends at the depot.
Geetha et al., (2012)	**(1)** A load of each vehicle should not exceed the given vehicle capacity
	(2) Each customer is serviced exactly once
	(3) Each vehicle route starts and ends at the depot
Liu and He, (2012b)	**(1)** guarantees that each stop will be visited precisely once;
	(2) states that each rotation of a vehicle will start at the garage.
	Defines a simple route satisfying capacity constraints **(3)** and both ends constraints **(6);**
	(4) and **(5)** impose a limit on the total duration of a rotation and time windows of all vertexes;
	(7) shows that when a vehicle goes to a vertex, it also leaves it;
	(8) is sub tour elimination constraints
Gomes et al., (2007)	**(1)** demand is concentrated in a set of discrete locations (demand nodes) that have fixed total demands;
	(2) every demand node shall be allocated to the closest remediation unit;
	(3) there is no interaction between remediation units;
	(4) there are no spatial constraints (forbidden areas, barriers) to the location of the units.
Ombuki-Berman et al., (2007)	**(1)** Vehicle capacity constraints.
	(2) Route capacity constraints.
	(3) Time windows of stops and depot constraints.
	(4) Routing time limit per vehicle.
	(5) Disposal trips.

(*continued on next page*)

Table 7 (*continued*)

Author (Citation)	Constraints/Information considered
	(6) Driver's lunch break.
	(7) Each stop is serviced exactly once
Kim et al., (2006)	**(1)** Time windows of stops and the depot,
	(2) Vehicle capacity (i.e., volume, weight),
	(3) Route capacity (i.e., the maximum number of lifts, volume, and weight that can be handled per vehicle per day),
	(4) Routing time limit per vehicle,
	(5) Disposal trips (i.e., when a vehicle is full, it must go to a disposal facility),
	(6) Driver's lunch break.
Kontos et al., (2005)	**(1)** Hydrological/hydrogeological criteria (Distance from water sources; Water permeability)
	(2) Environmental criteria; (Land Cover; Sensitive Ecosystems; Surface waters)
	(3) Social Criteria; (Visibility; Land Uses; Cultural Areas; Urban Areas)
	(4) Technical Criteria (Wind orientation; morphology)
Tango, (2002)	**(1)** Dealing with multiple sources;
	(2) Selection of unknown exposure functions
	(3) Hazardous substance levels may tend to have a peek at some distance from the putative source of hazard

non-linear programming applications. Therefore, this factor would leave an opening, for instance, in comparing computational times using improved methodologies in similar databases or even memory requirements for executing the proposed algorithm. More frequently used than mathematical Modelling in waste disposal research was the heuristic approach. About the tables presented in Section 4, most works focused mainly on using a specific heuristic for a defined use and were not concerned with comparing techniques to choose the more appropriate. In addition to comparing two or more techniques to gauge better the one that should be implemented for the real problem, a combination of techniques could be considered an option.

Another aspect that deserves to be mentioned is that none of the 41 papers in waste disposal application mentioned using hybrid techniques in their methodologies, considering the algorithms solely in their root form. Utilizing hybrid techniques, one could improve the results by aiding the exploitation (probing a limited region of the search space with the hope of improving a promising solution) when improving the solutions found in the search space of the algorithm as well as the exploration (probing a larger portion of the search space with the hope of finding other promising solutions that are yet to be refined) of the results.

Although using more general constraints and objective functions is highly recommended when researching with as large a scope as possible, when various options of these topics are presented, the results can be more beneficial concerning the problem in question. Considering different constraints could help the model adapt better to the solution and solve the real problem. This adaptation will make the proposed methodology more useful for real-world applications instead of a more theoretical solution.

The second portion of this discussion is on the subject of waste collection research. As shown in Figure 6, Figure 9, and Table 6, this was the most influential field considering the volume it represents in the selected portfolio of papers and the number of citations it has garnered. Initially, observing Table 6, we can see that the most considerable amount of papers concentrated on reducing and analyzing either travel time or its length (12 documents). We will also include, at this point, the two applications on the prediction of travel time (2 papers) since it is a similar subject. A suggestion for future studies might be the use of different objectives. Considering more monitoring systems associated with route risk (the two least mentioned objectives) would help develop the route network and improve waste collection services.

Considering this application, not one literature review was found in the selected papers, suggesting an opportunity for this methodology to be developed in this genre. Now, observing the applied methodologies and algorithms, only three documents used linear programming, one of them not specifying the sub-type (Chun-Lin et al., 2019), and the other two using Mixed-Integer Linear Programming (Abbatecola et al., 2016; Fanti et al., 2016). Considering the extensions of constraints in this area, this phenomenon can occur due to these algorithms' computational complexity. Abbatecola et al. (2016) and Fanti et al. (2016) are from a similar set of authors, and both used 16 constraints to develop their model. Besides non-linear ones, the other restrictions used are not far from a generic vehicle routing problem. Both reduce computational costs and implement more specific restrictions that could be more useful in real-world solutions using hybrids, relax-and-fix heuristics, and other initial solutions techniques.

Continuing this analysis of methodologies, only two works dealt with hybrid techniques, and both were from the same authors (Geetha et al., 2012, 2013), in which a hybrid of Particle Swarm Optimization (PSO) was used. Although there was a type of hybrid, a wide gap remains in this type of methodology. Different hybrids with PSO could be used as well as other metaheuristics, such as Genetic Algorithms (GA), Variable Neighborhood Search (VNS), and Ant Colony Optimization (ACO).

Finally, concerning the constraints, 12 of the papers presented the restrictions of their studies and of those, where five were more specific concerning the limits of their methodology (Kim et al., 2006; Ombuki-Berman et al., 2007; Perea et al., 2016; Chun-Lin et al., 2019; Jammeli et al., 2019), and the constraints in Kim et al. (2006) and Ombuki-Berman et al. (2007) were very similar. The use of different constraints could be broader in this field when adapting the solution to the real-world problem better. Suggestions from specialists and more fitting constraints related to the evaluated data could make the works seem less theoretical and more visually applicable.

6. Conclusion

This research's main objective is to review and analyze research progress in terms of clustering analysis in Waste Management applications and, thus, identify gaps in this research field. After all filters applied (Figure 2), 61 documents remained for full content evaluation. Initially, we presented a bibliometric assessment where we demonstrated this document's relevance by presenting the number of papers from journals and conferences and the publishing media's ranking. These documents were categorized into nine application types framed within the waste management field for, in Section 4, we presented all the analyses, where waste management issues and research efforts were more frequently assessed using clustering techniques. Section 5 then included an agenda of what is happening in terms of research, which we presented from two different perspectives: methodological and application. With the applied analysis and research method, we found that the popular k-means and their variations are the preferred technique for clustering analysis on waste management issues, and the most common application would be waste collection research.

Some gaps were found related to the investigation of more complicated situations in each problem. The authors chose to use generic objective functions and constraints for their methodologies. The exploration of more specific situations could be more beneficial to real-world problems, where general solutions are more theoretically oriented results. Moreover, suggestions from specialists in each field found in this review could choose more fitting constraints related to the evaluated data.

Another gap was related to the applied techniques, as there was little comparison between the algorithms. Still related to techniques, there were only two uses of hybrid algorithms (in waste collection problems). It would be advisable to use those types of techniques since they could improve results from exploitation and exploration point of views.

Of course, as with many types of research, this work has its limitations. We considered only exclusion criteria and not inclusion options. Also, we used a single paper database for paper selection. We did not present an extensive analysis of each paper's user database, or comparing countries' focuses. And finally, we solely observed each work only in terms of method and application, not assessing each technique's effectiveness.

Examining the research opportunities identified following the content assessment, two suggestions could be made. First, in terms of future reviews, subjects could be tackled to address the limitations presented in this paper. For instance, keywords such as waste composition analysis in order to observe a less business related and more operational approach.

The second suggestion is about the subject of research. We observed that other themes differently from waste collection research could be further explored in terms of real problems, such as landfill locations and reverse logistic applications. Moreover, to bridge the gaps found in the literature, authors could engage specialists in the field to adapt their methodology to the real-world problem in question. In terms of techniques, more hybrid algorithms could be used and compared with the staple techniques found in the literature, such as linear programming, k-means, and machine learning.

Declarations

Author contribution statement

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Additional information

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