

Review

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Review

Ranking of MCDA Criteria and Methods Used for Selecting Landfill Sites: A Systematic Literature Review

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Abstract: One of the most important requirements in the installation of landfills is the identification and evaluation of suitable areas, a complex decision due to the various factors and criteria involved. The aim of this work was to present the main criteria and methods of Multicriteria Decision Analysis (MCDA), with emphasis on the Hierarchical Analysis Process (AHP) method, used in the selection of landfill sites in Brazil and other countries. The methodology consisted of creating a ranking of the most used criteria for selecting areas suitable for landfill, based on a Systematic Literature Review, with data from a search strategy in the journals Scopus, Web of Science and Google Scholar. The criteria selected were based on those established in standards, resolutions and laws in force in Brazil and criteria from other countries. Of the 89 studies selected, there was a recurrence among the main criteria used, namely: distance from water resources (96%), topographical characterization (90%), access (89%), distance from population centers and geology and existing soil types, both with 80%. As for the AHP method, studies have revealed other methods associated with it, such as the Geographic Information System (GIS), Weighted Linear Combination (WLC), Fuzzy, Fuzzy-AHP and Remote Sensing.

Keywords: site selection; sanitary landfill; AHP; systematic literature review

1. Introduction

The excessive production of solid waste in the current context is one of the main global challenges. The complexity and inefficiency of waste management, in addition to raising financial costs, result in adverse impacts that directly affect environmental quality and public health. This problem stems from and has been driven by various interrelated factors, especially the disorganized expansion of urban areas, along with population growth and significant changes in consumption patterns [1].

According to the Global Waste Management Outlook 2024 [2], it is estimated that the annual global production of Municipal Solid Waste (MSW) in 2020 was approximately 2.1 billion tons, 38% of which was not disposed of in an environmentally appropriate manner. It also stresses that, due to the combination of economic and population growth, an increase of 56% is projected, reaching 3.8 billion tons by 2050, if urgent measures are not implemented.

Regarding Brazil's waste production, information from the "Thematic Diagnosis of Waste Management" based on data from the National Basic Sanitation Information System (SINISA) highlighted a total of 63.8 million tons of MSW collected in 2022. Of this amount, it is estimated that the total mass recovered from dry recyclable and organic materials was 1.3 million tons, around 2.04%, while the estimate of the total mass (62.49 million tons) for final disposal in landfills was 46.08 million tons (73.7%) [3].

Globally, in low-income countries, only 3% of waste was disposed of in landfills, while in upper-middle-income countries, 54% was disposed of in landfills [4]. Among the various strategies associated with MSW management are recovery, treatment and final disposal techniques, which aim to reduce the amount of waste sent to landfills. Even in nations where recycling rates are high and other waste treatment technologies are implemented, landfills remain an essential component of waste management [5].

The problems arising from the improper disposal of solid waste in the environment significantly compromise environmental quality, and the main impacts can be exemplified as: “environmental pollution; visual pollution; contamination of soil and groundwater; waterlogging and flooding in rainy periods; proliferation of endemic diseases; damage to local tourism; increased public spending on cleaning” [6] (p. 10).

Thus, a sanitary landfill is a method that uses engineering principles to confine solid waste to the smallest possible area and reduce its volume to the minimum permissible, covering it with a layer of earth at the end of each working day or at shorter intervals, as necessary [7,8].

To this end, the initial stage of a landfill project therefore involves identifying suitable areas for its installation. The selection of these sites, as outlined in the literature, is an intrinsically complex process that requires the consideration of multiple social, environmental, technical and economic criteria [9].

Thus, each region is subject to federal, state and/or municipal standards for the implementation of a sanitary landfill, such as the following in Brazil: ABNT NBR 13.896/1997 [10]; ABNT NBR 8.419/1992 [7] which deal with “Non-hazardous waste landfills - Criteria for design, implementation and operation” and “Presentation of urban solid waste landfill projects”, presenting specific criteria aimed at minimizing socio-environmental damage, respectively; ABNT 15. 849/2010 [11] - Urban solid waste - Small sanitary landfill - Guidelines for location, design, implementation, operation and closure; and CONAMA resolution 404/2008 [12] - Establishes criteria and guidelines for the environmental licensing of small sanitary landfills for urban solid waste. However, some extremely important criteria are not established in these documents, such as the minimum distances between landfills and aerodromes.

The application of methodologies for selecting suitable sites for the implementation of sanitary landfills is mostly based on tools associated with Geographic Information Systems (GIS) with different Multi Criteria Decision Analysis (MCDA) methods, such as Weighted Linear Combination (WLC), Fuzzy, Analytic Hierarchy Process (AHP) [13]; Ratio Scale Weighting (RSW) [14]; and Simple Additive Weighting (SAW) [14].

Among the MCDA methods, the AHP method stands out, widely used in research in various thematic areas, considered an essential method to support decision-making in the context of solid waste management, as highlighted in the works by [16–18].

In this context, the main objective of this study was to analyze, through a Systematic Literature Review (SLR), the main MCDA criteria and methods used in Brazil and other countries to select suitable areas for landfills, with an emphasis on the AHP method.

2. Materials and Methods

The methodology was structured in three main stages: 1 - Systematic Literature Review (SLR); 2 - systematization of the results; and 3 - ranking of the criteria.

2.1. Stage 1: Systematic Literature Review (SLR)

The SRL phases were developed according to the methodology proposed by [19], characterized and structured in three phases: 1 - research questions; 2 - search and selection of articles; and 3 - description and classification of publications, as shown in Figure 1. The scope of the research was limited to journal articles published between 2013 and 2023, exported from the Scopus and Web of Science databases and the Google Scholar database.

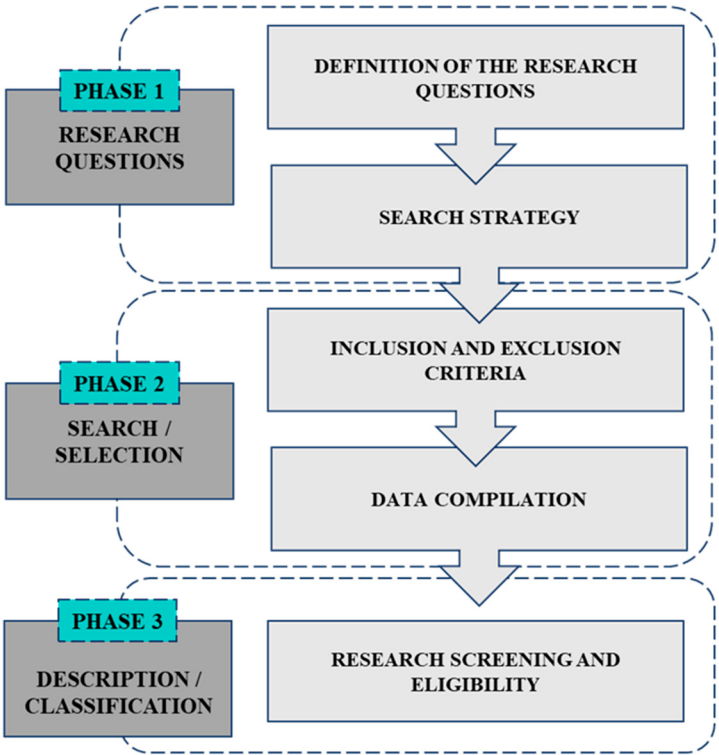


Figure 1. Stages of the RSL - adapted [19].

2.1.1. Phase 1: Defining Research Questions and Search Strategies

The formulation of the research questions is one of the initial stages, and its elaboration is crucial to the success of the RSL, since this stage directly interferes with the aspect and excellence of the data collection and analysis system [20]. In this way, the research questions in Table 1 were composed with the aim of understanding and capturing the main procedures of the research area.

Table 1. Research questions.

Questions of research
What are the most criteria used in the application of AHP to choose landfill sites in Brazil and other countries?
What main MCDA methods used in Brazil and other countries for the selection of suitable areas for sanitary landfills?

¹ Tables may have a footer.

According to [21], the purpose of an RSL is to identify as many relevant primary studies as possible to clarify the proposed research questions. Therefore, once the research questions had been formulated, the next step was to define the search strategies, illustrated in Figure 2, to retrieve the information from the databases.

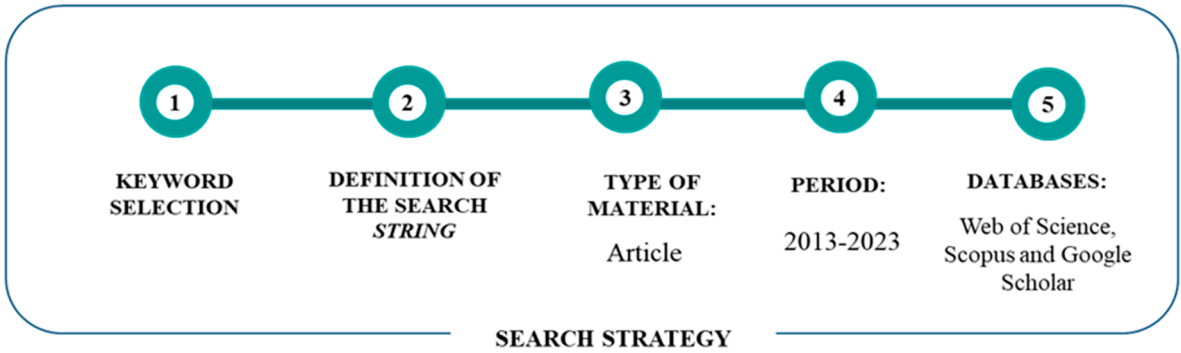


Figure 2. Search strategies. String: sequence composed of logical operators and keywords [22].

To create the strings, the search terms were grouped into a set of words in Portuguese and English related to the scope of this review, as shown in Table 2.

Table 2. Terms of Research in portugueses, and english.

Terms in portugueses	Terms in english
seleção de áreas, seleção de local, seleção de local de aterro sanitário	selection of areas, site selection, landfill site selection
aterro de resíduos sólidos, resíduos sólidos, gestão de resíduos, aterro sanitário	dat-solid waste landfill, solid waste, waste management, landfilla
decisão multicritério, multicritério, análise de decisão multicritério	multi-criteria decision, multi-criteria, multi-criteria decision analysis
processo hierárquico analítico, AHP	Analytic Hierarchy Process

The study used three search strings operated in two stages: in the first stage, strings 1 and 2 were applied, with terms in English, Boolean operators and truncation technique in the Scopus and Web of Science databases, for the period from 2013 to 2023; and in the second stage, a new search string (string 3), this time only with terms in Portuguese, in the Google Scholar database, for the same period, see Table 3.

Table 3. Search strings.

Stage 1	
String 1	
Database: Scopus e Web of Science	("selection of areas" OR "site selection" OR "landfill site selection") AND ("solid waste landfill" OR "solid waste" OR "waste management" OR "landfill*") AND ("multicriteria decision" OR "multi-criteria" OR "multi-criteria decision analysis") OR ("seleção de áreas" AND "aterro sanitário")
String 2	
processo hierárquico analítico, AHP	("selection of areas" OR "site selection" OR "landfill site selection") AND ("solid waste landfill" OR "solid waste" OR "waste management" OR "landfill*") AND ("multicriteria decision" OR "multi-criteria" OR "multi-criteria decision analysis") AND ("Analytic Hierarchy Process" OR "AHP") OR ("seleção de áreas" AND "aterro sanitário")
Stage 2	
String 3	
Database: Google Academic	"seleção de áreas para aterro sanitário" AND "AHP"

The second stage was included because there were few Brazilian articles in the first stage (Scopus and Web of Science databases). It was therefore felt that the inclusion of a new database, Google Scholar, could identify other publications on the subject of the study.

2.1.2. Phase 2: Inclusion/Exclusion Criteria and Data Compilation

There were 6 criteria, 3 for inclusion and 3 for exclusion. With the search strategy and criteria stages defined, the strings were then used in the databases and the raw results were aggregated with the help of the RStudio software.

Table 4. Description of the inclusion and exclusion criteria used in the SLR.

Decision	Criteria (Cn)
Inclusion	C1 When the predefined keywords exist in the title, or at least in the keywords or abstract section of the article
	C2 Articles with the main theme of selecting landfill sites using the AHP method
	C3 Articles with the main topic of selecting landfill sites for municipal solid waste
Exclusion	C4 Duplicate articles from the research documents
	C5 Articles not fully accessible
	C6 Articles with incoherent titles

Once the search strategies and criteria had been defined, the strings were used in the databases and the raw results were aggregated using the RStudio software.

In RStudio, duplicate articles were identified and excluded automatically using the Bibliometrix R package, which has a set of resources for the precise processing of bibliographic data, including file format conversion, data grouping, locating and excluding duplicate documents, descriptive analysis, matrix construction and similarity normalization for network analysis [23].

In the second stage, applying string 3 to the Google Scholar database resulted in a smaller number of documents, so the articles were selected manually from the database itself, without the aid of the RStudio software. After these steps, all the articles were organized in an Excel spreadsheet for the critical analysis process.

2.1.3. Phase 3: Screening and Eligibility of Articles

Screening was carried out using the criteria set out in Table 2, with the aim of checking whether the articles were aligned with the main theme of the research, and consequently excluding those that were 7out of scope. This stage was subdivided into three phases, shown in Figure 3: 1 - checking the titles; 2 - analyzing the abstracts; and 3 - reading in full.

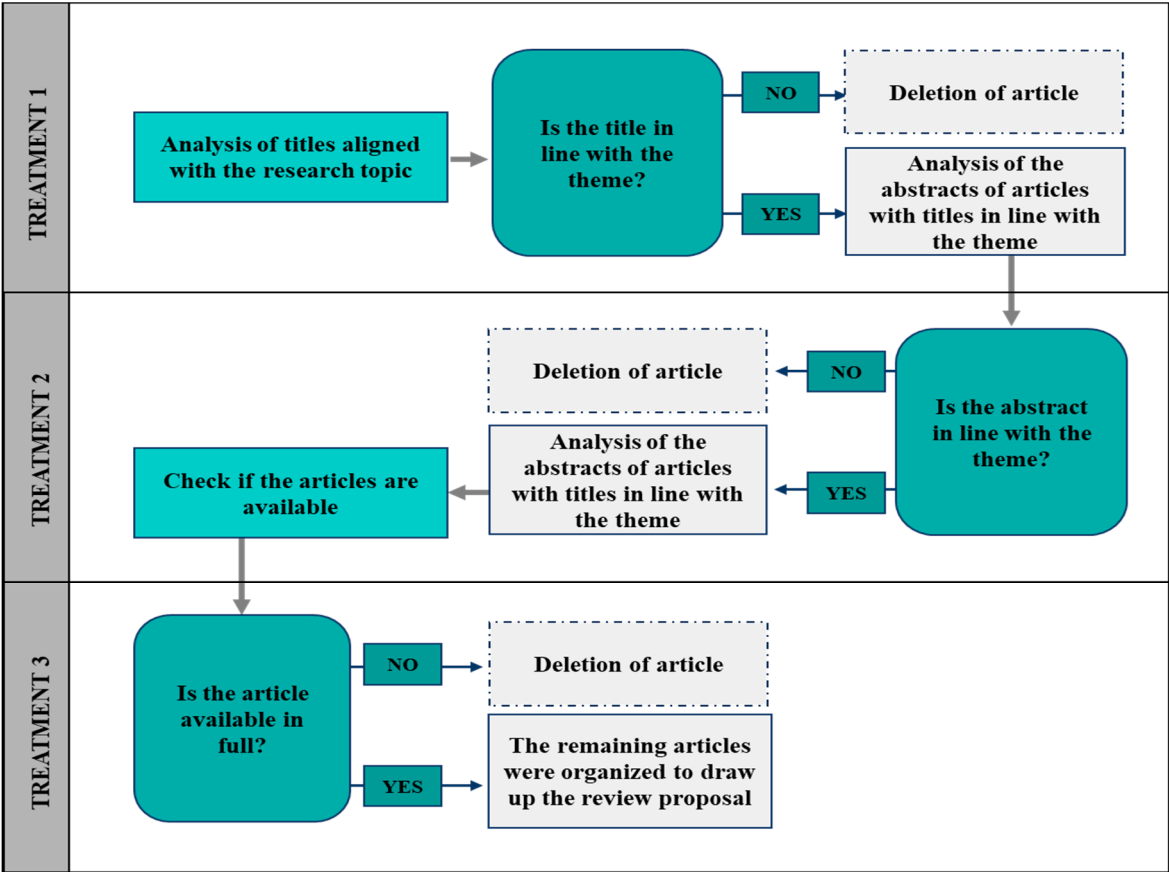


Figure 3. Stages in the sorting process - based [19].

2.2. Stage 2: Systematization of Results of SLR

After developing the three phases of the RSL, we went on to systematize the resulting articles and their final analysis, organizing them in an Excel table, presenting information such as title, author(s), year of publication, country, continent, methodology(ies) and criteria. Organizing the information from the selected articles enabled graphs to be drawn up for analysis of time distribution, production of articles by country, production of articles by continent and an overview of the main MCDA criteria and methods used in Brazil and other countries to select suitable areas for landfills.

2.3. Stage3: Ranking of Criteria

To develop the ranking system, we considered the highest frequency of criteria observed in the articles resulting from the three phases of the RSL. This procedure included both the criteria identified in articles produced in Brazil and those from other countries, since many had different terminologies but the same meaning. Thus, the parameters were subjected to a thorough analysis and the equivalent terms were grouped together and linked to a single criterion. In this way, the criteria terminologies were established according to the standards, resolutions and laws in force in Brazil, as described in Table 5.

Table 5. Nomenclature of criteria established according to Brazilian standards (BS), CONAMA’s resolution, and law – source [7,10–12,24].

Nomenclature of the criteria	Standards, resolution and law
Approval of the installation by the local population	BS 13.896/1997
Distance from water resources	BS 13.896/1997; BS 15.849/2010; BS 8.419/1992
Distance from airports	Law nº 12.725/2012
Size of plant	BS 13.896/1997
Topographical characterization	BS 13.896/1997; BS 15.849/2010; BS 8.419/1992
Geology and existing soil types	BS 13.896/1997; BS 15.849/2010; BS 8.419/1992; CONAMA’s Resolution 404/2008
Distance from population centers	BS 13.896/1997; BS 15.849/2010; BS 8.419/1992
Cost	BS 13.896/1997 e BS 8.419/1992
Access	BS 13.896/1997; BS 8.419/1992; CONAMA’s Resolution 404/2008
Land use and occupation	BS 13.896/1997; BS 8.419/1992; CONAMA’s Resolution 404/2008
Occurrence of flooding	BS 15.849/2010, and CONAMA’s Resolution404/2008
Useful life	BS 15.849/2010 e CONAMA’s Resolution 404/2008
Climatological characterization	BS 8.419/1992
Transportation savings	BS 8.419/1992
Titling of the chosen area	BS 8.419/1992

The criterion relating to distance from aerodromes is not specified in the landfill design standards in force in Brazil. However, according to Law No. 12,725/2012 [24], this type of undertaking is recognized as an activity with the potential to attract fauna. Therefore, there is a need to establish a minimum distance in order to mitigate the risk of accidents and aeronautical incidents resulting from aircraft colliding with specimens of fauna in the vicinity of aerodromes.

There was no search for criteria in legislation or documentation from other countries, given that the study aimed to present a document that could help professionals in landfill implementation projects in Brazil. Therefore, in order to establish a ranking of the ten most commonly used criteria in the selection of areas for landfills in Brazil and other countries, the criteria found in RSL were organized in an Excel spreadsheet, containing columns for the criteria variables, the quantity used per article and the percentage of this frequency, making it possible to sort according to the frequencies.

3. Results

3.1. Systematic Literature Review - Selection of Recovered Articles

The total number of papers selected and identified in the SLR was 89: 82 resulting from stage 1 (string 1 and 2) and 7 from stage 2 (string 3). Figure 4 shows the flowchart of the main stages of the review, together with the results obtained.

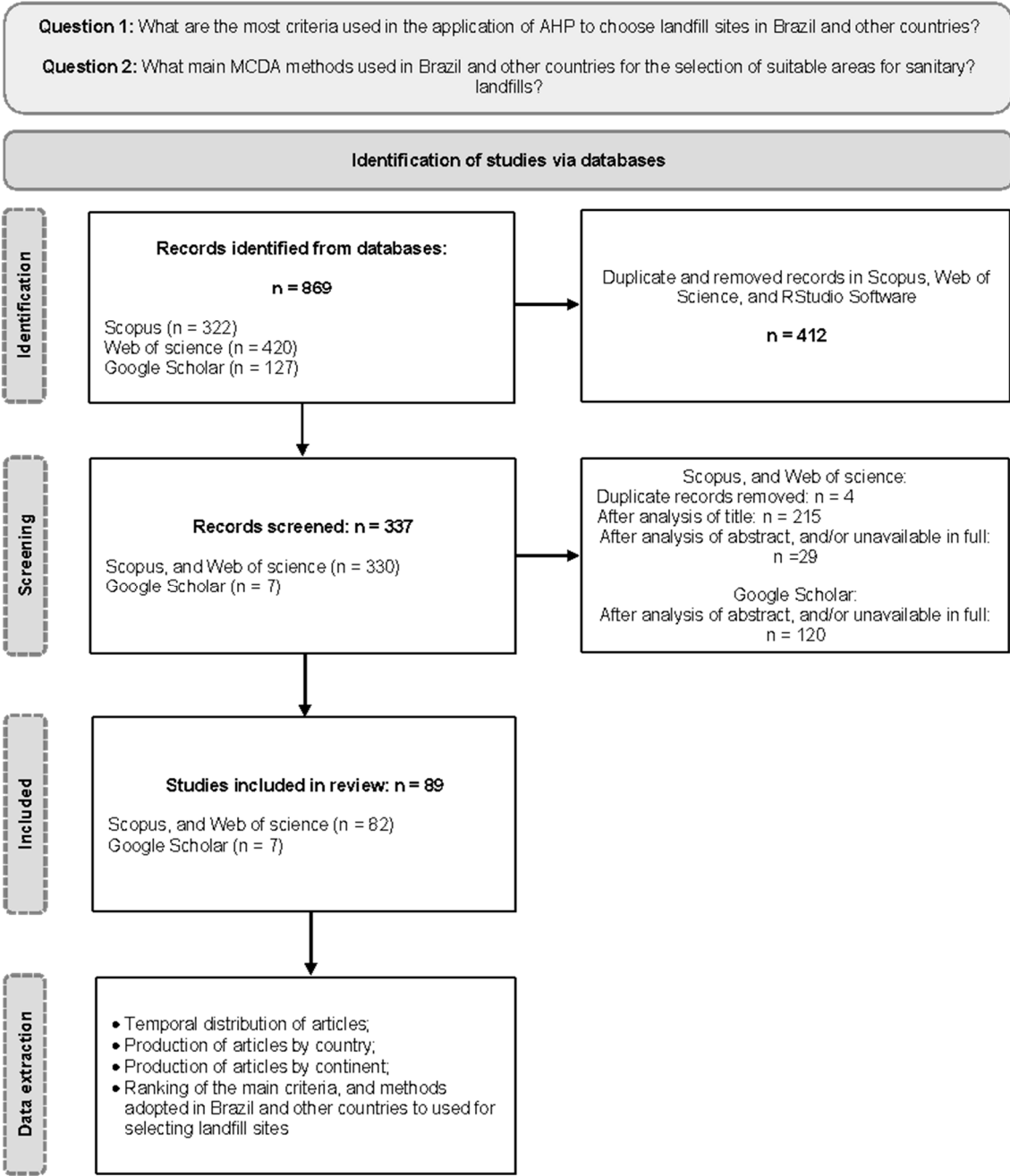


Figure 4. Results of recovered articles by Systematic Literature Review.

In this first stage, the application of strings 1 and 2 in the Scopus and Web of Science databases resulted in 742 articles. This total was exported to the RStudio software, through which 412 articles identified as duplicates were automatically excluded, resulting in 330 unique articles.

The total number of articles selected and included in the review after the second stage was 7. Figure 4 shows the main procedures of each stage, together with the results found.

With regard to summarizing the data that the software allows us to develop, we highlight a cloud of words, shown in Figure 5, which are frequently used in the works exported from the databases, making it easier to identify and visualize the frequency of the main terms used, as well as additional terms that were not included in the search strings, but which may be useful in future research.



Figure 5. Keywords more utilized.

Although the RStudio software was able to automatically identify duplicate articles, four articles in this category were still identified in the Excel software. At the end of all the screening and eligibility stages, a total of 660 papers were excluded, resulting in 82 articles.

A summary of the application of the strings in the databases for each stage is shown in Table 6.

Table 6. Results of databases in the two stages.

STRINGS, AND DATABASES		Scopus	Web of Google Science Scholar	Total	
Stage 1	String 1 (“selection of areas” OR “site selection” OR “landfill site selection”) AND (“solid waste landfill” OR “solid waste” OR “waste management” OR “landfill*”) AND (“multi-criteria decision” OR “multi-criteria” OR “multi-criteria decision analysis”) OR (“seleção de áreas” AND “aterro sanitário”)	209	242	-	451
	String 2 (“selection of areas” OR “site selection” OR “landfill site selection”) AND (“solid waste landfill” OR “solid waste” OR “waste management” OR “landfill*”) AND (“multi-criteria decision” OR “multi-criteria” OR “multi-criteria decision analysis”) AND (“Analytic Hierarchy Process” OR “AHP”) OR (“seleção de áreas” AND “aterro sanitário”)	113	178	-	291
	String 3 “seleção de áreas para aterro sanitário” AND “AHP”	-	-	127	127
Total		322	420	127	869

Of the total number of articles retrieved after the two stages (869), 420 corresponded to Web of Science, around 48% of the total sample, Scopus, 322 articles, equivalent to 37%, while Google Scholar retrieved 127 articles, 15% of the total. Of the 869 resulting articles, around 780 were excluded, either because they were duplicates or because they did not meet the established criteria (e.g. titles and abstracts that were not aligned with the RSL theme).

Although many of these excluded papers contained selected terms organized in the defined strings, such as "area selection", "landfill", "sanitary landfill" and "AHP", many of them dealt with topics that diverged from the main focus, for example, they dealt with the selection of areas for the

construction of shopping malls using AHP, or the selection of areas for landfills of mining waste, health service waste or industrial waste.

3.2. Analysis of Recovered Articles

Of the articles selected, in relation to the period of publication, from 2013 to 2023, Figure 6 shows a progressive increase in the production of those dealing with MCDA criteria and methods for selecting areas for landfills, the main theme of this study, with the years 2021 and 2022 showing the highest volume of publications, each with 16 articles.

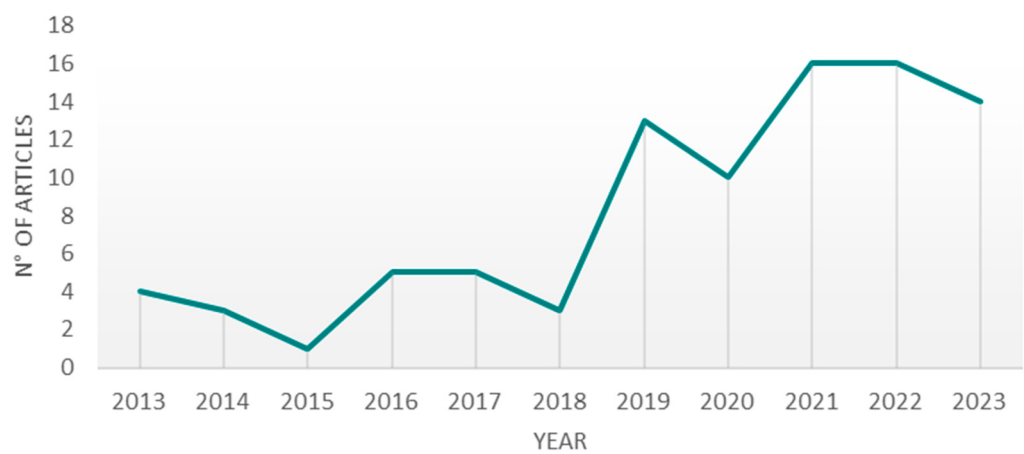


Figure 6. Temporal evolution of the production of articles on the main theme of this study.

Figure 7 shows the production of articles by country in phases 1 and 2. The highest number of articles produced in the first phase was in countries such as Turkey, India and Ethiopia. These results reflect, for example, that in developing or underdeveloped countries, where around 80% of the world's population resides, the issue of solid waste has become a complex and serious problem, especially due to the scarcity of financial resources [25], accelerated urbanization, poor urban planning and a lack of management skills [26], with the majority being sent to landfills to the detriment of other sources of treatment, such as recycling or energy recovery.

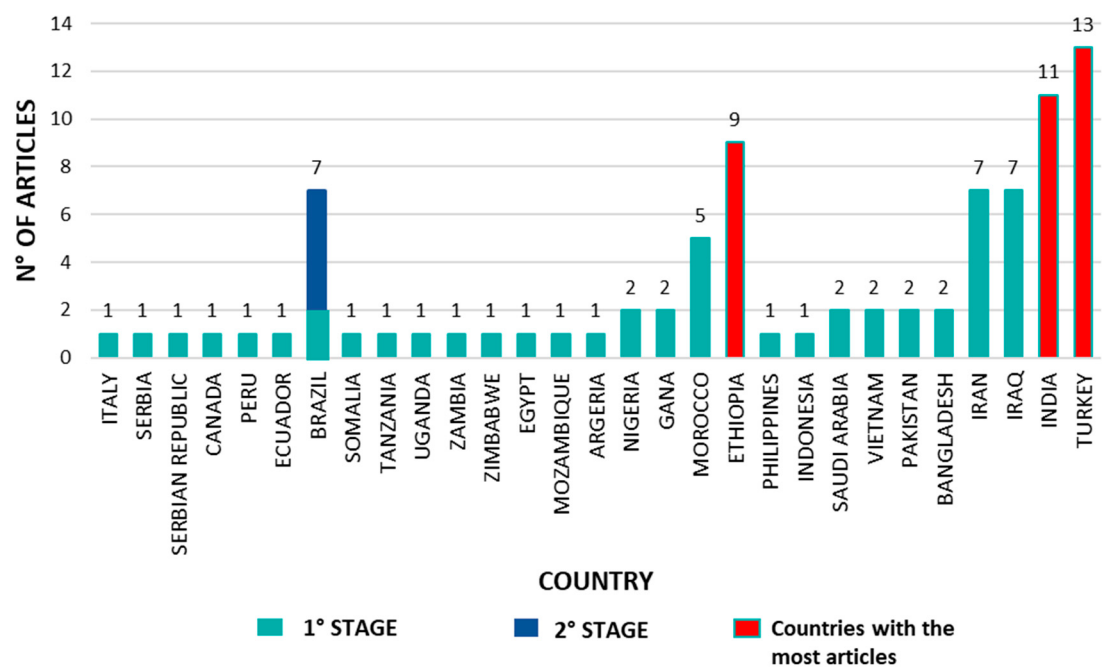


Figure 7. Article production by country.

In Brazil, 9 articles were produced, 2 of which came from the first stage and 7 from the second stage. This number is still considered low compared to the number of articles produced in other countries, which also do not yet have satisfactory management. It should also be noted that this number of publications may be associated with the strings used, i.e. they were not sufficient to include more articles, or the articles were published in journals not indexed in the databases used in this research.

Figure 8 identifies the production of articles by continent, with emphasis on Asia, the continent with the largest production of articles on the selection of suitable areas for landfills using the AHP method.

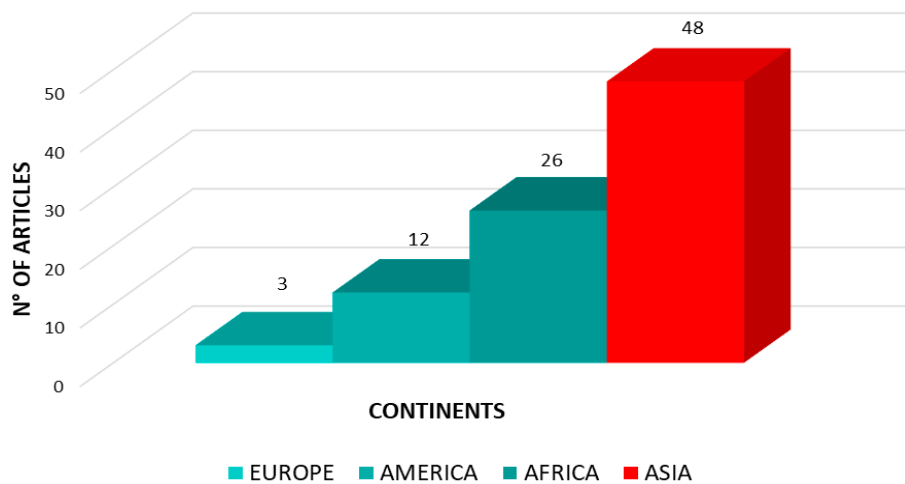


Figure 8. Article production by continent.

According to the Global Waste Management Outlook 2024 [2], which highlights the regional distribution of MSW destinations, as shown in Figure 9, the lowest levels of MSW management are in Asia (Central and South) and Africa (Sub-Saharan), which may justify the higher production of items on these continents, with the future prospect of landfills or other destinations. Asia has more than 80% of its waste disposed of in an uncontrolled manner (open dumping and burning).

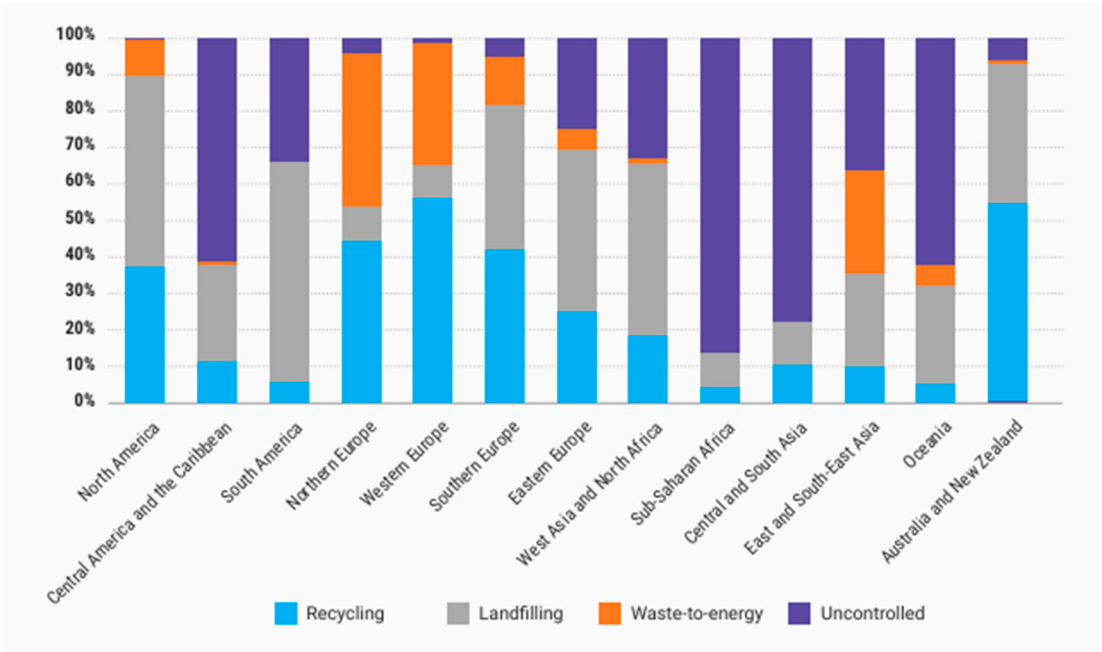


Figure 9. Main destinations for MSW in the world – source [2].

The African continent had the second highest number of articles selected, with Ethiopia standing out as the main producer of papers found in this RSL. Authors [27] analyzed solid waste disposal sites in Shambu (Ethiopia) and found no sites that met scientific and urban standards. Consequently, they found that the population disposed of their waste in ditches, roads and water sources. Data indicate that in African countries less than half of the MSW was collected and that 95% of this waste was disposed of indiscriminately [28].

3.3. *Ranking of the Main Criteria Adopted in Brazil and Other Countries*

The SLR revealed a total of 108 different terms for the criteria covered in the articles. This abundance of terms may have been influenced by the translation process of the papers, as most of the articles found were in English. These terms were therefore grouped together and linked to a single criterion. At the end of this procedure, they were reduced to 47 different criteria terms, which made it possible to analyze their frequency in the articles, allowing them to be structured in a ranking with the 10 most used criteria, see Table 7, of the 89 articles selected.

Table 7. Ranking of 10 criteria of 89 select articles on SLR.

Criteria	Frequency/ Quantity of articles	Frequency of occurrence (%)
Distance from water resources	86	96
Topographical characterization	81	90
Access	80	89
Distance from population centers	72	80
Geology and soil types	72	80
Land use and occupation	64	71
Protected areas / Sensitive sites	53	59
Climatological characterization	25	28
Distance from airports	23	26
Distance from railroads	17	19

As for the criteria used only in articles produced in Brazil, 14 different criteria were identified, as shown in Table 8.

Table 8. Ranking of criteria of 9 brazilian articles selected on SLR.

Criteria	Frequency/ Quantity of articles	Frequency of occurrence (%)
Distance from water resources	8	89
Topographical characterization	8	89
Access	7	78
Distance from population centers	7	78
Geology and soil types	6	67
Distance from protected areas / sensitive sites	4	44
Land use and cover	3	33
Distance to waste production area	2	22
Distance to drainage	2	22
Climatological characterization	1	11
Habitat, Flora and Fauna	1	11
Distance from airports	1	11
Land value	1	11
Geomorphology	1	11

It can be seen that these include criteria specified in the standards, resolutions and laws in force in the country, as well as criteria not identified in them, such as distance to the waste production area, distance to drainage, land value and geomorphology. It should also be noted that the other criteria showed similar frequencies to the 10 main criteria found in the RSL, which includes other countries, defined in the general ranking in Table 7.

When listing the criteria by continent, Figure 10 shows that they do not follow the same order as the ranking in Table 7.

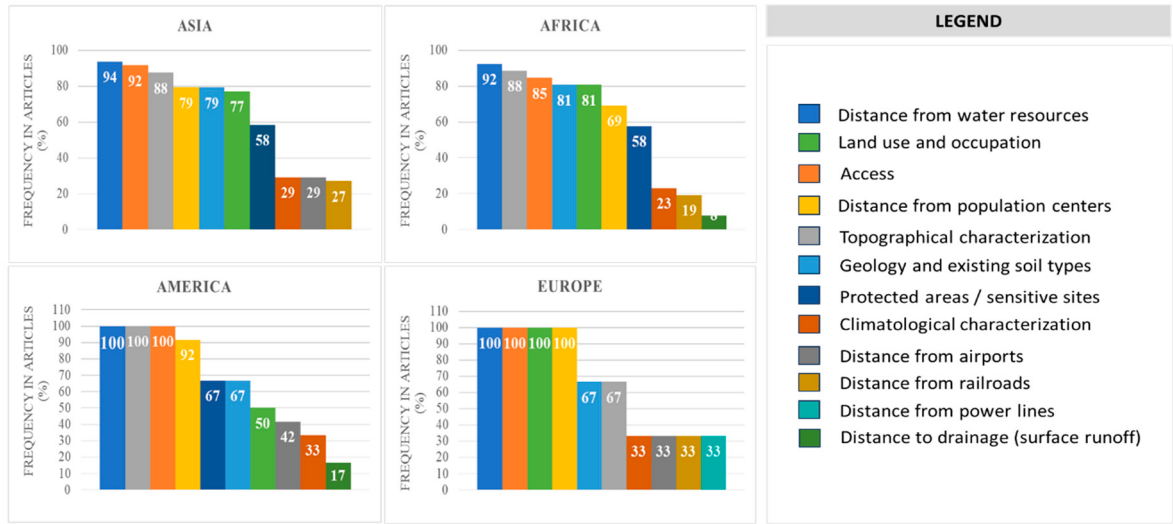


Figure 10. Ranking of criteria by continent.

The ranking of the criteria in Asia and Africa was like the overall ranking (Table 7). The Asian continent stands out, with only one difference in positioning between the access and topographic characterization criteria. In the African ranking, an additional criterion that emerges is drainage distance (surface runoff), which is closely related to the surface and underground formation of the areas in each study, providing information on the region's surface runoff from drainage density.

The continents of America and Europe showed agreement in the first three criteria (distance from water resources, land use and occupation and access), with similar frequencies, showing that these parameters are widely used and should be considered relevant for research conducted in these regions. This shows that there is no priority for universal criteria to be used when selecting suitable areas for landfill, but rather criteria that can help reduce socio-environmental impacts and that meet the specific standards of each country and its specificities.

An example of a criterion not identified in this RSL ranking but presented by [29] when identifying suitable sites for new landfills in the province of Kocaeli, Turkey, was the distance from areas considered sacred/religious, a factor that is not considered in other regions and/or continents, but which reflects local priorities. In addition, these authors highlighted the difficulty of obtaining a suitable area for the landfill, given that the region had 45% of its territory in forest areas, as well as being considered, at the time, the most industrialized area in Turkey.

On the other hand, the RSL identified a predominance of certain criteria listed in Figure 10, which include: distance from water resources; topographical characterization; and access and distance from population centers, with a recurrence rate of between 80% and 100%.

3.4. Main methods of Multicriteria Decision Analysis

Although this study used the term "AHP" in the strings to search for articles that used this method to choose areas for landfills, we observed the combination and application of other methods in conjunction with the AHP, such as Geographic Information Systems (GIS) to analyze and support

decision-making in the selection of areas for landfills. Studies such as those by [30–35] have highlighted the importance of GIS and the AHP method in solid waste management.

Approximately 53% of the selected studies used the AHP method and GIS as tools to aid decision-making when choosing an area to build a landfill, as it also requires the use of spatial data to produce maps that represent the most important criteria for choosing a site, as it is a complex process that involves various factors (socio-environmental, economic, cultural, etc.). In the other studies, these tools were combined with other methodologies, as shown in Table 9.

Table 9. Frequency of other tools combination with AHP, and SIG.

Tools combination with AHP, and SIG	Frequency	Autors
BO (sobreposição booleana)	1	Othman et al. (2021)
DEMATEL (Método de eliminação e aproximação por etapas)	1	Kharat et al. (2016)
FDM (Método Fuzzy Delphi)	1	Kharat et al. (2016)
Fuzzy	8	Felicori e Marques (2017); Pinheiro et al. (2021); Ajibade et al. (2019); Christian e Macwan (2016); Ali et al. (2021); Mousavi et al. (2022); Abdulhasan et al. (2019); Unal; Cilek; Guner (2020)
Fuzzy-AHP	6	Hanine; Boutkhoul; Tikniouine (2016); Islam; Kashem; Morshed (2020); Kharat et al. (2016); Pasalari et al. (2019); Elkharachy; Alhamami; Alyami (2023); Sener e Sener (2020)
MCE (Método de Avaliação e Classificação de Escolhas)	1	Majid e Mir (2021)
Método binário excessivamente (lógica booleana)	1	Dahwa; Mazhindu; Chirenje (2023)
Método booleano	2	Mousavi et al. (2022); Armanuos et al. (2023)
Método Fuzzy TODIM	1	Hanine; Boutkhoul; Tikniouine (2016)
Método Simos	1	Unal; Cilek; Guner (2020)
OFAT (One-Factor-at-a-Time)	1	Alhamami; Alyami (2023)
OWA (média ponderada ordenada)	1	Mousavi et al. (2022)
RSW (ponderação de escala de proporção)	2	Armanuos et al. (2023); Chabuk et al. (2019)
SAW (ponderação aditiva simples)	2	Chakuk et al. (2017); Karakus et al. (2020)
Sensoriamento remoto	6	Abdulhasan et al. (2019); Silva et al. (2022); Mohammedshum et al. (2014); Desta et al. (2023); Okot; Ogao; Bandu (2019); Netaji; Sekhar; Shankar (2019)
SRS (soma de classificação direta)	2	Armanuos et al. (2023); Alkaradaghi et al. (2019)
TOPSIS (Técnica para desempenho de pedidos por similaridade a uma solução ideal)	5	Ali et al. (2021); Khorsandi et al. (2019); Othman et al. (2021); Yal e Akgun (2013); Yal e Akgun (2014)
WLC (Combinação linear ponderada)	16	Felicori e Marques (2017); Pinheiro et al. (2021); Mousavi et al. (2022); Silva et al. (2022); Balew; Alelum; Feye (2022); Mussa e Suryabhagavan (2021); Asori et al. (2022); Mohamed; Asfaha; Wachemo (2023); Mvula; Mundike; Nguvulu (2023); Dahwa; Mazhindu; Chirenje (2023); Asif et al. (2020); Islam; Murshed; Hasan (2020);

Nayab e Quaff (2022); Ohri e Singh (2013); Titu-Eki e Kotta (2021); Ali et al. (2023)		
WPM (Método ponderado de produto)	1	Othman et al. (2021)
WSM (Método de soma ponderada)	1	Othman et al. (2021)

Figure 11 shows the frequency of occurrence of tools combined with AHP and GIS. Other Multicriteria Decision Analysis methods are widely used, including Weighted Linear Combination (WLC), mentioned in 16 articles; followed by the Fuzzy tool, with 8 articles, as well as Remote Sensing and Fuzzy-AHP, both mentioned in 6 articles.

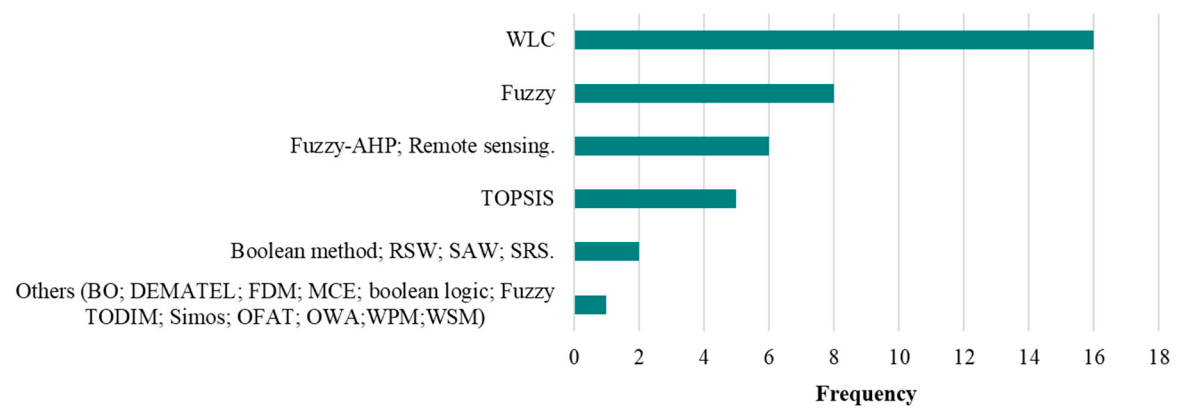


Figure 11. Frequency of methodology combinations with AHP and SIG.

4. Conclusions

The applicability of RSL proved to be a viable procedure for surveying and identifying the main Multicriteria Decision Analysis methods and criteria used to select areas for landfill sites in Brazil and other countries.

The ranking of the 10 criteria most used in the work was, in this order: distance from water resources; topographical characterization; access; geology and existing soil types; distance from population centers; land use and occupation; distance from protected areas/sensitive sites; climatological characterization; distance from airports and distance from railroads.

The criteria vary according to several factors, mainly the individual characteristics of each site, such as: climatic conditions; vegetation; topographical characterization; geology, among others. It should be noted that there are more specific criteria, which were not found in all the studies, as they differ according to the geographical reality of each region, such as: distance from earthquake epicenters; active volcanic areas; and even religious/sacred sites.

Regarding the use of the tools most used in the strategy for selecting areas for landfills, the results obtained from the RSL indicated that there is an integration of at least two tools, as in the case of studies that used the AHP method in conjunction with GIS. It should also be noted that other tools linked to AHP and GIS, such as Weighted Linear Combination (WLC), Fuzzy, Remote Sensing and Fuzzy-AHP are applied.

In this way, this study has shown that the application of tools such as GIS and AHP associated with the WLC method can be a good alternative for future studies, as it will show the spatialization of information and mapping of suitable areas, based on the most used criteria, resulting in viable and more effective solutions when choosing areas for landfills.

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