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# A review on criteria and decision-making techniques in solving landfill site selection problems

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Nur Azriati Mat[1,*], Aida Mauziah Benjamin[1], Syariza Abdul-Rahman[1]

[1] Department of Decision Science, School of Quantitative Sciences, Universiti Utara Malaysia, 06010 Sintok, Kedah, Malaysia

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**ABSTRACT**

The selection of landfill, which happens to be an environmental issue, has attracted the attention of many researchers from the fields of waste management and environmental sciences worldwide. Hence, in the attempt to overcome this problem, some decision-making techniques, including Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA), have been widely utilized in prior studies, where multiple criteria, particularly in site selection process, have been employed. With that, this article identifies the selection criteria for landfill selection and presents a review concerning decision-making techniques that have been used in past studies for two important phases involved during the process of site selection, namely, (1) preliminary site screening, and (2) assessment of site suitability. As such, some 82 articles chosen from 34 peer-reviewed journals had been investigated in detail. The results showed that 42.68% of the selected articles integrated GIS and MCDA techniques to solve the problem of landfill site selection, and this is followed by integrating GIS and fuzzy MCDA technique (18.29%). Both these techniques are indeed powerful tools that can guide decision-makers to solve problems in making decisions on the basis of various criteria under certainty and uncertainty results, mainly involving environmental issues.

***Keywords:***
Landfill site selection, landfill siting, GIS, MCDA, selection criteria



## 1. Introduction

Solid waste management (SWM) refers to all activities that manage solid waste beginning from its generation source to its disposal. These activities can be classified into six operational elements, which are (1) waste generation, (2) waste handling and separation, storage, and processing at the source, (3) collection, (4) separation and processing, and transformation of solid wastes, (5) transfer and transport, as well as (6) disposal [1]. Moreover, studies pertaining to SWM issues are increasingly being carried out based on real life applications. Some instances of such researches are estimation of solid waste generation rate [2, 3], waste collection vehicle routing problem [4, 5], solid waste composition [6, 7], use of recycled plastic in concrete [8], incinerator ashes detoxification [9], electronic waste management [10], and construction waste management [11]. Nevertheless, this

* *Corresponding author.*
*E-mail address: Nur Azriati Mat (nur_azriati@ahsgs.uum.edu.my)*

review only focused on the last operational element, which is disposal, as the final destination of all solid wastes. Besides, various methods are available at this present time in SWM to manage and to dispose solid wastes, such as landfilling, thermal treatment, biological treatment, and recycling [12, 13]. Of these methods, landfilling appears to be the most common approach widely used to dispose solid wastes in many nations worldwide [14–16].

In fact, managing and planning of SWM are some of the most challenging tasks worldwide and they have become part of vital environmental issues in developing and fast growing countries, primarily due to rapidly developing areas and uncontrolled population growth. As a consequence, this fast population growth has led to the vast amount of solid wastes into the environment, along with the high probability of pollution to occur. Upon considering the fast population growth rate, these landfills have to sustain the needs of waste disposal [17] so as to accommodate excess wastes that cannot be accommodated by the present landfills. Furthermore, in the SWM system, the trickiest steps in solid waste planning refer to the identification of the most suitable or an optimal landfill site. This is, in fact, a complex, tedious, and time-consuming process that demands assessment of several factors with varying characteristics [15, 18, 19] for the decision-making process.

In addition, some prior studies have suggested that the process of selecting a landfill site is comprised of two main steps, which are: (1) the identification of potential locations via preliminary screening, and (2) the evaluation of landfill suitability in regard to environmental, economic, engineering, and cost constraints [20]. Apart from that, [19] described that the landfill site selection process is carried out in four main phases, which are: (1) the identification of candidate sites via preliminary screening based on exclusionary criteria, (2) the evaluation of candidate sites based on attributes and ranking, where suitable sites are selected and identified, (3) the evaluation of site suitability based on environmental impact assessment, economic feasibility, engineering design, and cost comparison, and lastly, (4) the selection of the best site in the final phase.

Upon determining a new location to construct a landfill site, several significant criteria have to be considered, such as social, environmental, technical, financial [21, 22], and government regulations aspects [21]. This is because; improper planning can lead to a negative impact on economic, ecological, and environmental health elements [23, 24]. Furthermore, previous studies have suggested that the construction of a new landfill must fulfil the requirements and regulations outlined by the government so as to reduce economic, environmental, health, and social costs [25]. This is of utmost significance to avoid adverse effects upon the surrounding communities. For instance, determining a new location for landfill development at a minimum cost is indeed possible, but some important aspects might need to be sacrificed; thus could badly affect the condition of the landfill in near future and could only function within short period [26]. Therefore, opinions from experts in particular areas, such as engineers, geographers, geologists, sociologists, and economists, are required in the selection process.

Nevertheless, landfill site selection has become more intricate when the decisions made are often opposed from the society [27], for example, the “not in my backyard (NIMBY)”, “not in anyone’s backyard (NIABY)” [18], [28–30], “not in my neighbour’s backyard (NIMNBY)”, and “build absolutely nothing anywhere near anyone (BANANA)” notions [29, 30]. Such phenomena have turned into trending issues, thus imposing high pressure on the decision makers involved in the landfill site selection process.

Furthermore, various decision-making techniques have been depicted in the literature to address issues related to landfill site selection, for example, GIS [15], MCDA [31], heuristic [32], integer linear programming [26], and fuzzy [33]. Besides, a total of 82 selected published articles had been selected from 34 peer-reviewed journals in this review.

As such, the main objective of this paper is to review the selection criteria and the techniques depicted in the literature for landfill site selection phases: (1) preliminary site screening, and (2) landfill suitability assessment. The rest of this paper is organized as follows: landfill site selection criteria, followed by the techniques used for preliminary site screening, as well as landfill suitability assessment, and a discussion on the present trends of landfill site selection. Lastly, this paper ends with a conclusion.

## 2. Landfill Site Selection Criteria

A criterion refers to the basis of a decision that can be measured and evaluated [34]. Moreover, two types of criteria are usually considered in the process of selecting a landfill site, which are: (1) exclusionary criteria, and (2) non-exclusionary criteria. These selection criteria can be retrieved from literature review, experts via questionnaire survey or interview, and guidelines prepared by the local government [35].

On top of that, the exclusionary criteria or also commonly known as constraints (denoted as C in the following table) refers to the criteria for selecting a landfill site. Besides, a constraint serves to limit the alternatives in the research area and can be further categorized into two classes; where unsuitable areas are given a value of 0, while suitable areas are given a value of 1 [34, 36]. This type of criteria is usually utilized in the preliminary site screening process phase in order to gather several potential candidate locations for further analysis in determining a viable landfill.

Meanwhile, the non-exclusionary criteria (denoted as F in the following table) are used to perform further analysis on the potential candidate alternative, in choosing the best site. Nonetheless, the suitable alternative may be reduced after these criteria are weighed in [34, 36]. Hence, this type of criteria is used in the landfill suitability assessment to identify the best and the most suitable location for landfill siting. In this paper, the landfill site selection criteria had been identified from 82 selected published articles. As a whole, a total of 201 sub-criteria had been considered to be classified under the exclusionary criteria/constraints and the non-exclusionary criteria/factors.

**Table 1**
List of Landfill Site Selection Criteria based on the frequency used in the literature

| Constraint/Factor | Category | Total Citation |
|---|---|---|
| Accessibility (roads network) | C/F | 66 |
| Slope | C/F | 53 |
| Land use/Adjacent land use | C/F | 51 |
| Heritage/Archaeological/ Protected/ Sensitive/ Historic/Cultural/Scenic/ Religious/ Tourism sites/Aesthetics/ Natural monuments/Parks/ Recreation sites | C/F | 44 |
| Ground water table/depth | C/F | 43 |
| Geology/Lithology | C/F | 35 |
| Surface water | C/F | 32 |
| Urban/Rural/City/Town | C/F | 31 |
| Airport/Flight paths | C/F | 29 |
| Residential areas/habitat/dwelling | C/F | 27 |

Table 1 presents the list of the most important criteria highlighted in prior studies for the process of selecting a landfill. More details can be obtained from the appendix that portrays the complete list of landfill site selection criteria with references.

Based on the reviews, the most frequently used landfill selection criterion had been accessibility. Accessibility or road network appeared to be the most important criterion in the landfill site selection process. In fact, this criterion is taken into account beginning from the screening process until the evaluation process to choose the most appropriate site to be used as a landfill. Next, the second frequently used selection criterion was slope and followed by land use. The slope should be considered to prevent the occurrence of leachate contamination at the landfill site. Other than that, land that lacks benefit to the country or with low economic values also is a popular criterion for landfill siting.

Other than that, land cost seemed to be an important economic criterion in selecting a new landfill site. The land price, hence, has always been a constraint in selecting a new landfill site [37]. Besides, land price heavily depends on the population of an area and the distance to the main road from that area. The central business district, or also called as the expensive area, is given a lower price, thus unsuitable for landfill siting. Meanwhile, the expensive price is given to suburban areas, where these areas are highly suitable for the construction of a landfill. Moreover, the potential areas for landfill siting, also, should not be too far from the waste production centres so as to reduce the distance travelled by the trucks from the collection points to the landfill site. In fact, the transportation cost can be reduced if waste production centres are considered in landfill site selection process [38]. Other than that, areas with less rainfall is another criterion that must be emphasized while selecting landfill site [39]. Groundwater quality is also an essential technical element for it functions as an alternative source of drinking water [40, 41]. Besides, more information pertaining to landfill siting analysis criteria can be referred to the article published by [42].

## 3. Preliminary Site Screening Techniques

Preliminary site screening refers to the process of eliminating unsuitable areas, while maintaining the potential areas to construct disposal sites for further evaluation process [20]. As such, several techniques have been portrayed in the literature to carry out the preliminary site screening phase. Some instances of such techniques are given in Table 2.

**Table 2**
The summary of techniques used for preliminary site screening

| Techniques | Total Articles | Percentage (%) |
|---|---|---|
| GIS | 58 | 70.73 |
| Integrated GIS and RS | 4 | 4.88 |
| Other preliminary screening techniques | 2 | 2.44 |
| Researches without preliminary site screening | 18 | 21.95 |
| | 82 | |

GIS: Geographic information systems;
RS: Remote sensing

### *3.1 Geographic Information Systems (GIS)*

GIS is an important tool that identifies the most suitable sites for landfill siting. Besides, using GIS for landfill siting does not only give a positive impact to cost and time management, but also affords a digital data bank for long-term site monitoring. Moreover, GIS has the ability in maintaining account data to facilitate collection operation, to provide customer service, to analyse optimal locations for transfer stations, to plan routes for vehicles transporting wastes to transfer stations and from transfer stations to landfills, as well as to monitor long-term landfill. Furthermore, the advantages of utilizing GIS for the landfill siting process include [43]:

- Selection of objective zone exclusion process based on the set of screening criteria provided.
- Zoning and buffering.
- Performing ‘what if’ data analysis and investigating various potential scenarios related to population growth and area development, besides ascertaining the importance of the various influencing factors.
- Handling and correlating large amounts of complex geographical data.
- Visualization of the results through graphical representation.

As such, the advantages of GIS have attracted many researchers to further look into the fields of solid waste disposal and landfill site selection. In addition, based on the reviews, a total of 62 out of 82 articles (75.61%) utilized GIS to solve issues related to landfill site selection. Other than that, 6 articles used GIS as the sole technique to solve the problem. Furthermore, a GIS-based decision approach was proposed to identify the best locations for landfill [44]. In fact, the selection process is comprised of two stages, which are: 1) exclusionary analysis, as well as 2) site evaluation and ranking. The obtained final score and ranking had been based on the evaluation of criteria compliance priority. Moreover, both stages were examined using the GIS itself, which relied on the capabilities of the GIS. Furthermore, several GIS-based inter-disciplinary approaches, such as Boolean logic, binary evidence, and overlapping index, had been suggested for sanitary landfill siting in the Cuitzeo Lake Basin located at Mexico [45]. Meanwhile, the integrated GIS and landfill susceptibility zonation approach was employed to identify a suitable location for hazardous Khorasan Razavi province located in North Eastern Iran [46]. In fact, the site selection process was conducted in three stages; 1) exclusion of restricted areas, 2) preparation of landfill zonation map, and 3) landfill suitability assessment based on economic and environmental impacts.

In addition, suitable locations should be examined by varied evaluation techniques and the most suitable site should be identified based on the solutions [16]. As such, they utilized the raster-based GIS approach to address the landfill site selection problem, where the results showed that the proposed approach gave more effective solutions, when compared to traditional methods. Other than that, the GIS analysis was employed to select a suitable location for the construction of the treatment site, as well as disposal and recycling centres, located in the Markavi province, Iran [47]. Furthermore, the landfill site selection and assessment processes for Çorlu District at Turkey had been carried out by integrating the point count index and constraining overlaying using the GIS approach [15].

On top of that, 52 articles have combined GIS with other solution techniques to address issues related of landfill site selection, as shown in Table 3.

All these articles employed the GIS methods to identify suitable candidate sites for the construction of a new landfill. Next, the proposed candidate sites were further evaluated by using specific methods to rank or to identify the best location for landfill siting.

**Table 3**
The summary of GIS and its integration techniques in solving landfill site selection issues

| GIS and its integration techniques | References |
|---|---|
| GIS | [15], [16], [44–47] |
| GIS + MCDA | [12], [17], [21], [22], [34], [35], [38], [39], [43], [48–73] |
| GIS + Fuzzy | [74] |
| GIS + Heuristic | [32] |
| GIS + Fuzzy + MCDA | [18], [19], [23], [24], [36], [37], [75–83] |

### *3.2 Integrated GIS and Remote Sensing*

Remote sensing (RS) is a geographical tool that is usually used to measure the properties of object on the surface of the earth using data retrieved from aircraft and satellites. This technique can also process images and monitor both long- and short-term changes that take place on the Earth resulting from human activities [84]. In solving the landfill site selection problem, 4 articles were identified from the literature, which combined GIS with RS. These integrated techniques have turned into powerful tools for preliminary studies due to their ability in handling massive volumes of spatial data from a diversity of sources [13, 85]. Moreover, GIS supported by RS technology had been used to observe the effects of landfill sites upon the environment through the use of satellite image processing of the landscape, mainly to identify the suitable locations for landfill siting in the surrounding area [86]. Furthermore, the combination of GIS and RS provides an outstanding framework for data capture, storage, synthesis, analysis, and display [87]. Moreover, GIS data can be updated regularly to imitate the real-time changes that take place in attributes within the study area.

### *3.3 Other Preliminary Site Screening Techniques*

Several suitable candidate sites had been identified by using the site screening approach via overlayer technique [14]. In their study, the overlayer procedure was performed manually, where the criteria maps (climate, transportation, earthquake, erosion, topography, land use, and geology) were drawn on transparent film and superimposed on each other to obtain the final composite map. Meanwhile, both exclusionary and preferential area mapping techniques were applied for the preliminary site identification process [88], which had been carried out with three steps, which are (1) sites presentation for technical facilities on maps, (2) narrowing down the potential areas until the actual location is determined, and (3) sites documentation based on the specialist maps.

### *3.4 Researches without Preliminary Site Screening*

From the reviews that had been carried out, a number of articles did not include the screening process to obtain potential locations for landfill siting. The candidate alternative sites, nonetheless, were provided by the authorities. For example, the site evaluation process was performed by using the data of candidate sites provided by the local authority at the area [89, 90, 31].

## 4. Techniques in the Landfill Suitability Assessment

Due to the complexity of landfill site selection issue that involved various quantitative and qualitative types of data, more than half of the selected articles reviewed in this paper integrated multiple techniques for the landfill suitability assessment process. Hence, these techniques were classified into two groups: (1) decision-making techniques under certainty environment, and (2) decision-making techniques under uncertainty environment. Table 4 indicates the summary of techniques used in past studies since 2002 until 2016 for both types of environments.

**Table 4**
The summary of techniques used in landfill suitability assessment process under certainty and uncertainty environments

| Techniques | Total articles | Percentage (%) |
|---|---|---|
| Decision-making techniques under certainty environment | | |
| AHP* | 19 | 23.17 |
| ANP | 3 | 3.66 |
| SAW/WLC | 5 | 6.10 |
| Integrated AHP | 15 | 18.29 |
| Integrated ANP | 2 | 2.44 |
| Other integrated MCDA techniques | 1 | 1.22 |
| Other decision-making techniques | 2 | 2.44 |
| Decision-making techniques under uncertainty environment | | |
| Integrated fuzzy AHP | 15 | 18.29 |
| Integrated fuzzy ANP | 3 | 3.66 |
| Integrated fuzzy TOPSIS | 3 | 3.66 |
| Integrated fuzzy VIKOR | 2 | 2.44 |
| Other integrated fuzzy techniques | 5 | 6.10 |
| Researches without landfill suitability assessment phase | 7 | 8.53 |
| | 82 | |

*AHP: Analytic hierarchy process; ANP: Analytic network process; SAW: Simple additive weighting; WLC: Weighted linear combination

### *4.1 Decision-Making Techniques under Certainty Environment*

Decisions made under certainty depend on the availability of some vital information. If the decision maker has complete information regarding a sticky situation, the decision can be said to have been made under certainty [91]. Besides, various techniques have been applied in the literature to address issues related to landfill site selection decision under certainty environment. Some instances of such techniques are AHP, ANP, SAW, and WLC as depicted in the following section.

#### *4.1.1 Analytic hierarchy process (AHP)*

AHP was first developed by Thomas L. Saaty in the 1970s. AHP refers to a structured method that is capable in handling a complex decision problem. In AHP, the decision problem is converted into a simpler decision problem to form a decision hierarchy. When constructing a hierarchy, the top level is the final goal, which refers to the landfill site selection. Upon completing the conversion stage, the fundamental ranking for criteria is determined by using pairwise comparison [66]. Pairwise comparison is performed among the criteria to determine the relative significance of each criterion. Next, a comparison matrix of the criteria was developed, in which the eigenvectors were calculated to represent the ranking of the criteria. In calculating the ratings linked to each criterion, a pairwise comparison of alternatives by each criterion had been carried out. Besides, by comparing the matrix between alternatives and information about the ranking criteria, the AHP could generate an overall ranking of the solutions. This alternative with the highest eigenvector value was considered as the first option [43].

In addition, based on the review carried out, 19 out of 34 articles applied the AHP as the sole technique for suitability assessment under certainty decision-making environment ([13], [39], [43], [49], [51], [57], [58], [62]–[64], [67], [69]–[72], [85], [88], [92], [93]). Other than that, the remaining 15 articles integrated AHP with other decision-making techniques, such as SAW [12] [22] [48] [52]–[54] [60] [66], TOPSIS [17] [38], weighted sum model [68], analytic network process [30], weighted linear combination [35], and Delphi [87].

#### *4.1.2 Analytic network process (ANP)*

ANP denotes the generalization of AHP, which deals with dependencies or also known as feedback network. The purpose of ANP is to model a decision problem in a network form. Hence, ANP establishes the relationship that arises between certain elements, such as alternatives, criteria, sub-criteria, and goal [94]. Moreover, as in AHP, ANP also ranks the alternatives beginning from the most important to the least important based on decision maker preferences [90]. Besides, based on this comprehensive review, ANP appeared to be the third popular MCDA technique that has been widely used in solving landfill site selection issues. Moreover, ANP had been employed to identify the most appropriate site for landfill siting, where each candidate site was assessed based on benefits, opportunity, cost, and risk (BOCR) analysis [31] [55] [90]. Furthermore, the combination of ANP-BOCR approach makes the decision-making process more traceable and reliable [31]. This also aids the decision makers to move forward in sharing and justifying the decisions.

#### *4.1.3 Simple additive weighting (SAW) / Weighted linear combination (WLC)*

The SAW method is the simplest and a widely used technique that handles spatial multi attribute decision-making problems. In the literature, this method is also known as weighted linear combination or scoring method. This method was introduced based on the concept of a weighted average, where the decision makers would need to allocate weightage for each attribute based on their “relative importance”. Next, a total score is obtained for each alternative by multiplying the important weight assigned for each attribute by the scaled value, given to the alternative on that attribute, and summing the products over all attributes. After that, the alternative with the highest overall score is selected. Formally, the decision rule evaluates each alternative $A_i$, by the following formula:

$$A_i = \sum_j w_j x_{ij} \qquad (1)$$

where $x_{ij}$ is the score of the $i$ th alternative with respect to the $j$ th criterion, while the weight $w_j$ is a normalized weight, so that $\sum w_j = 1$. The weights represent the relative importance of the criterion. Besides, the most preferred alternative is selected by identifying the maximum value of $A_i(i = 1,2,...,m)$ [91]. As such, several studies have emphasized this method in evaluating landfill suitability, including [21], [34], [50], [61], and [73].

#### *4.1.4 Integrated AHP techniques*

A number of articles have presented the integration of AHP with other techniques, such as SAW, TOPSIS, ANP, and WLC. From the review that had been carried out, eight articles displayed integration between AHP and SAW method in solving the landfill site selection problems. For example, the AHP method had been employed to rank the criteria weight, while the SAW approach was used to calculate the ranking index of candidate sites in the island of Lesvos located at Greece [22]. Meanwhile, in 2005, another study conducted in the Lemnos Island located at Greece had applied the similar AHP-SAW method, except for the addition of spatial clustering process to expose the most suitable location for landfill siting [12]. Furthermore, the spatial clustering process also can provide an initial ranking of the suitable areas for landfill siting. For instance, the AHP-SAW method was applied to calculate the relative importance of the criteria, as well as to evaluate the suitability of the land for landfill siting [48] [52] [53] [66]. On the other hand, a suitable site for hazardous landfill siting had been located by using AHP-priority scale weighting (PSW) and SAW-pairwise comparison technique (PCT) techniques [54], in which both techniques exemplified the same ranking list for landfill siting.

Based on the review, two articles integrated AHP with TOPSIS to solve issues related to landfill site selection. In the first study, AHP and TOPSIS were integrated to rank alternative sites in the Thrace region based on Manhattan, Euclidean, and Chebyshev distance metrics [38]. Furthermore, it was the only study that combined those techniques in raster-based GIS approach. Based on the analysis, Euclidean distance metric and TOPSIS exhibited strong similarities, however, in terms of the results, TOPSIS generated better results, in comparison to Euclidean distance metric, and close to Manhattan distance metric. The overall results displayed that Chebyshev distance metric resulted in the highest performance to select the most suitable site for landfill siting. On the other hand, AHP and TOPSIS were combined to identify the best alternative for Ankara city in the Sincan municipality located in Turkey [17].

Other integrated AHP techniques were proposed by [68], where the AHP-weighted sum model was employed to evaluate and to select the best suitable site among alternative sites. Besides, an optimal site was chosen for municipal landfill siting in the Valencia city located at Spain by applying ANP and AHP separately [30]. Furthermore, the comparison between both techniques showed that ANP was indeed a worthwhile tool that facilitated the decision makers in making trustworthy decisions. Meanwhile, the best suitable location was identified for municipal landfill siting in the area of Varanasi city located at India based on AHP and WLC methods [35]. In addition, the most appropriate location for landfill siting in Kolkata city located at India had been determined by using both AHP and Delphi methods [87]. Hence, the relative importance of each criterion was calculated using pairwise comparison, as in AHP method, whereas the Delphi method was utilized to calculate the sensitivity index value of the criteria, and the site sensitivity index was applied to rank the candidate sites.

#### *4.1.5 Integrated ANP techniques*

Nonetheless, only a handful of articles had integrated ANP with other techniques to solve issues regarding landfill site selection. An instance of such article combined ANP and DEA to evaluate the most suitable sites for undesirable facility siting [95]. In their research, ANP was used in the first phase of the evaluation process to assign both the criterion weight and output from ANP, which functioned as the input for the second phase. Meanwhile, the DEA method was utilized in the second phase to identify the best location for landfill facility. Other than that, ANP was combined with

PROMETHEE II to evaluate landfill suitability in the areas of Kouhdasht basin located at Iran [59]. In their study, ANP was used to calculate criterion weight, whereas PROMETHEE II was applied to obtain a complete alternative ranking from the most to the least preferred sites. Thus, it was concluded that the combination of these techniques had been very effective for raster-based site selection process.

#### *4.1.6 Other integrated MCDM techniques*

Apart from the techniques mentioned above, an integrated MCDA technique between ELECTRE and PROMETHEE had been employed to identify the suitable location for landfill siting in the West Thessaly at Greece with consideration of community participation, as well as their acceptance [89]. The study discovered that this integrated technique resulted in trustworthy results, where this proposed solution had taken into consideration expert knowledge, local authority, and public opinion.

#### *4.1.7 Other decision-making techniques*

Apart from the MCDA techniques, a single article had solved this landfill site selection issue using the heuristic approach. This article applied the two-stage heuristic method, along with multiple factor, to identify an optimal location for landfill siting [32]. In the first stage, a rectangular sub-area was identified for landfill siting and the optimal site within the rectangular sub-area was determined in the second stage. Furthermore, the landfill suitability was calculated by using weighted sum model. As a result, the study revealed that this approach could help decision makers in addressing problems related to raster-based landfill siting, besides reducing the search time for a suitable site in a large area.

### *4.2 Decision-making Techniques under Uncertainty Environment*

All decisions, beyond doubt, require information. Availability of information, hence, strongly influences the decision-making process. If the information known by the decision maker regarding the problematic situation involves uncertainty, then the decision made is considered as under uncertainty [91]. As such, various techniques have been depicted in the literature to solve landfill site selection decision problem under uncertainty environment, for example, AHP, WLC, TOPSIS, and ELECTRE, as discussed in the following section.

#### *4.2.1 Integrated fuzzy AHP techniques*

Fuzzy AHP is a type of fuzzy MCDA technique. Besides, a number of articles have integrated fuzzy AHP with other techniques, such as ordered weighting additive (OWA), weighted linear combination (WLC), and ELECTRE. These integrated techniques can address both imprecision and haziness issues in real life situation. In fact, the triangular fuzzy numbers and the AHP had been amalgamated for landfill siting [18] [19] [76] [83]. Meanwhile, the integrated fuzzy set membership functions, as well as AHP and OWA operator, had been investigated for siting of municipal solid waste landfill in Evros prefecture (northeast Greece) and Polog Region in Macedonia, respectively [24], [79]. Additionally, the integrated fuzzy set membership functions, AHP, and WLC were considered for landfill site selection process in the Karaj city of Tehran province in Iran [82], where the spatial clustering analysis, as suggested in [12], had been applied to identify the suitable location among the alternatives for landfill siting [82]. Next, AHP, WLC, and neighbourhood proximity analysis were combined to rank the alternative candidate sites and further established the final site selection by weighing in fuzzy-dominance relationships when dealing with domain experts [65]. Besides, the study also discovered that the neighbourhood proximity analysis gave effective solutions for both short- and long-term landfill siting options.

Furthermore, the fuzzy set membership function was integrated with AHP and WLC to solve landfill site selection problems in the Polog region at Macedonia and the Saqqez city of Kurdistan province in Iran [23] [86]. Meanwhile, the sigmoidal fuzzy membership function, linear fuzzy membership function, AHP, WLC, and OWA had been applied to model landfill location in a Sierra Leone city, Bo [37]. Besides, the fuzzy set membership function, WLC, AHP, and ELECTRE methods were employed to locate a suitable site for the construction of a landfill site in the Ariana region at Tunisia [77]. Furthermore, a landfill suitability assessment was carried out by using the index overlay method and fuzzy gamma in the metropolitan regions of Italy [78]. On top of that, fuzzy AHP was employed with VIKOR for a sanitary landfill siting in Kolubara region at Serbia [81].

*4.2.2 Integrated fuzzy ANP techniques*

Three articles (3.66%) have applied the ANP method to perform landfill suitability analysis under fuzzy environment. For example, the triangular fuzzy number was combined with the ANP method to solve sanitary landfill site selection problem in the Kahak town at Iran [80]. As such, the study found that the relationships between the criteria can be assessed effectively to achieve the goals of the study. Meanwhile, integrated fuzzy logic operation and ANP method had been applied to assign criterion weightage, as well as to identify the best suitable location for landfill siting in seven cities located in the Isfahan city at Iran [75]. Next, fuzzy logic, fuzzy linguistic quantifier, ANP, OWA operator, and WLC were applied to identify the best and the most suitable location for landfill siting in the Birjand plain at Iran [36].

*4.2.3 Integrated fuzzy TOPSIS techniques*

Furthermore, five MCDA methods; SWA, WPM, CGT, TOPSIS, and ELECTRE, were compared in order to locate an optimal site for landfill siting in the city of Regina located at Canada under uncertainty environment [96]. In fact, the Left-Right scoring approach was used to convert linguistic terms into numerical values to form an impact matrix. Upon considering the various MCDA techniques used, inconsistent solutions were gained. Besides, the average ranking procedure was utilized to overcome the problem in establishing the reliability of the solutions. A year later, a similar research was conducted by integrating five MCDA methods (SWA, WPM, CGT, TOPSIS, and ELECTRE) with inexact mixed integer linear programming (IMILP) model separately, and compared in order to locate an optimal site [26]. Furthermore, the IMILP was applied to discover the minimal total cost of municipal waste flow for each potential landfill site. In fact, IMILP can accept uncertain input parameters in interval form, where this data format is often available in the real world setting. The total cost derived from the IMILP analysis functioned as input parameters to MCDA methods for further analysis so as to identify the best location for landfill site. Besides, they also concluded that the combination of IMILP and MCDA methods had been effective, where the subjective judgment of the decision maker was also considered, thus indicating trustworthy findings. Other than that, three candidate landfill sites in the Istanbul metropolitan city were investigated by using fuzzy AHP and fuzzy TOPSIS methods [97]. Besides, fuzzy AHP was employed to calculate the criteria weights, while fuzzy TOPSIS was utilized to evaluate the alternative sites.

#### *4.2.4 Integrated fuzzy VIKOR techniques*

VIKOR or "*Visekriterijumska optimizacija i kompromisno resenje"* was first proposed by Serafim Opricovic in 1998 to solve a complex multi-criteria decision-making problems that involved non-commensurable and conflicting criteria [98]. This method ranks and selects the solution from a set of alternatives by considering the conflicting criteria. It also introduces the multi-criteria ranking index based on the particular measures of "closeness" to "ideal" solution [99]. Moreover, two researches utilized this method to evaluate the suitability of locations for landfill siting under uncertainty environment. For example, the trapezoidal fuzzy number (TFN) was integrated with the VIKOR method to solve landfill site selection problem in Shanghai, China [100]. TFN was used to rank and to assign weight for each criterion. Besides, the ordered weighted averaging (OWA) operator was employed to convert the fuzzy decision matrix into crisp values to imitate the attitudinal character of the decision maker. Next, the ranking list of alternative site was generated by using the VIKOR method. Additionally, the 2-tuple linguistic approach and the VIKOR method were amalgamated to locate a suitable site for RDF combustion plant siting in Istanbul located at Turkey [98].

#### *4.2.5 Other integrated fuzzy techniques*

The alternative ranking order based on value analysis and fuzzy logic approach had been looked into [101]. Besides, an intelligent system was proposed by [33] to identify a suitable location for landfill site in Amman, Jordan based on the fuzzy inference system. The advantage of fuzzy inference system is that it has the ability to encode environmental expertise, in which their knowledge can be updated. Meanwhile, the fuzzy logic was employed to solve landfill site selection problem due to its capability in dealing with spatial information [74].

Furthermore, the fuzzy utility method and the multi-nominal logit theory had been integrated to identify an optimal location for landfill siting in Jhunjhunu district at Rajasthan [102]. In fact, the triangular fuzzy numbers were used for rating and assigning criterion weightage based on the decision makers' judgment. The fuzzy utility method, on the other hand, was applied to calculate the utility value for each alternative site. Moreover, the probabilities of alternatives being accepted were estimated based on the multi-nominal logit model. As such, the most accepted location was determined based on the higher utility value due to the least impact upon the surrounding environment.

## **5. Discussion**

### *5.1 Distribution of Articles by Decision-Making Techniques*

In general, three techniques emerged as popular in prior studies to address landfill site selection problems, which were: geographic information systems (GIS), multi-criteria decision analysis (MCDA), and fuzzy-based techniques. GIS was used for site screening process to obtain a set of potential candidate site. Then, these candidate sites were further analysed by using MCDA or fuzzy-based techniques to determine the best and the most suitable site for landfill siting.

Figure 1 illustrates that the most frequently used techniques to solve landfill selection problem had been the integration of GIS and MCDA (41.46%), followed by the combination of GIS and fuzzy MCDA (19.51%), and MCDA as an individual technique (9.76%). The MCDA appeared to be a well-known method from the literature due to its ability in managing intricate decision-making problems experienced by decision makers. However, the MCDA has a drawback as it cannot address the vagueness of the decision problem. Hence, in order to overcome this vagueness, a fuzzy set theory had been introduced. Other than that, 54 articles had managed to solve this landfill selection problem under certain decision-making, while the remaining 28 articles solved issues under fuzzy environment.

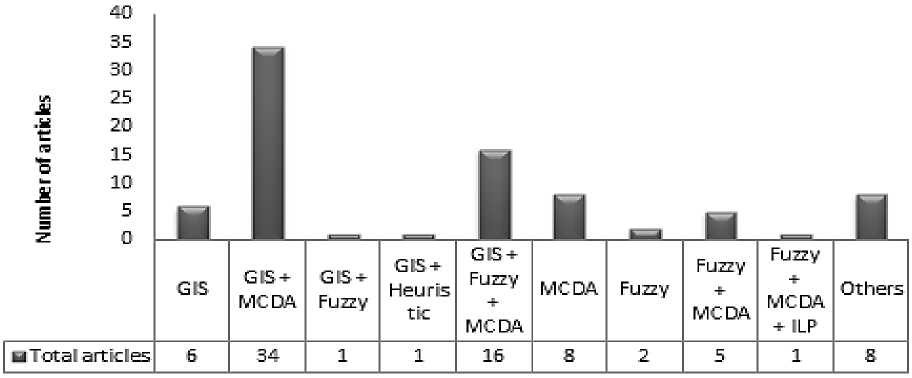


**Fig. 1.** Distribution of articles by decision-making techniques

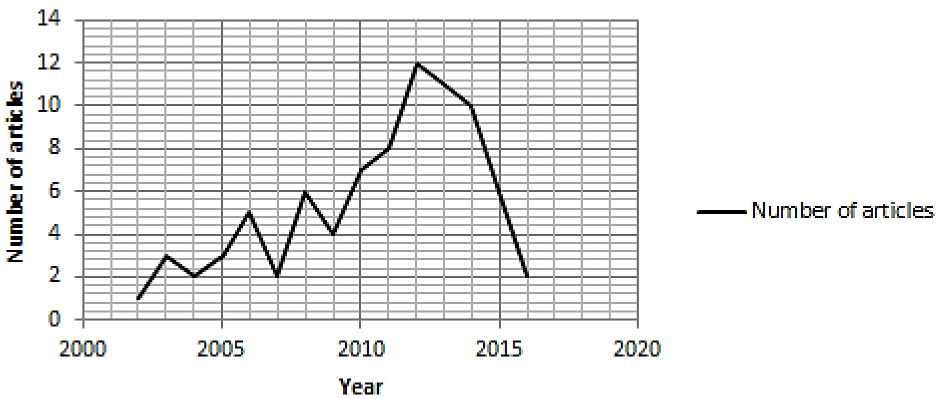


**Fig. 2.** Evolution of landfill site selection researches in the waste management field

*5.2 Distribution of Articles by Year and Country*

Figure 2 presents the evolution of landfill site selection researches from 2002 until 2016. However, the values may be inaccurate. Furthermore, the solutions were analysed based on the selected articles used in this paper. Based on the review carried out, many studies have been conducted from 2012 until 2014. In this study, it had been believed that the need for a decision-making tool to assist decision-makers in addressing issues related to disposal site selection is indeed essential. This would not only save time, but also costs incurred to generate new landfills that are environmentally friendly.

Table 5 shows the distribution of articles based on the research area (country). From the intensive review carried out in this study, the landfill site selection problem had been investigated in 26 countries, including Turkey, Iran, Italy, Palestine, China, United States, Mexico, and Spain. In fact, a total of 19.51% and 20.73% of these studies were carried out in Turkey and Iran respectively, followed by Italy and India at 7.32%, where they share similar value. Based on the observations made, most of the studies were carried out in the Europe, Middle East, East Asia, and Western Asia.

**Table 5**
Distribution of articles by country

| Country | Total articles | Country | Total articles |
|---|---|---|---|
| Turkey | 16 | Mexico | 1 |
| Iran | 17 | Sierra Leone | 1 |
| Italy | 6 | Tunisia | 1 |
| India | 6 | Jordan | 1 |
| Greece | 5 | Lebanon | 1 |
| China | 3 | Colombia | 1 |
| Canada | 3 | Cape Verde | 1 |
| Egypt | 3 | Kenya | 1 |
| Spain | 2 | Serbia | 2 |
| Macedonia | 2 | Morocco | 1 |
| Palestine | 2 | Brazil | 2 |
| Mauritius | 1 | Cyprus | 1 |
| USA | 1 | Iraq | 1 |
| Not stated | 2 | | |
| Total articles: 82 | | | |

## 6. Conclusion

Landfill site selection is a process of making an important decision. Decisions made should accurately mainly because it involves human life and nature. Therefore, a strong and stable technique is required to support this decision-making process. With that, this paper presents a review of articles that were published from 2002 and onwards in identifying the selection criteria, as well as the present methods employed to solve this problem. Furthermore, this article is focused on their methods and findings. As such, the methods were grouped into two main classes: preliminary site screening techniques, and landfill suitability assessment techniques.

As for the preliminary site screening techniques, GIS, either as an individual approach or integrated approach, depicted the highest usage (75.61%), in comparison to decision-making without using GIS. Moreover, GIS has been widely used in the literature due to its ability in supporting and analysing both spatial and attribute data for decision-making purposes. On top of that, GIS can also be integrated with other advanced geographical technologies, such as RS, global positioning system (GPS), computer aided design (CAD), automated mapping and facilities management (AM/FM) [91], and satellite image enhancement [103] to further improve the accuracy in analysing spatial data. Meanwhile, in the landfill suitability assessment techniques, AHP emerged as the most frequently used technique to identify the best and the most suitable location for landfill siting. Its advantage is to turn the decision problem in a hierarchy form, in which suits the landfill site selection problems that involve various criteria, apart from incorporating expert judgment.

Therefore, this paper is beneficial and helpful to new researchers, especially those in the waste management field, in obtaining some overview on the studies related to landfill site selection, as well as the generation of several new ideas that are absent in other prior studies. In addition, this paper may also help practitioners in the SWM team to identify the shortcomings in the present system and to improve the system by using the proposed techniques proposed in the prior studies.

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