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REVIEW ARTICLE

# Comprehensive Review of the Landfill Site Selection Methodologies and Criteria

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**Abstract** | This paper presents a comprehensive review of the methodological frameworks and criteria used for municipal solid waste landfill selection. The review is based on 89 scientific papers published in peer reviewed journals from 1983 onwards. The descriptive statistical analyses of the reviewed papers consider temporal, location-based quantitative, and qualitative factors. The papers considered are classified by the country where the case studies were carried out, and the qualitative ranking is performed according to the number of citations. Afterwards, the employed methods and criteria for landfill site selection were extensively analyzed and classified. The summary of the conducted analyses shows that Geographical Information Systems (GIS), either as an individual technique or in combination with other approaches are extensively used. Weighted linear combination is the most frequently applied multi-criteria decision analysis method for ranking of alternatives. The analytical hierarchy process is the dominating method for weighting the criteria. A combination of GIS with Remote Sensing techniques is used in several landfill siting studies as a more appealing approach, due to the capability of real-time data updates. The evaluations of the landfill siting criteria indicate that the most frequent main criterion is environmental, followed by economic and social criteria, while the most preferred sub-criteria is distance to the surface waters. These findings and classifications are beneficial to both, the researchers and decision makers, while serving as a support to the complex and difficult process of real-world landfill site selection.

**Keywords:** *Landfill site selection, Methodology, Landfill siting criteria, Multicriteria decision analysis*

## 1 Introduction

Municipal solid waste (MSW) management remains one of the major problems in today's society. Commonly, many combinations of waste management practices like minimization of waste generation at source, reuse, recycling and material/energy recovery are employed. Nonetheless, there are still waste residuals that must be disposed on a landfill. Besides its position at the bottom of the hierarchy of integrated waste management options, landfilling has been the most commonly used method for solid waste disposal[1].

Landfills offer a relatively simple and affordable option for MSW disposal in carefully constructed and appropriately designed structures that protect the environment, and therefore, human health. Contemporary landfills are associated with number of tasks that need adequate managing in the phases of planning, design, operation and post-closure. Directive 1999/31/EC on the landfill of waste set by the European Commission, enforces strict regulations on planning, operation and monitoring of landfill sites, as well as, on post-closure maintenance for preventing

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or reducing negative impacts on the environment and on human health[2,3]. Although landfill design and management have significantly improved over the last decades, the historical mismanagement of open dumping practices resulting in many negative environmental impacts has provoked the public opposition. Hostovsky[4] presents a comprehensive literature linking planning theory and waste management, while researching the waste facility siting failures and the continued public opposition in the USA and Canada.

Selection of the most suitable location for a new landfill is one of the most critical tasks related to a MSW management system. The process is driven by many issues such as: multiple regional and state regulations, land availability, and various criteria related to economic and environmental health sectors[5,6]. The selected location must comply with the governmental regulation requirements and the assigned criteria for achieving the goals of minimizing the negative environmental impacts, public health risks, and landfill costs, all the while maximizing the level of service to the facility users[7].

Some prior studies have described landfill site selection as a two-stage process[8], or more general four-stage process[9]. The work of Chang et al.[8] includes preliminary identification of potential sites/areas through an initial screening procedure as a first stage. The second phase employs a detailed suitability assessment of the selected sites that meet the initial goals. This results in a ranked list of candidate sites and a summarized final selection. The four-stage landfill site selection process is illustrated in Fig. 1. In the first phase of landfill site selection, all areas in the studied region that are considered to be generally unsuitable for landfill siting (exclusionary areas) should be excluded. The leftover areas considered potentially suitable for a landfill are further compared through preliminary assessment process and reduced progressively to number of potential areas/sites based on the landfill siting selection criteria. The third phase includes detailed investigations like: bedrock type, hydrogeology, land use and other factors of local importance, engineering design, environmental impact assessment and landfill cost comparison, and assessment for the remaining short list of sites/areas to select the preferred site[9]. The final phase employs detailed design procedures, EIA licensing and construction.

The main objective of this paper is to provide a comprehensive review of the methodological frameworks and criteria performed in MSW landfill site selection analysis. The research provides a chronological survey of the landfill siting methodologies from the earliest records of published journal papers in electronic databases. The implemented methodology in this study consists of three phases: data collection (search of scientific papers), descriptive statistical analysis, and presentation of the results. The search for the most relevant scientific papers was performed in the electronic databases of the peer reviewed scientific journal publishers: Elsevier (https://www.elsevier.com), SpringerLink (https://link.springer.com/), ASCE (https://ascelibrary.org/journals), Sage journals (https://journals.sagepub.com/) and Taylor and Francis (https://www.tandfonline.com/). Afterwards, the Google-Scholar browser was extensively searched for additional papers and their citations. The search was performed from August 2020 to September 2020, without any filtering on the year of publication. The following general terms were used: landfill site selection, landfill siting and landfill allocating, in the title, abstract, and keywords of the papers. All recorded papers were subsequently filtered to those in English language and ordered according to their relevance, resulting in the final list of 89 scientific papers.

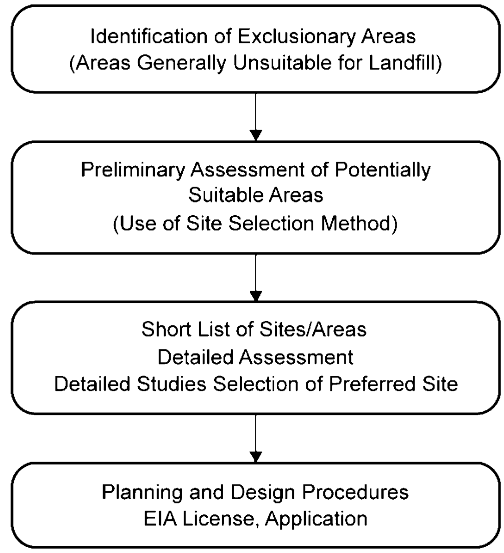


***Figure 1:*** Phases of landfill site selection process.

Existing related review papers, their methodology, and results, are evaluated to compare the differences. Demesouka et al.[10] present a review of the Geographical Information Systems (GIS)-based landfill suitability analysis using Multi Criteria Decision Analysis (MCDA) methods, based on research of 36 papers published in the

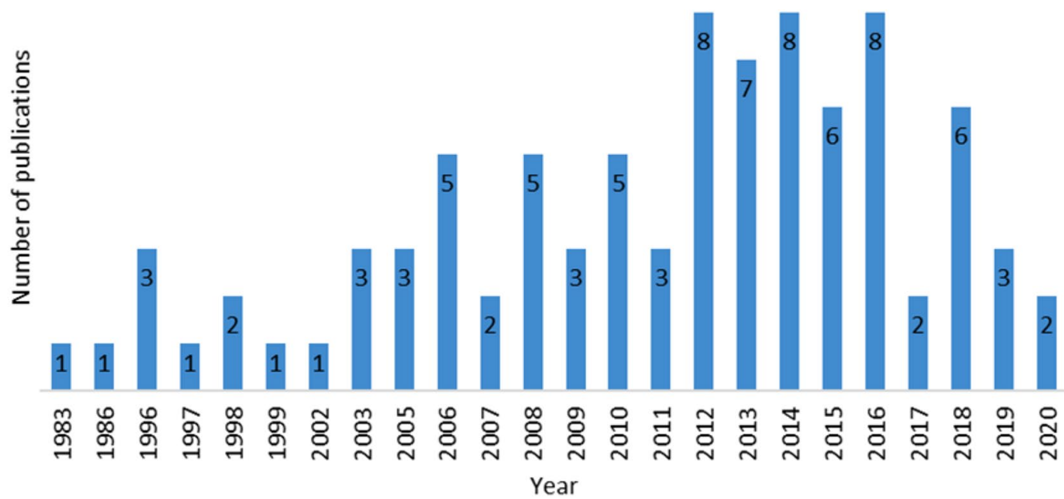


***Figure 2:*** Temporal distributions of scientific articles per year.

period between 2006 and 2013. They also include a detailed analysis of the landfill siting criteria classified into constraints, decision criteria, and decision criteria that consider the formation of constraint zones. Mat et al.[11] in their study increase the number of the researched papers to 82, published in the period from 2002 until 2016. They focus on the landfill site selection problem and the decision-making techniques in the phase of preliminary landfill site screening and the phase of assessment of site suitability. An up-to date comprehensive review by Özkan et al.[12] related to landfill site suitability analysis using GIS-based multi-criteria decision-making modeling, is based on analysis of 106 articles published between 2005 and 2019. They categorized the surveyed articles using the following criteria: used GIS software, application area, decisions under condition of certainty and uncertainty, applied multi-criteria decision-making model, sizes of the cells in GIS, and evaluation criteria. Compared to the related reviews, our study focuses on a comprehensive survey of all methods that have been implemented in landfill site selection.

## 2 Statistical Analyses

Figure 2 shows temporal distribution of publication of the 89 scientific articles since 1983. The sample of number of articles for the 2020 (current) year is not representative due to the timing of the databases search (July–November 2020). Based on the frequency of appearance, significant increase in research papers has been identified in the period from 2012 until 2017.

The authors of all reviewed papers propose a landfill siting methodology and conduct their research on a case study. Table 1 presents the country where the case study was carried out, and the frequency/total number of publications per country out of total number of identified 30 case study countries. Iran, Turkey, India, Greece and USA and are the top five countries rated according to the number of case studies per country representing 57.3% of total articles. However, Lin and Kao[13] use a hypothetical case study in their research.

The reviewed scientific papers were statistically analyzed and ranked according to their citations. The numbers of citations of each paper obtained by Google-scholar on 01 November 2020 were used as metrics for impact analysis. Table 2 presents the ten most popular scientific papers according to their citation by other studies. The paper researched by Chang et al. [8] is the most significant paper with total 667 citations.

## 3 Landfill Siting Methodologies

The earliest classification of methods for landfill site selection presented by McBean et al.[7] includes: Ad hoc, checklist, economic, cartographic, pairwise comparison, and matrix methods (descriptive and mathematical matrices).

Depending on the number of landfill parameters, Siddiqui et al.[14] categorize landfill siting processes in two general classes. The first one evaluates a single landfill parameter as in DRASTIC[15] and the Le Grand methods. The second class evaluates any number of parameters like interaction matrices, weighted ranking

**Table 1:** Countries and frequency of scientific articles publication considering landfill site selection problem.

| Case study country | Frequency | Authors |
|---|---|---|
| Brasil | 2 | [74,94] |
| Canada | 1 | [58] |
| China | 4 | [44,54,68,101] |
| Egypt | 1 | [1] |
| Ethiopia | 1 | [14] |
| Greece | 7 | [6,26,28,41,60,61,99] |
| Hong Kong | 1 | [22] |
| Hypothetical case study | 1 | [65] |
| India | 7 | [7,45,57,59,62,85,95] |
| Iran | 16 | [2,5,12,34–36,46,49,56,69,75,76,79,89,90,96] |
| Iraq | 2 | [18,19] |
| Italy | 4 | [13,24,39,42] |
| Jordan | 1 | [8] |
| Malaysia | 1 | [3] |
| Mexico | 1 | [25] |
| Morocco | 1 | [47] |
| North Macedonia | 2 | [30,43] |
| Northern Cyprus | 1 | [55] |
| Palestine | 1 | [32] |
| Serbia | 2 | [29,98] |
| Sierra Leone | 1 | [40] |
| South Korea | 1 | [64] |
| Spain | 1 | [107] |
| Taiwan | 3 | [23,53,66] |
| Thailand | 2 | [21,52] |
| Tunisia | 1 | [10] |
| Turkey | 15 | [4,15,17,31,33,51,77,86–88,93,97,103–105] |
| UK | 1 | [11] |
| United Arab Emirates | 1 | [9] |
| USA | 6 | [20,50,63,67,78,92] |

method, and GIS. Sharma and Reddy[16] define siting methodology depending on the type of the waste (hazardous or nonhazardous) to be disposed. Their proposed methodology for MSW landfills site selection includes: calculation of landfill acreage, review of local conditions, review of regulations (federal, state, local), generating maps and implementing map overlay procedure, identification of potential landfill sites and preliminary site investigation.

GIS methods and techniques have been increasingly used in planning and management processes because of their interdisciplinary character[6]. The advantages of GIS application like sophisticated spatial analyses and modeling have provoked many researchers to use it in the landfill site selection process. A total of 76 out of 89 reviewed scientific papers (85.4%) use GIS techniques in combination with other solution techniques in the landfill siting process. Additionally, the analysis of landfill suitability siting conducted by Delgado et al.[17] used only GIS as a technique in problem solving.

The scientific paper survey of Malczewski[18] illustrates the trends and advantages derived by the combination of GIS and MCDA methods in

***Table 2:*** Ten most popular scientific papers according to number of citations.

| Authors | Journal | Cited by |
|---|---|---|
| Chang et al.[20] | Journal of Environmental Management | 667 |
| Siddiqui et al.[92] | Journal of Environmental Engineering | 474 |
| Guiqin et al.[44] | Journal of Environmental Management | 444 |
| Şener et al.[86] | Environmental Geology | 418 |
| Sumathi et al.[95] | Waste Management | 390 |
| Kontos et al.[61] | Waste Management | 333 |
| Gorsevski et al.[43] | Waste Management | 327 |
| Şener et al.[87] | Waste Management | 325 |
| Nas et al.[77] | Environmental Monitoring and Assessment | 297 |
| Ekmekçioğlu et al.[31] | Waste Management | 240 |

alternative selection studies. The combination of GIS and MCDA presents an excellent analysis tool. The feasible alternatives, fulfilling all constraints, are identified either by use of exclusive constraints/criteria (Boolean constraints) or by meeting target constraints on all alternatives[19]. The exclusionary criteria/constraints are based on legal restrictions on landfill siting (the distance from the site to the residential and recreation areas, airports, water bodies, public drinking water sources, flood risk areas, cultural heritage, etc.) or physical impracticality (surface water bodies, national parks, etc.). Boolean constraints are implemented using GIS overlay operations and Boolean logic algebra. Feasible alternatives usually lie in the union (logical OR) where a single criterion is met or intersection (logical AND) where every criterion is met[6]. Subsequently, feasible alternatives are ranked using non exclusionary criteria based on recorded attributes on data maps.

A large number of articles consider the use of the combined GIS and MCDA approach in landfill site selection process[6,8,14,20–29]; etc.). Jensen and Christensen[30] illustrate a raster-based GIS application with Boolean overlay to identify potential sites for the storage of industrial wastes using constraint criteria, Lin and Kao[13] present a vector-based spatial model for landfill siting, while Vatalis and Manoliadis[31] use a two-stage multicriteria vector GIS approach for selecting a landfill site out of eight candidate sites. A comprehensive review on GIS-based (both raster and vector-driven analyses) solid waste landfill siting analysis using MCDA methods[10], indicates that depending on the geographical data model, the use of GIS raster is prevailing over GIS vector analysis. Our research analyses present that 59% of the 89 reviewed scientific papers use MCDA in the issues related to the landfill siting.

The weighted linear combination (WLC, or Simple Additive Weighting) method[32] is the most frequently used to rank alternatives in MCDA because of the simplicity of the additive weight model. In the WLC, the criteria are standardized for comparison on a common scale. Afterwards, weights are applied to the corresponding standardized criteria so that more significant criteria have a greater influence on the final solution. Assigned weights to each criterion allow a full compensation among evaluation criteria, whereas high criteria weights can compensate for low criteria scores. A total of 29 (33%) out of 89 reviewed scientific papers use WLC method to rank the alternatives. Khamehchiyan et al.[23] propose a combined GIS and MCDA methodology for hazardous landfill site selection in Zanjan province in Iran. Their approach is a two-stage process: the former is a primary selection of the suitable land and the latter are the field study and final site selection. This two-stage process solves the multi-criteria problem by implementing simple additive weighting method and evaluating the final suitability index.

In the WLC procedure, weight estimation is essential to an analysis. Commonly used methods for elicitation of criteria weights are equal weighting, ratio scale weighting and the Analytic Hierarchy Process (AHP). The AHP[33] enables decision makers to achieve a solution that best suits their multiple and diverse goals. It provides a hierarchical structure by reducing multiple criteria into pairwise comparisons that are then used to determine the relative importance of each decision criterion. Calculating weights is checked for consistency and therefore requires iterative revisions of the pairwise judgments due to their inconsistency. The AHP method also allows consideration of both qualitative and quantitative information in the decision makings. Siddiqui et al.[14] were among the first to combine GIS and AHP for landfill siting. They used spatial AHP method to identify and rank potential landfill areas for preliminary site assessment. Spatial AHP takes the advantage of GIS to manage and present spatial data and an AHP as decision-making method. There are many studies that take advantage of the AHP method to solve various landfill problems using GIS-based multi-criteria evaluation[1,9,20,21,34–36]. Mahini and Gholamalifard [1], assess the most suitable landfill sites in the Gorgan city region in Iran using WLC as multi-criteria evaluation method and GIS. They estimate relative importance of criteria weights using the AHP offering much flexibility in the decision-making process. Guiqin et al.[37] considered mostly economic factors in conjunction with calculated criteria weights from AHP to build a hierarchy model for solving the solid waste landfill site-selection problem in Beijing, China. Their methodology provides essential support for decision-makers through candidate sites expressed by the following linguistic terms: 'best', 'good' and 'unsuitable' landfill areas. The AHP is the most popular method for weighting the criteria. Less frequently, AHP is used for ranking the alternatives. The AHP method is used in 38 papers (43%) out of the 89 reviewed papers.

The analytic network process (ANP) as MCDA technique is also used for weighting the criteria. ANP is generalization of AHP, represented by a network, rather than a hierarchy[38]. The ANP is popular technique in landfill site selection that had been used in 4 out of 89 scientific papers in this review. ANP is applied in different studies by Afzali et al.[39], Banar et al. [40], Hamzeh et al.[41] and Ferretti [42] for weighting the criteria and ranking the alternatives.

A common computational framework that is used by various authors combines the AHP and the fuzzy set theory. Fuzzy set theory[43] was designed to deal with the uncertainties of the real phenomena and to solve vague problems which occur during the analysis and the decision process. The fuzzy-AHP has been also used in landfill site selection[9,21,34,35,44–47]. Nazari et al.[9] develop a methodology and a computer model for ranking and selecting a landfill site using fuzzy AHP-based multiple attribute decision-making method. They propose a model for the second phase of landfill site selection process consisted of AHP for assigning global weights to the decision criteria and fuzzy-AHP method for setting preference order of the alternatives. The basic advantage of their program is the use of linguistic terms that leads to simplicity of the program application.

Chang et al.[8] implemented two-stage analysis for final landfill site assessment to form a spatial decision support system for waste management in a fast-growing urban region in south Texas. The first stage uses thematic maps in GIS for initial screening of unsuitable land, followed by the second stage that uses the fuzzy multi-criteria decision-making method to identify the most suitable site using the expert knowledge. The expert knowledge involved the use of a questionnaire survey with linguistic variables, which are converted to fuzzy numbers for rating expert's opinions for multiple candidate sites.

Fuzzy TOPSIS was employed by Ekmekçioğlu et al.[48] for the evaluation of appropriate disposal method and alternative site for MSW employing uncertainty in the decision-making process. Kharat et al.[46] integrate fuzzy AHP with fuzzy TOPSIS for landfill site selection problem for the Mumbai city. They use fuzzy AHP to make pairwise comparisons and assign weights to the criteria and fuzzy TOPSIS to evaluate the alternatives, enhancing the accuracy of the landfill site selection procedure. Beskese et al.[44] implement the same integrated fussy AHP and fuzzy TOPSIS technique in selecting a landfill site for the city of Istanbul.

A recently developed approach, the Ordered Weighted Average (OWA)[49] is another multi-criteria decision technique analogous to WLC. It considers two sets of weights: the first set are global weights representing the relative importance of specific criterion, while the second set controls the order of the aggregation of the weighted criteria. OWA technique is implemented for selection of a new landfill site and is cited in five reviewed papers (5.6%)[6,21,50–52]. The aim of the OWA approach is not to find the most preferable solution, but to show other strengths associated with the weighting flexibility of the OWA[6].

Remote Sensing (RS) as a technique enables processing of surface images of the Earth using satellite data and monitoring of natural and human induced changes of the Earth's surface. A number of integrated GIS methods combined with RS have been used to evaluate suitable landfill locations. Alexakis and Sarris[53] combined GIS and fuzzy multi-criteria decision analysis in combination with AHP method in their study of a landfill site selection. They also used satellite RS images to calculate vegetation index and incorporate the vegetation map to the GIS landfill risk assessment model. Abd-El Monsef and Smith[54] and Şener et al.[36] practiced the same approach of combining GIS and RS to prepare a geospatial database, and AHP to rank the alternatives. The advantage of the combination of GIS and RS techniques is that the data can be regularly updated by the real-time data retrieved from a satellite. Nowadays, these integrated techniques are becoming more popular in landfill siting preliminary studies due to their ability to manage large volume of spatial data from a variety of sources[36].

Compromise programming, as well-known MCDA method, has been implemented by Vatalis and Manoliadis[31] in selecting a landfill site out of eight alternative sites. Demesouka et al.[55] use a combination of AHP and compromise programming method in GIS raster-driven analysis for selection of landfill location in Northeastern Greece.

Apart from the integrated techniques mentioned above, other authors also combine several methods to solve landfill siting problem. Gupta et al.[35] implement fuzzy logic in the environmental impact assessment of landfill siting, therefore including uncertainty and future impacts into the assessment. Chau[56] integrated heuristic and empirical knowledge into a decision support system for landfill site selection considering only risk criteria. Hamzeh et al.[41] integrate Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) II and ANP to identify land suitability for landfilling. Demesouka et al. [57] implement Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) method in GIS raster-driven analysis of potential landfill site in the region of Northeastern Greece. Comparing the results with other well-known methods, the research discovered that implementation of MACBETH method provides trustworthy results. Liu et al.[58] propose hierarchy multi-criteria decision model based on fuzzy set theory and VIKOR (VIsekriteriumska optimizacija i KOmpromsino Resenje) method for MSW site selection problem for the city of Shanghai, China. VIKOR is MCDA method developed by Opricovic to solve complex decision problems requiring many conflicting and noncommensurable (different units) criteria[59]. The selection of the 'compromise' solution, the closest solution to the ideal, is based on evaluation of the alternatives according to the determined criteria. Santhosh and Sivakumar Babu[60] implement novel method combining DRASTIC method for assessment of groundwater vulnerability to contamination of existing landfill sites with AHP and GIS tools in selecting reliable landfill locations. Reliability maps of the case study area of Bengaluru city presenting probability of low, moderate and high suitability zones are used in assessment of the total suitable area for landfills.

Geneletti[22] employed a method based on the combination of stakeholder analysis and spatial multicriteria evaluation for inert landfill site selection in the Sarca's Plain, Italy. Stakeholder analysis is carried out for identification of criteria and aggregated through multi-criteria analysis techniques to obtain a suitability map of the study region. The sensitivity analyses performed on the results were intended to help with the assessment of the ranking stability, with respect to variations in the criteria inputs from the stakeholders.

## 4 Landfill Site Selection Criteria

Numerous and different sets of criteria are commonly used in the site assessment process for landfill location selection. In general, two types of criteria are employed according to their role in the decision-making process: exclusionary, and non-exclusionary criteria[14]. The exclusionary criteria or constraints are considered as crucial, employed during a preliminary screening process to exclude the unsuitable areas from further consideration. Constraints prohibit landfill siting in areas that do not fulfill legal restrictions on landfill siting like: the distance from the site to the sanitary protection zones around public water supply, waterways and water bodies, cultural heritage, airports, national parks and other protected natural zones, boundary of the residential and the recreation areas, flood risk areas, etc. Constraints are also based on physical impracticality of some areas as landfill location like: surface water bodies, national parks and protected areas, faults, land with urban and rural settlements, and transportation infrastructure. In GIS environment, unsuitable areas are excluded using Boolean logic algebra.

The non-exclusionary criteria are employed to rank the remaining suitable areas and choose the potential landfill location candidate. Some researchers select the suitable alternative after aggregating non-exclusionary criteria that are weighed. Ranking of suitable areas involves consideration of non-exclusionary criteria that might be not easily measurable or be incommensurable (criteria are measured on different scales). Sometimes, expert knowledge is employed in criteria measurement contributing to a certain degree of imprecision and uncertainty in criteria values. Aggregation of incommensurable criteria requires data standardization to transform

*Table 3:* The 20 most used sub-criteria and their frequency.

| Criteria | Frequency | Criteria | Frequency |
|---|---|---|---|
| Distance to surface water (river) | 26 | Distance to public water supply | 12 |
| Distance to urban area/rural area | 25 | Altitude/elevation | 11 |
| Distance to road | 23 | Distance to wetlands/swamp | 10 |
| Slope/morphology | 22 | Distance to waste production/generation centers | 10 |
| Distance to surface water (lake) | 20 | Distance to faults/seismic risk | 10 |
| Depth to water table/aquifer | 19 | Wind direction/site orientation | 10 |
| Hydrogeology | 14 | Distance to archaeological sites/cultural areas | 9 |
| Distance to sensitive ecosystems/ natural protected areas | 13 | Agricultural land (high class) | 8 |
| Land use | 13 | Distance to airport runway | 7 |
| Soil types/ | 13 | Geology | 6 |

and rescale the original criteria into comparable units[6]. Fuzzy set theory is commonly employed for criteria standardization as a primary aim. Application of fuzzy theory is also very popular for criteria standardization for its capability of managing uncertainty and imprecision in data. Our research takes into consideration landfill siting criteria in all reviewed papers. The summary of the conducted analyses indicates that there are two different approaches in the selection process from the aspect of the number of categories according to the hierarchical levels of the criteria used by the researchers. The first one represents the cases when all considered criteria belong to one group. The second approach includes two levels of criteria according to their hierarchy: (a) main criteria/group of criteria, including all criteria aiming to fulfill particular objective like environmental, social, economic and (b) sub-criteria/ factors including solely the non-exclusionary criteria (slope and elevation of the terrain, hydrogeology, distance from rivers and distance from lakes, distance form springs, land use, distance to settlements, distance from faults, etc.).

The summary of the statistical analyses of siting criteria refers to the 30 most popular scientific papers according to the number of citations. Main criteria and sub-criteria are analyzed according to their frequency of occurrence. Among the totally 21 different main criteria that have been observed, the 5 most popular are: *environmental*[6,8,20,24,27,29,37,44,50,55,61–66], *economic*[6,8,20,24,27,34,37,44,48,50,55,61–64,66,67], *social*[24,28,29,34,36,50,61–64,66,67], *hydrogeology*[14,21,24,26,28,34,36,44,48,55,66,68] and *topographical/ morphological*[26,36,44,48,55,69].

It is observed that there is no strict division of main criteria and sub-criteria in some articles[8,26,48,69]. Some criteria like land-use, for instance, is used as main criteria/criteria[14,26,48,68] in several articles, while in other is used as a sub-criteria[6,20,21,24,27,28,36,44,55,63–66].

Sub-criteria analysis indicate there are totally 45 different sub-criteria cited by the authors of the top 30 papers. Due to numerous and diverse results of the sub-criteria, some criteria with similar meaning are combined. For example, the distance to mineral resources (non-ferrous metals) used by Vasiljević, et al.[66] and distance to quarries used by De Feo and De Gisi[62] are considered as one sub-criterion. Subsequently, the sub-criteria were ranked according to their frequency of occurrence and the most popular 20 criteria are presented in Table 3. It can be observed that almost all papers focus on distance to surface water (rivers and lakes), distance to settlements (urban and rural areas), distance to roads, slope of the terrain, distance to ground water level, hydrogeology, distance to natural protected areas/ sensitive ecosystems, distance to public water supply and land use.

The selection of the criteria in each research depends on the particular site characteristics like: proximity to state borders, costal area, faults, railway, pipeline, airport, public water supply, etc. An analysis of the most frequently used criteria indicates that the criteria 'distance to surface water (rivers)' is used in 86.6% of the reviewed papers. In some papers, this sub-criterion is presented like 'distance to surface water', some authors are specifying the term 'surface water' by: 'river', or 'lake' or 'wetland/swamp'. However, all these terms are considered as one sub-criteria. The second most frequently used sub-criterion is 'distance to urban area/rural area/public utilities', used in 83.3% of the reviewed papers, followed by 'distance to road' with 76.7% and 'slope/morphology' sub-criterion with 73.3%.

Only 2, out of 30 reviewed papers regarding siting criteria, include sub-criteria related to 'community/public acceptance' of the landfill site[50,61]. More information and extensive discussion related to analysis of landfill siting criteria, criteria classification and threshold values are presented by Demesouka et al.[10] and Özkan et al.[12].

## 5 Conclusions

This study presents a comprehensive review of the methodologies and criteria for MSW landfill site selection employed in scientific papers that were published between 1983 and 2020. The research provides a chronological survey of all landfill siting methodologies and criteria used in landfill site selection.

Statistical analysis of the reviewed papers indicates significant increase in published papers in the period between 2012 and 2017. Considering the country of case study application: Iran, Turkey, India, Greece and the USA are the top five countries rated according to the number of case studies per country.

Based on the conducted review, it is observed that the GIS either as an individual technique or combined with other approaches has been used by huge majority of the researchers (85.4%). The WLC method is extensively used method to rank alternatives in MCDA by 33% of the authors, while OWA as recently developed research is applied by several authors (5.6%). Equal weighting, ratio scale weighting and the AHP are commonly used methods for elicitation of criteria weights. The AHP is the most frequently used multi-criteria decision method for weighting the criteria (applied by 43% of the researchers), while its application for ranking the alternatives is insignificant. The ANP as MCDA technique is popular for weighting the criteria and ranking the alternatives as well. A combination of GIS with RS is used in several landfill siting studies, as a more appealing approach due to the capability to manage large volume of diverse spatial data.

Among the main criteria/group of criteria, five groups of main criteria are identified as the most popular in landfill site selection: environmental, economic, social, hydrogeology and topographical/morphological. Distance to surface water (rivers) is the most preferred sub-criteria, followed by distance to urban area/rural area and distance to roads criteria. Since selecting a site for a landfill depends on public and political opinion in conjunction with engineering and technical protocols, the reviewed papers were searched for criteria related to acceptance of the local population. This paper recognizes the lack of papers considering public acceptance and risk assessment as criteria /sub-criteria in landfill site selection process.

In summary, the present review of the landfill siting methodologies and criteria is beneficial to the researchers and engineers for providing directions for future research and modelling. The review facilitates a better understanding of landfill site selection methods and supports the complexity and difficulty of decision-making in real-world landfill site selection problems.

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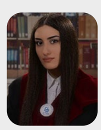

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