

## Research Article

# Use of a Combination of MRSS-ANP for Making an Innovative Landfill Siting Decision Model

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Landfill siting is a complex, multicriteria decision-making problem that needs an extensive evaluation of environmental, social, land use, and operational criteria. Integration of a median ranked sample set (MRSS) and an analytic network process (ANP) has been implemented to rank the associated criteria and select a suitable landfill site. It minimizes the uncertainty and the subjectivity of human judgments. Four groups of experts with different backgrounds participated in this study, and each group contained four experts. The respondent preferences were ranked in a 4-by-4 matrix to obtain the judgment sets for the MRSS. These sets were subsequently analyzed using ANP to obtain the priorities in the landfill siting criteria. The results show that land topology and distance from surface water are the most influential factors, with priorities of 0.18 and 0.17, respectively. The proposed integrated model may become a promising tool for the environmental planners and decision makers.

## 1. Introduction

Facility site selection model is complex and needs extensive assessment and comparison efforts [1]. Proper landfill siting is essential to reduce the environmental and health impacts associated with its construction and operation [2]. In general, solid waste treatment and disposal facilities belong to a group of obnoxious or undesirable facilities, and, therefore, landfill siting faces two major challenges: (i) social objection represented by a phenomenon known as BANANA (build absolutely nothing anywhere near anyone) or NIMBY (not in my back yard) and (ii) the large number of technical, social, and environmental factors that must be considered in selecting the best location to minimize nuisances and maximize efficiency and social acceptance [3]. Solid waste landfill remains a convenient method for the disposal of an increasing amount of municipal solid waste, notably in developing countries [4]. Landfill site selection requires a different type of criteria processing to account for the unequal criteria importance [5–9]. Moreover, increasing the number of participating parties in the decision-making process

widens its popularity and strengthens it [10], but analyzing and homogenizing the preferences of these stakeholders are complex issue, especially with conflict of interests among the participated interest groups.

Decision support systems like the analytic hierarchy process (AHP) and its generalization (ANP) have been widely implemented to handle the complex problems. Multicriteria decision-making (MCDM) using ANP is composed of the following steps: (i) identifying the factors and the components within the network together with their interactions and relations; (ii) conducting pairwise comparisons among the network elements and the main/subcriteria to build the unweighted supermatrix; (iii) obtaining the weighted supermatrix via weighting the blocks of the unweighted supermatrix by the corresponding priorities of the clusters (from which the resulting matrix is column stochastic); and (iv) developing the limit matrix by increasing the power of the weighted supermatrix until the weights converge [11].

The ANP is implemented to drive the relative priorities of the criteria using the judgment of individuals [12]. However, ANP implementation requires higher number of judgments

TABLE 1: Definition of the scale of importance [58].

Intensity of importance	Definition	Explanation
9	Extremely important	This activity is of the highest possible order of affirmation
7	Strongly important	This activity is strongly favored (dominant) over other activities
5	Moderately important	This activity is moderately favored over other activities
3	Slightly important	This activity is slightly favored over other activities
1	Equally important	This activity equally contributes to the objective
2, 4, 6, and 8		Intermediate importance between two adjacent responses

than AHP. Because of the ability of ANP to treat the interactions and feedback and thus justify the decision [13], ANP is widely used in many decision-making applications. However, ANP-based decisions are limited by the uncertainty in judgment during the pairwise comparison [14]. A previous study [1] combined ANP and data envelopment analysis to leverage both the available qualitative and quantitative data for the location of a landfill site. Additional studies [15, 16] implemented ANP to suggest the best location of a landfill site. Several researchers [17, 18] integrated a fuzzy set, AHP, and a weighted linear method to prioritize the site evaluation criteria and applied this process using Geographic Information System (GIS) software. Moreover, hybrid model of an ANP and a triangular fuzzy function were used by [14] to measure remedial countermeasures. A landfill site suitability analysis using an AHP and a compromised programming method was also reported [19]. An AHP was applied to find the weighted site evaluation criteria and was used in GIS to suggest the best landfill location [20].

The ranked sample set (RSS) was first proposed by McIntyre in 1952 to estimate the population mean, and since that time it was modified and developed many times [21, 22]. Applying of the RSS to estimate the population mean and median leads to notable gains in precision [23]. The MRSS is an adaptation of RSS, and, in this method, only the median observation is considered from each of randomly selected sets. The MRSS is advantageous (relative to RSS) because it minimizes the ranking errors and enhances the estimation efficiency [24]. The MRSS proposes promising applications in environmental researches because of its capability to represent a population without extensive observations [25]. For instance, the spray deposits on the leaves of apple trees were assessed using RSS [26]. An RSS method was also applied to collect samples from gasoline stations for analysis intended to verify the conformity of these stations with clean air regulations [27]. Prior sample knowledge was also integrated with RSS to minimize the cost of evaluating a stream habitat region for salmon [28].

This study presents a model to reduce the imprecision and vagueness of the human decision-making. It identifies the relative importance of landfill siting criteria as a case study. The presented model leverages the power of an expert system to extract knowledge that is subsequently applied to a hybrid MRSS-ANP system to obtain the criteria weights.

## 2. Methodology

Landfill siting is a multicriteria decision-making process. The proposed model decomposes this process into three levels: problem construction, criteria analysis, and selection [7]. Problem (case) construction determines the problem, aims, assessment criteria, the experts, and their groups. Criteria analysis extracts the expert knowledge and performs data analysis using MRSS. The selection step determines the importance of the landfill siting criteria using ANP and the rank of the final priorities.

**2.1. Case Construction.** The problem construction starts with a literature review used to determine the main and sub-criteria of the landfill site selection. There are no general approaches to select a set of evaluation criteria but it can be selected through an examination of the relevant literature, analysis study, and expert opinions [29]. However, the criteria selection was based on the usage (the most commonly found in literature), expert opinions, and data availability. These criteria were subsequently arranged in a hierarchical structure, and the hierarchical tree defines the most general network. The landfill siting criteria were classified into four main groups: social [30, 31], operational [16, 18], environmental [32, 33], and land use [34–36]. Moreover, the subcriteria fall under each main group, as shown in Figure 1. After the initial classifying, the experts were determined and divided into four clusters (groups). A cluster analysis splits the data into meaningful groups that are usually associated or share characteristics [37]. The resulting groups involved the governmental sector, private sector, academia, and nongovernment organizations interested in solid waste and environmental issues.

A developed questionnaire asked the stakeholders to draw pairwise comparisons among the criteria and the subcriteria with respect to landfill site selection. The used questionnaire takes into account the interactions and feedbacks between the criteria. Table 1 shows the intensity of the importance of the criteria. The odd-numbered rankings were used to determine the criteria importance, whereas the entire range from 1 to 9 was used to develop the ANP multicriteria decision analysis.

**2.2. Criteria Analysis.** The stakeholders preferences were grouped into four random sets. Each set consists of the

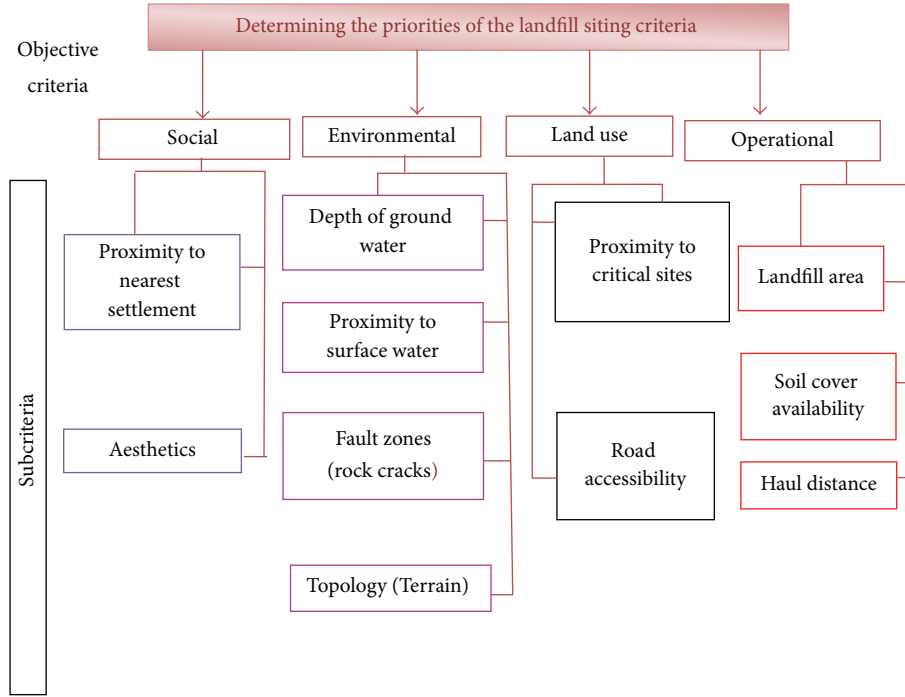


FIGURE 1: Hierarchical structure of the landfill siting criteria.

TABLE 2: Comparison of the importance of land use with the importance of operation methods.

Sector	Government	Private sector	NGO	Academia
Expert group number 1	7	0.33	0.20	1
Expert group number 2	1	3	1	0.14
Expert group number 3	7	5	3	7
Expert group number 4	3	3	3	0.20

responses of one government, private, academia, and NGO respondent. The respondents are experts in the field of solid waste management and landfill siting issues through their work experience. Table 2 shows an example of one of the comparisons by displaying the obtained preferences of the respondents and their sets. Next, these responses were ranked in increasing order for each individual set, as shown in Table 3. After that, the importance of the landfill siting criteria was obtained using the second scenario [21]:

- (i) If the sample size,  $n$ , is odd, then the median is selected by  $((n + 1)/2)$ th. This observation can be denoted as  $X_{((n+1)/2:n)}$ , and the general formula is

$$\{X_{((n+1)/2:n)1}, X_{((n+1)/2:n)2}, \dots, X_{((n+1)/2:n)n}\}. \quad (1)$$

- (ii) If the sample size  $n$  is even,

then the median is selected by  $(n/2)$ th. This observation can be denoted as  $X_{(n/2:n)}$ , and the general formula is

$$\{X_{(n/2:n)1}, X_{(n/2:n)2}, \dots, X_{(n/2:n)n}\}. \quad (2)$$

**2.3. Final Priority Selection.** The study aim is to determine the overall priority of each criterion and apply it in the case study considering the interactions and the feedbacks among the main and subcriteria. ANP systematically breaks down the problem to justify the decision [38, 39]. To capture the interactions and feedback, a hierarchical framework that contains all main and subcriteria must be constructed. Thus the comparisons can be performed and synthesized to determine the unweighted, weighted, and limit matrices that determine the priorities of importance of the landfill siting criteria. Figure 2 shows the interactions and feedback between the landfill siting components. An arrow and/or loop arrow specify the dependence and feedback for which the two-side (double) arrows indicate the influences between the elements on both groups. The inner-dependence or self-feedback is indicated by a loop arrow at the top of each group.

The resulting relative importance sets from the previous step contain the preferences of government, private, NGO, and academic stakeholders and are used in the ANP. This step is repeated for the sixty-three pairwise comparisons to build the comparison matrix (unweighted supermatrix). The inputs of the supermatrix depend on the presence and the type of dependence among the group elements that are shown in Figure 2. The matrix is subsequently input into the Super Decisions (version 2.2) software to develop the weighted and limit matrices [40]. The weights obtained in the limit matrix represent the final importance priorities. Finally, the integrated landfill siting procedures are summarized in Figure 3. This figure illustrates the guidelines for such decision-making problem.

**2.4. Case Study.** Selangor is the most populated and highly developed state in Malaysia; it has a diversified economy

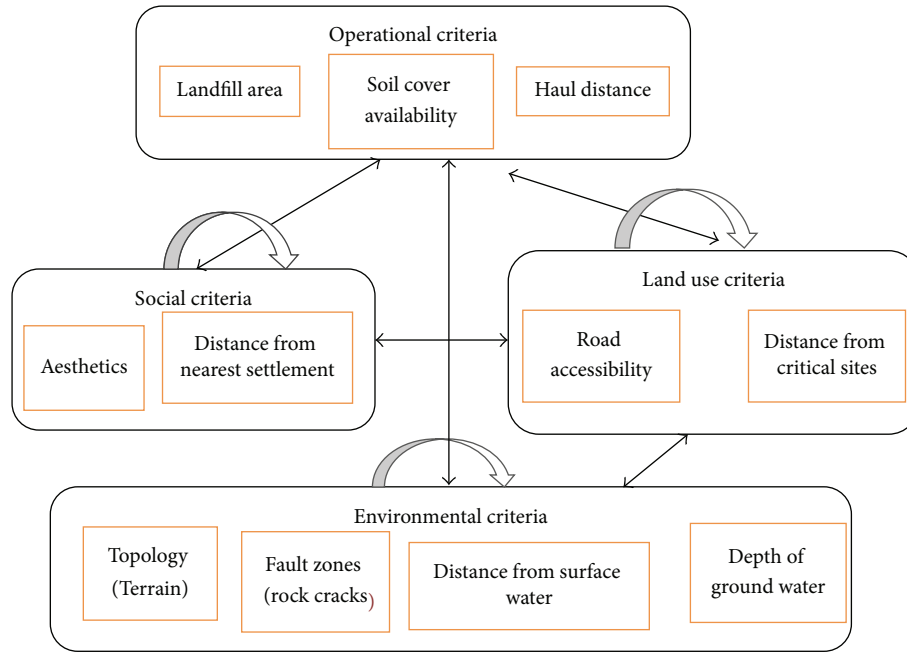


FIGURE 2: Interactions and feedback between criteria.

including industry, commerce, agriculture, and tourism. Moreover, Selangor completely surrounds two federal territories, which are Kuala Lumpur (KL), the national capital of Malaysia, and Putrajaya the federal capital. The areas of Selangor, Kuala Lumpur, and Putrajaya are 7,930, 243, and 92 km<sup>2</sup>, respectively. There is a great demand to depend on scientific approach for determining a landfill site in Selangor due to increasing amounts of solid waste and land scarcity. Thus Boolean logic was implemented to exclude unsuitable areas that cannot be used as a disposal site [19]. The exclusion is done by overlaying technique and in dependence on constraint factors [6, 41]; these factors are based on Malaysian guidelines for development of solid waste sanitary landfill [42]. However, the Boolean logic is restrictive in nature [43]; thus, by its implementation, the study area is classified into two classes suitable area with value (1) and unsuitable area with value (0) as shown in Figure 4 and described in (3):

$$\text{Boolean Suitability Index} = \prod_{j=1}^n b_j, \quad (3)$$

where Boolean Suitability Index has a value (0 or 1),  $b_j$  is the Suitability Index for each constraint criterion and has a value (0 or 1), and  $n$  the total number of constraint criteria [2]. Finally, the potential landfill sites were suggested based on assumed landfill area and ranked using the obtained MRSS-ANP weights and Suitability Index (SI), which is the sum of products of the standardized score of each criterion multiplied by the weight of each criterion:

$$SI = \sum W_i * C_i, \quad (4)$$

where  $W_i$  is weight of factor  $I$  and  $C_i$  is criteria grading of factor map  $i$  [34].

### 3. Results and Discussion

**3.1. Case Construction.** Figure 1 shows the developed hierarchical structure of the landfill site evaluation criteria. Each main criterion has an ultimate goal, that is, to maximize the preservation of nature (environmental), acceptance by the public (social), or appropriateness of the site (land use). Additionally, the target of operational criteria is minimizing the costs. The eleven subcriteria that share common characteristics were grouped together under the main criteria. Since the solid waste hauling distance, availability of soil cover for daily landfill operations, and landfill area are controlled during landfill construction or operation, they were classified under one group (operational) [43].

Moreover, land use involves the locations of critical sites highways and roads that are identified by the town planning department and these locations are highlighted for specific consideration in future plans. Examples of critical sites include airports, hospitals, railway, and other institutes [18]. Landfills serve large communities, but only subset of those communities commonly experiences the impacts of the landfill (typically the ones that are located near it) [44]. However, these effects can be minimized using special arrangements designed to reduce the nuisances caused during waste transportation and enhance the landscaping around the landfill to create a green buffer. The environmental criteria aim to conserve air, water, and soil and to minimize land altering activities [32] by applying the best available techniques and environmental practices to achieve these goals.

Figure 2 displays the dependence and feedback among the criteria. The environmental criteria do not relate to the aesthetics or distance from the nearest settlement; therefore, an interconnection or feedback between the environmental

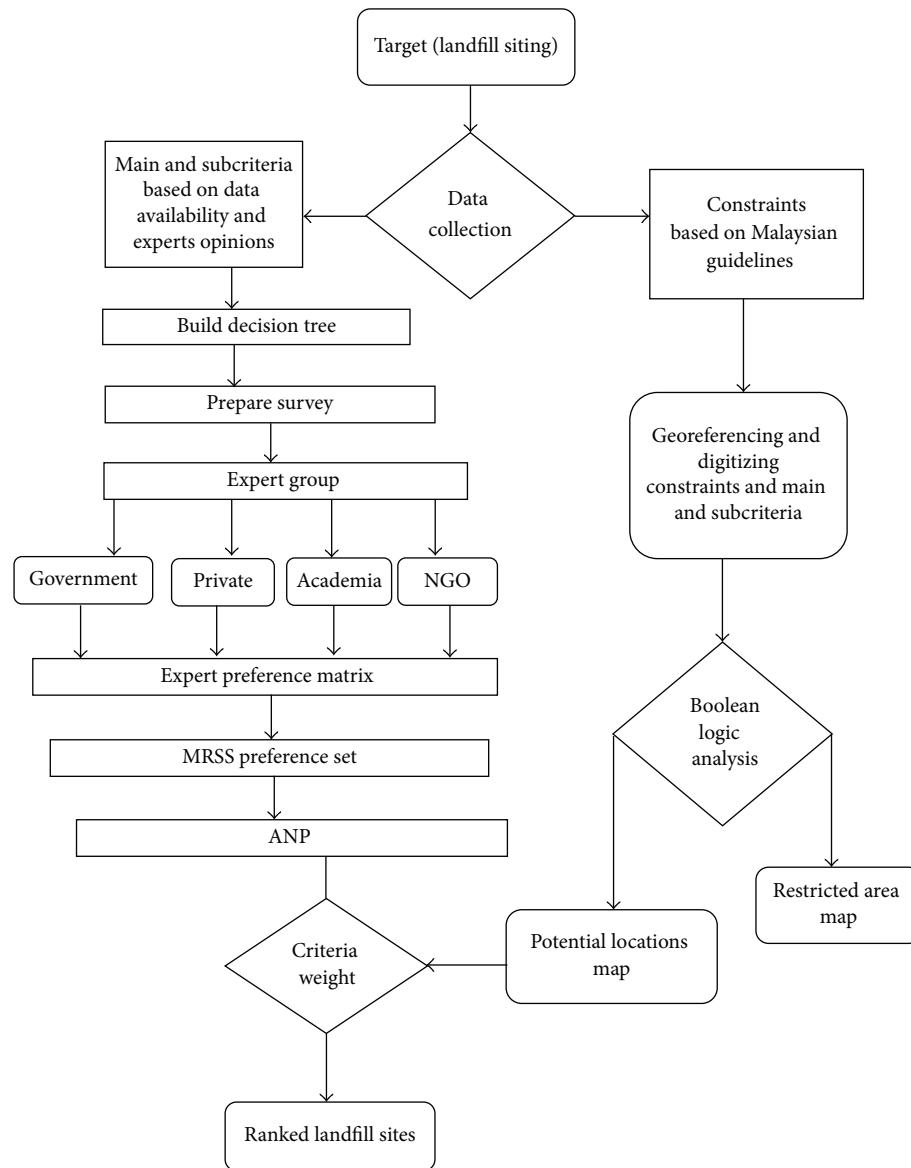


FIGURE 3: The landfill site selection algorithm.

and social main group is not shown. One or more of the remaining subcriteria relate to an additional criterion from outside of the group. For example, reciprocal effects were noted between the land topology and surface water. Surface water alters the land topology, whereas the topology affects the water runoff and maximizes or minimizes the movement of pollutants. Pairwise comparisons were used to compare the criteria and to allocate the criteria priorities using the Saaty method [39, 45]. The respondents were divided into four stakeholder sets to reduce vagueness and enhance quality.

**3.2. Criteria Analysis.** Based on the interactions and feedback among the criteria, sixty-three pairwise comparisons were required. The preferences of each respondent were recorded for each comparison. Every set of responses contained the opinion of one expert from each group, that is, government,

private, academia, and NGO. Therefore, the response range within the same set is relatively large because of the conflicts of interest of the stakeholders. The expert responses within the same group were observed to converge, but outlier responses were noted due to human nature and the various backgrounds of the experts. For instance, one governmental expert might emphasize environmental concerns because of personal involvement in environmental regulations, whereas another governmental expert may emphasize planning and land development because of personal involvement in a planning department. Similarly, one NGO representative could emphasize conservation, whereas another NGO representative might emphasize service to society. Therefore, points of view can diverge within an identical group.

Sixty-three pairwise comparisons were performed to identify the relative importance of the landfill siting criteria. An example of one of these comparisons is shown in Table 2.

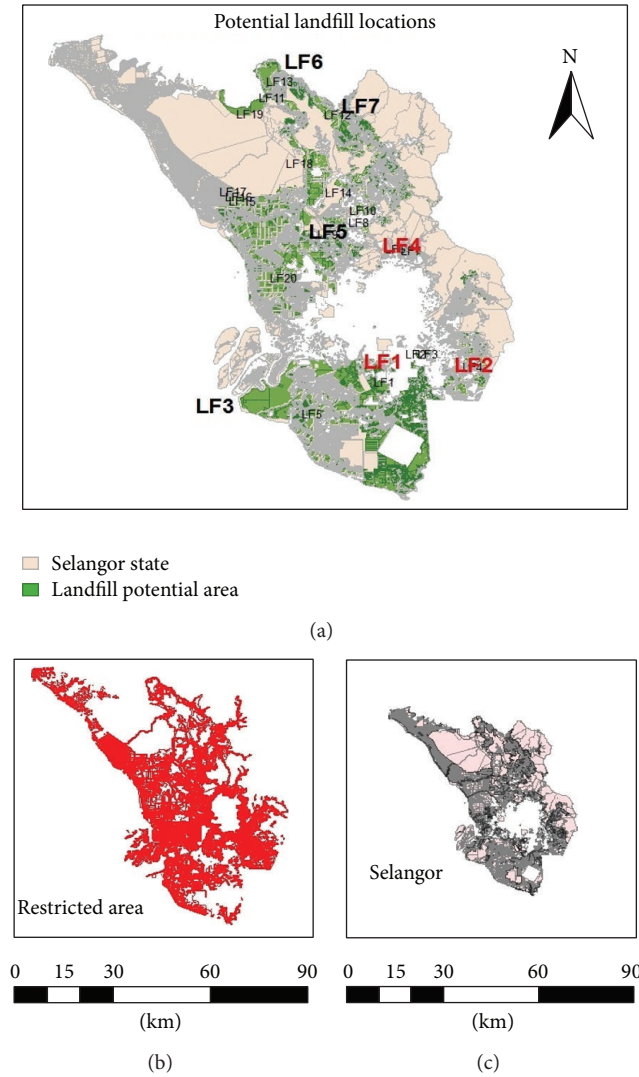


FIGURE 4: Selangor and potential landfill sites maps.

This table compares land use and operational methods to create a positive social impression with respect to the landfill site. For instance, the second expert in the first group indicates that operation method is slightly more important than the land use. In Table 3, the relative weights are ranked in increasing order. Because four preferences are contained in each set, the median weight set is determined using (2). Therefore, the second and the third quarters represent the MRSS and determine the relative importance set of the landfill siting criteria. The obtained relative importance set displayed in Table 3 is “1; 5; 7; 3.” This technique guarantees representation of the best set regardless of the origin of the responses. This result is displayed in Table 3 in which an increasing response rank is required regardless of the sector.

**3.3. Final Priority Selection.** The ANP uses three matrices: unweighted supermatrix, weighted supermatrix, and limit matrix. The unweighted supermatrix is the relative importance of all main components and subcomponents.

TABLE 3: Ranked comparison of the importance of land use with operational methods.

Ranked experts preferences				
Expert group number 1	0.20	0.33	1	7
Expert group number 2	0.14	1	1	3
Expert group number 3	3	5	7	7
Expert group number 4	0.20	3	3	3

TABLE 4: Priorities group matrix of the main criteria.

Sector	Land use	Environmental	Operational	Social
Land use	0.183	0.143	0.116	0.540
Environmental	0.526	0.571	0.488	0.0
Operational	0.204	0.286	0.275	0.163
Social	0.087	0.0	0.121	0.297

TABLE 5: Final priorities of the main criteria.

Main criteria	Final priority
Land use	0.142
Environmental	0.546
Operational	0.262
Social	0.05

The weighted supermatrix clarifies the values of each group and its elements. The limit matrix represents the priorities results and is obtained by raising the weighted supermatrix to a high power to acquire constant values.

Table 4 shows the priorities group matrix. Zero values mean that there are no interconnections between the criteria in the matrix; this independence is shown in Figure 2 in which no interactions are displayed between the environmental and social groups. The priority value of each main criterion in Table 4 depends on the relationship between the criteria groups. For instance, operations have an importance of 0.286 with respect to minimizing the landfill effects on the environment. This importance decreases to 0.16 when considering the creation of a positive social opinion with respect to the landfill site.

The final priorities of the main criteria group are shown in Table 5, and the highest rank of 0.54 is shown for environmental criteria, followed by operational methods and techniques (priority rank of 0.26). A landfill should be located and designed to protect human health and to conserve the environment. Therefore, environmental criteria gained the highest rank and this is the present worldwide trend [29]. In addition, according to the obtained results we can conclude that the social and operational criteria are considered to be insignificant by stakeholders. However, such results were reported by many researchers. For instance, Ismail (2011) [46] reported ground water, surface water, and protected area as the most important factors followed by land slope. Afzali et al. (2011) ranked the surface water (19%) followed by ground water (13%) as the most important physical criteria. Nadi et al. (2010) [47] ranked the hydrology and water as the most important criteria (33.4%) and social and financial

TABLE 6: Weight priorities of the overall subcriteria.

Group	Criteria	Priority normalized by group	Final priority
Environmental	SW	0.317	0.173
	GW	0.157	0.085
	FZ	0.181	0.099
	TO	0.345	0.188
Land use	CS	0.409	0.058
	RA	0.591	0.083
Operational	HD	0.145	0.038
	LA	0.511	0.135
	SA	0.344	0.091
Social	AE	0.579	0.029
	NS	0.421	0.021

SW: proximity to surface water, GW: depth of ground water, FZ: proximity to fault zone, TO: topology, CS: proximity to critical site, RA: road accessibility, HD: haul distance, LA: landfill area, SA: soil availability, AE: aesthetic, and NS: nearest settlement.

TABLE 7: Summary of the rankings and SI for the potential landfill sites.

Site number	Environmental				Land use		Operational			Social		SI
	SW	GW	FZ	TO	CS	RA	HD	LA	SA	AE	NS	
LF1	0.173	0.085	0.040	0.113	0.058	0.017	0.038	0.135	0.091	0.029	0.004	0.782
LF2	0.173	0.068	0.040	0.113	0.058	0.083	0.038	0.135	0.091	0.029	0.004	0.832
LF3	0.035	0.017	0.020	0.188	0.058	0.083	0.038	0.135	0.091	0.029	0.008	0.702
LF4	0.138	0.068	0.099	0.113	0.058	0.083	0.038	0.135	0.091	0.023	0.013	0.859
LF5	0.104	0.085	0.020	0.075	0.058	0.066	0.038	0.135	0.091	0.017	0.021	0.711
LF6	0.138	0.051	0.040	0.150	0.058	0.064	0.038	0.135	0.091	0.017	0.004	0.787
LF7	0.035	0.017	0.099	0.113	0.058	0.083	0.038	0.135	0.091	0.029	0.008	0.706

criteria as the least important criteria with weight equal to 15.5% and 15.3, respectively. Demessouka et al. (2013) indicated the hydrology as the most important factor followed by the environmental criteria and ranked the social and economic factors as the least important or insignificant factors. In a study done by [48], the social and technoeconomic criteria gained the lowest importance of 9% and 6%, respectively. Moreover, such conclusion was also reported by Ismail (2011) for landfill siting in Malaysia because the social and operational (technical) criteria can be extended and modified. A study done by [49] reported that urban area and water resources are the most important criteria that should be considered for construction intermunicipality landfill. However, sometimes it is inappropriate to compare among studies from different countries because the obtained weights are dependent upon surveyed respondents, different studied factors, and different local and environmental conditions.

The final priorities of the factors related to landfill site selection are shown in Table 6. The overall highest rank is for land topology (18.8%) because of its direct effect on both surface water and groundwater as well as on soil erosion by control of water runoff [50]. Surface water is the second highest factor (17.3%). Surface water can easily become polluted and can therefore propagate pollutants. The

third highest rank is for landfill area (13.5%); this ranking is due to the requirement to locate the landfill in a manner that reduces the price of the land because the land price represents the highest cost for a landfill. In addition, the landfill size must be optimized to minimize environmental effects and the costs associated with identifying a new landfill site.

However, applying (2) produced Table 8 that describes the preference sets of the performed sixty-three comparisons. Each element in the set represents the preferences of each expert group. Table 9 is a result of applying the preferences sets in ANP and represents the unweighted supermatrix. It is two-dimensional matrix of element by element, and it provides relative importance of all components (main criteria and subcriteria) [45]. The weighted and limit matrices are described by Tables 10 and 11, respectively. In the limit matrix, the constant values of each value are determined by taking the necessary limit of the weighted supermatrix [38]. Social criteria and haul distance got the lowest rank. The influence of these criteria on the design of a landfill can be minimized with suitable arrangements. For example, if appropriate transfer station is used, then the solid waste hauling cost is reduced. Additionally, planted buffer zones and special landscaping can reduce visual and odor pollution to minimize the nuisance to neighbors. Moreover, shifting traffic as far as possible

TABLE 8: MRSS preference sets.

Number	Comparison target	Comparison elements	MRSS preference sets
1	To create positive social opinion	Land use (operational)	0.33, 1, 7, and 3
2		Land use (social)	1, 1, 5, and 1
3		Operation (social)	0.2, 1, 0.2, and 1
4	To protect environmental elements	Environmental (land use)	1, 3, 5, and 5
5		Environmental (operational)	1, 1, 5, and 1
6		Land use (operational)	1, 1, 5, and 1
7	For sustainable and strategic land use planning	Environmental (land use)	1, 3, 3, and 3
8		Environmental (operational)	1, 1, 7, and 3
9		Environmental (social)	5, 1, 7, and 7
10		Land use (operational)	0.33, 0.2, 1, and 3
11		Land use (social)	1, 0.14, 3, and 3
12		Operation (social)	1, 1, 5, and 5
13	To minimize the operational cost and to operate the landfill with best available techniques and best environmental practices	Environmental (land use)	1, 7, 5, and 5
14		Environmental (operational)	1, 1, 3, and 3
15		Environmental (social)	1, 1, 5, and 3
16		Land use (operational)	0.33, 1, 1, and 1
17		Land use (social)	1, 0.2, 3, and 1
18		Operation (social)	5, 1, 5, and 3
19	To protect surface water	Proximity to critical sites (road accessibility)	0.2, 0.11, 0.33, and 1
20		Soil cove availability (landfill area)	0.33, 1, 5, and 1
21		Avoiding faulting zones (depth of ground water)	0.33, 0.14, 3, and 1
22		Avoiding faulting zones (topology)	1, 0.14, 3, and 1
23		Depth of ground water (topology)	3, 1, 1, and 1
24	To reduce the effects on fault zones	Landfill area (soil cover)	1, 0.2, 5, and 3
25		Proximity to surface water (depth of ground water)	1, 1, 3, and 1
26		Proximity to surface water (topology)	1, 1, 1, and 1
27		Depth of ground water (topology)	1, 1, 1, and 1
28	To protect the ground water from pollutants	Landfill area (soil cover)	1, 1, 5, and 1
29		Proximity to surface water (avoiding fault zones)	1, 1, 1, and 1
30		Proximity to surface water (topology)	1, 1, 0.2, and 0.3
31		Avoiding fault zones (topology)	1, 1, 5, and 3
32	To reduce altering the land topology	Landfill area (soil cover)	1, 0.14, 3, and 1
33		Proximity to surface water (avoiding fault zones)	1, 1, 3, and 3
34		Proximity to surface water (topology)	1, 1, 1, and 1
35		Avoiding fault zones (topology)	1, 0.2, 0.33, and 1
36	To protect the critical sites	Proximity to surface water (avoiding fault zones)	1, 1, 5, and 1
37		Proximity to surface water (depth of ground water)	1, 1, 5, and 7
38		Avoiding fault zones (depth of ground water)	1, 1, 3, and 3
39		Aesthetic (proximity to living settlement)	0.33, 1, 5, and 3
40		Road accessibility (proximity to critical sites)	0.33, 1, 1, and 3
41	To locate landfill in places easily accessed by roads	Proximity to surface water (topology)	0.33, 1, 0.2, and 0.2
42		Haul Distance (landfill Area)	5, 5, 5, and 5
43		Aesthetic (proximity to living settlement)	0.33, 1, 3, and 1
44	To minimize the solid waste haul distance	Proximity to surface water (topology)	1, 3, 5, and 1
45		Proximity to critical sites (road accessibility)	0.33, 0.2, 0.2, and 0.14
46		Landfill area (soil cover)	1, 1, 1, and 1
47		Aesthetic (proximity to living settlement)	0.33, 0.3, 1, and 1

TABLE 8: Continued.

Number	Comparison target	Comparison elements	MRSS preference sets
48	To determine the optimum landfill area	Proximity to surface water (avoiding fault zones)	1, 1, 3, and 3
49		Proximity to surface water(depth of ground water)	1, 1, 3, and 5
50		Proximity to surface water(topology)	3, 1, 7, and 7
51		Avoiding fault zones (depth of ground water)	1, 1, 3, and 3
52		Avoiding fault zones (topology)	3, 1, 7, and 3
53		Depth of ground water (topology)	0.33, 1, 3, and 3
54		Proximity to critical sites (road accessibility)	1, 1, 3, and 5
55		Solid waste haul distance (landfill area)	1, 1, 1, and 5
56		Solid waste haul distance (soil cover)	1, 1, 3, and 3
57		Landfill area (soil cover)	0.33, 1, 5, and 1
58		Aesthetic (proximity to living settlement)	0.33, 1, 1, and 1
59	To protect the soil cover from pollution	Proximity to surface water (topology)	0.33, 1, 0.2, and 0.33
60	To minimize the possibility of the landfill being seen	Proximity to critical sites (road accessibility)	0.33, 0.33, 1, and 1
61		Solid waste haul distance (landfill area)	1, 1, 3, and 1
62		Aesthetic (proximity to living settlement)	1, 0.33, 3, and 1
63	To locate the landfill as far as possible from settlements	Solid waste haul distance (landfill area)	1, 1, 7, and 7

TABLE 9: Unweighted supermatrix.

Group labels	SW	Environmental GW	FZ	TO	Land use CS	RA	HD	Operational LA	SA	Social AE	NS
Environmental											
SW	0.00	0.25	0.41	0.40	0.54	0.25	0.75	0.48	0.25	0.00	0.00
GW	0.55	0.00	0.26	0.00	0.16	0.00	0.00	0.15	0.00	0.00	0.00
FZ	0.21	0.46	0.00	0.20	0.30	0.00	0.00	0.29	0.00	0.00	0.00
TO	0.24	0.28	0.33	0.40	0.00	0.75	0.25	0.08	0.75	0.00	0.00
Land use											
CS	0.25	0.00	1.00	0.00	0.33	1.00	0.17	0.75	0.00	0.33	0.00
RA	0.75	0.00	0.00	1.00	0.67	0.00	0.83	0.25	0.00	0.67	1.00
Operational											
HD	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.49	0.00	0.67	0.83
LA	0.33	0.67	0.67	0.50	0.00	0.17	0.50	0.31	1.00	0.33	0.17
SA	0.67	0.33	0.33	0.50	0.00	0.00	0.50	0.20	0.00	0.00	0.00
Social											
AE	0.00	0.00	0.00	0.00	0.75	0.50	0.33	0.50	0.00	0.50	1.00
NS	0.00	0.00	0.00	0.00	0.25	0.50	0.67	0.50	0.00	0.55	0.00

from populated areas may minimize noise complaints. In general, these considerations are inexpensive and require minimal labor compared with the other criteria.

Finally, incorporating the participation of conflicting stakeholders minimizes the uncertainty and risk of reproducing homogenous decisions and enhances the quality of the decisions. Additionally, consistent and reliable results must be achieved [51, 52]. The landfill sitting factors and stakeholders are both predefined and grouped in sets. Stakeholder grouping and interviews are time-saving tools that effectively gather perceptions and values from the experts [53]. However, to ensure an efficient and unbiased representation of the expert

judgments, an MRSS was used to rank and calculate the judgment sets [27, 54].

**3.4. Case Study.** As consequence of rapid urbanization and economic growth the solid waste generation is increased dramatically in Selangor state. Owing to this increase, the search for and the provision of an efficient solid waste management method has become an essential matter [55]. Landfill is the main solid waste disposal method in Malaysia [4]. Figure 4(c) shows the map of Selangor including Putrajaya and Kuala Lumpur cities. The restricted area that cannot be used to construct a landfill is shown in Figure 4(b).

TABLE 10: Weighted supermatrix.

Group labels	Environmental			Land use			Operational			Social	
	SW	GW	FZ	TO	CS	RA	HD	LA	SA	AE	NS
Environmental											
SW	0.00	0.17	0.24	0.23	0.36	0.13	0.37	0.23	0.16	0.00	0.00
GW	0.31	0.00	0.15	0.00	0.11	0.00	0.00	0.08	0.00	0.00	0.00
FZ	0.12	0.31	0.00	0.11	0.20	0.00	0.00	0.14	0.00	0.00	0.00
TO	0.14	0.19	0.19	0.23	0.00	0.39	0.12	0.04	0.48	0.00	0.00
Land use											
CS	0.04	0.00	0.14	0.00	0.08	0.18	0.02	0.09	0.00	0.18	0.00
RA	0.11	0.00	0.00	0.14	0.15	0.00	0.10	0.03	0.00	0.36	0.54
Operational											
HD	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.14	0.00	0.11	0.14
LA	0.09	0.22	0.19	0.14	0.00	0.03	0.14	0.09	0.36	0.05	0.03
SA	0.19	0.11	0.10	0.14	0.00	0.00	0.14	0.05	0.00	0.00	0.00
Social											
AE	0.00	0.00	0.00	0.00	0.08	0.04	0.04	0.06	0.00	0.15	0.30
NS	0.00	0.00	0.00	0.00	0.03	0.04	0.08	0.06	0.00	0.15	0.00

TABLE 11: Limit matrix.

Group labels	Environmental			Land use			Operational			Social	
	SW	GW	FZ	TO	CS	RA	HD	LA	SA	AE	NS
Environmental											
SW	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173
GW	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085	0.085
FZ	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099
TO	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188	0.188
Land use											
CS	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058	0.058
RA	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.083
Operational											
HD	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
LA	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135
SA	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091	0.091
Social											
AE	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
NS	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021

The restriction map was obtained by implementing the guidelines issued by Department of Environment. These guidelines determine the prohibited landfill construction areas that are urban, sensitive ecological areas, heritage and cultural sites, strategic agricultural area like paddy fields, flood plain zones, swamps and water bodies, and parks. Moreover, it suggests a buffer distance, like distance from human settlements (500 m), highways (300 m), floodplain areas (100 m), and proximity to surface water (100 m buffer). The restriction area represents 80% of the total Selangor area. The top map in Figure 4(a) shows the potential area in green color. After that, seven sites were determined as a potential landfill sites based on their area. The landfill area assumed to be around 100 hectare, and this assumption is based on Pariatamby and Tanaka (2014) recommendation [56] for minimum landfill

size required for economically efficient gas collection system and the recommendation for potential impacts of landfill based on its size [57]. The ranks of the potential landfill sites are shown in Table 7. These ranks were obtained using the results of MRSS-ANP model for site evaluation criteria and Suitability Index (SI), which is the sum of products of the standardized score of each criterion multiplied by the weight of each criterion. The highest ranks are for sites numbers LF4 and LF2, with SI equal to 0.859 and 0.832, respectively, as shown in Figure 4.

#### 4. Conclusions

The siting of undesirable facilities is a process characterized by uncertainty and complexity, as well as multiple and

conflicting criteria. Determining the site evaluation criteria and constructing the dependence and connections among these factors is the key preliminary step in the siting process. Therefore, an appropriate hierarchical structure must be constructed for the evaluation criteria, and the expert groups must be determined. However, participation of all potential stakeholders in decision-making process is essential to justify and increase the decision acceptance and quality. Moreover, it minimizes the risk and avoids production of identical decision. Stakeholders grouping and interviewing are efficient way to collect their perceptions. Moreover, MRSS is a statistical tool that guarantees gathering unbiased representation of the study society, and thus it was used in this study.

Environmental criteria were assigned the highest priority (54.6%). Environmental effects have the highest complexity and represent the core of the mitigation measures. The second highest criterion was operational methods and techniques. These processes are pivotal in reducing the effects of a landfill. Social criteria were the least important because the social issues related to landfill sites can be minimized by proper management. Overall, land topology and distance from surface water were the most important subcriteria and have weights equal to 18.8% and 17.3%, respectively, whereas aesthetics and proximity to the nearest settlement have the lowest priorities of 2.9% and 2.2%, respectively. These results can be justified as the proposed site is a sanitary landfill with gas and leachate collection system; therefore, the main pollution threats are from the outside, namely, from rainwater. The risk of odor pollution is low because of the applied mitigation measures, that is, leachate and gas collection and buffering zones around the site. Furthermore, the landfill area lacks vegetation; therefore, the topology of the land primarily controls the water runoff and permeability, thus directly affecting soil erosion and surface and ground water.

Finally, this paper incorporated an MRSS and ANP to obtain a methodological framework with which to evaluate the landfill siting criteria. Compared with a traditional ANP, several additional benefits can be achieved using an MRSS-ANP model. First, this process can enhance handling of the vagueness and imprecision associated with the pairwise comparison process. Second benefit is addressing the interactions, interdependencies, and feedback among the decision evaluation criteria. Third, the combined approach can assist the decision makers to more confidently justify their decisions with minimum funds and expertise. This approach serves as a guide for applying the complex MCDM process to real-life and environmental problems in which the adequate participation of stakeholders and influence factors must be considered. This study represents a first attempt to combine statistical analysis with an ANP to prioritize landfill siting criteria, and further sensitivity analyses are suggested for future work.

## Appendix

For details see Tables 8, 9, 10, and 11.

## Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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