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Optimal Landfill Site Selection for Solid Waste of Three Municipalities Based on Boolean and Fuzzy Methods: A Case Study in Kermanshah Province, Iran

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Abstract: In recent decades, population increase and urban development have led to catastrophic environmental consequences. One of the principal objectives to achieve "sustainable development" is to find suitable landfills. Due to their physical characteristics, which have led to a lack of landfill sites and closeness to water bodies, agricultural fields, and residential areas, the cities of Javanrood, Paveh, and Ravansar were chosen as the necessary research regions. On the other hand, these landfills are unable to accommodate the growing urban population. Therefore, this study attempts to develop a framework for spotting the most suitable sites for landfill construction with these three cities as case studies. For this, 10 important driving factors (9 factors and 1 constraint) in landfill site selection were generated. Second, for the fuzzy membership function, the analytic hierarchy process (AHP) method was employed for the standardization of criteria and determining the weight of the driving factors. Then, the Boolean, weighted linear combination (WLC) and ordered weighted average (OWA) methods were utilized to spot optimal sites for landfills. Finally, two suitable sites were found for landfills: site (a) was obtained from the WLC, and site (b) was obtained from OWA-low risk some trade-off (LRST) methods. Our results proved the high efficiency of multi-criteria decision-making methodology for landfill site selection.

Keywords: landfill site selection; geographic information system; solid waste; AHP; fuzzy membership

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1. Introduction

Nowadays, the city population increase and migration from villages to cities as a consequence of flawed urban planning and environmental planning, as well as alterations in consumption patterns, have led to environmental pollution and a dramatic increase in waste generation [1,2]. One of the most crucial side effects of urbanization and industrialization is health issues which are caused by rapid population growth in cities. Hence, assessing and managing solid waste is a critical act in municipal administration. Furthermore, through solid waste biodegradation in landfills, greenhouse gases (GHGs) are released into the atmosphere, accelerating global warming [3,4]. Due to rapid economic growth, urbanization, population growth, and increasing types of waste, instead of a separate management system for each type of waste, we require an integrated, sustainable approach that encompasses all waste [5,6]. Currently, one of the major issues of the urban environment is selecting the methods to eliminate and dispose of solid waste from the city [7–9]. A comprehensive solid waste management strategy should take into account all aspects, from waste generation to disposal procedure, in order to preserve public health and promote environmental sustainability [10–12]. Waste management consists of numerous factors, e.g., waste source reduction, waste collection, on-site processing and storage, waste transportation, material and energy recovery, and waste disposal [13,14]. Despite various studies on alternative management methods, landfilling continues to be an inseparable part of solid waste management [15,16]. Municipalities and local governments are urged to manage a healthy and livable environment to overcome these challenges [17–19]. The use of singular tools and technologies is imperative to achieving a suitable landfill site. Although landfilling is one of the most broadly used and cost-effective disposal technologies, it requires detailed and wide evaluation, which takes into account the necessities of governmental and environmental regulations [6,20]. The landfill site selection depends on the specific factors which are encountered in a special significance and even have a limitation in the selection of landfills [21,22]. To assess, design, and select a suitable landfill site, extensive research has to be conducted, and all related factors, which include land use, geology, elevation, slope, distance from the residential area, fault, river, protected areas, and the road, should be considered [23–25]. In other words, selecting an optimal landfill site requires multi-criteria decision making (MCDM) [22,26,27]. Many landfill site selection studies have been conducted in Iran, such as in Fars province [28], in Naein [29], in Rudbar [30], in Ahvaz [31], in Naqadeh [32], and in Gilan city [33].

Additionally, plenty of investigations into landfill site selection have been conducted all around the world, such as in Iraq [34], in Morocco [35], in Serbia [36], in Turkey [37], and in Pakistan [38]. In these studies, modern tools, such as geographic information systems and remote sensing, are used for optimal landfill site selection in most of the world.

According to the literature review, the most common methods for landfill site selection, approaching multi-criteria decision (MCDM) are weighted linear combination (WLC), ordered weighted average (OWA), analytic hierarchy process (AHP) [39–42], fuzzy analytic hierarchy process (F-AHP) [6,29,43,44], TODIM, fuzzy TODIM [45], analytic network process (ANP) [26], fuzzy analytical network process (F-ANP) [16], and best–worst method (BWM) [1,10]. They all use GIS to combine spatial data, such as maps, aerial photographs, and satellite imagery with quantitative and qualitative databases, to select an optimal landfill that has the least negative impact on the environment. The main novelty of this research is the combination of AHP, fuzzy logic, Boolean, WLC, OWA and multi-criteria decision making for landfill site selection between three cities with special topographic conditions, such as steep slopes, and the existence of a large number of faults and rivers. Another addition to the novelty is the exploration of a landfill site which is accessible to all three cities in order to reduce the costs and also diminish the negative environmental impacts.

The reasons for choosing these three cities as the study area are that first, due to the topographic condition of Paveh city, there is no landfill site; second, the landfill of Ravansar city is very close to the water bodies and agricultural lands, so wide conflagrations spread rapidly through the land; and third, the landfill of Javanrood city is actually in the residential area. Additionally, the current landfills are insufficient to meet the growing population of this city. On the other hand, the accumulation of these cities' waste can cause a lot of health and environmental problems, such as leachate, soil pollution, and stench. Therefore, according to the demand for landfill sites in these cities and their proximity to each other, the best landfill was chosen outside of the residential area that has the least negative environmental impact. Furthermore, based on previous studies, the most important parameters for selecting a landfill site are as follows: residential areas [28], land-use type [46], faults, and water bodies' proximity [41], land slope [1], elevation [47], geology [5], protected areas [6], and roads [16]. The hypothesis of this research is that landfill site selection depends on driving factors, such as elevation, slope, geology, land use, distance from the river, road, residential area, protected area, and faults, and that by using GIS-based methods and the MCDM approach, suitable areas can be spotted. Due to data scarcity, especially in the developing countries, we need to make some simplifications; therefore, we select some more important driving factors. Selecting the optimal landfill site can significantly minimize the environmental impacts of landfills and help in achieving the sustainable development goals.

The goal of this investigation was to utilize GIS for selecting a suitable landfill site for three neighboring municipalities, as the case study, outside of the residential areas by regarding the environmental parameters as an efficient strategy that takes into account all constraints at the same time. As a result, first, the important factors for landfill site selection, including distance from water bodies, roads, faults, residential areas (city and village), protected areas, elevation, land use, geology, and slope, were applied. Second, the AHP method was used for the standardization of criteria and weighting of the factors. Then, by using the Boolean and fuzzy methods, which include WLC, and OWA, suitable locations were investigated for proper waste disposal.

2. Materials

2.1. Study Area

The study area in this paper was three cities, Javanrod, Paveh, and Ravansar, which are located in the North of Kermanshah province in the west of Iran (Table 1, Figure 1). These cities extend between 46°21′ E and 46°48′ E longitudes and 34°31′ N and 34°59′ N latitudes. These three cities are in the mountainous area, as the general height of the study area is varied from a minimum of 1540 m to a maximum of 3350 m above mean sea level with an area of 276,127 ha and a population of 183,257 people [48]. The average annual temperature is 15.7 °C, and the average annual precipitation is 643.6 mm, so they have a cold and moderate humid climate. The total forest area of these three cities is 113,025 ha, the total area of dryland cultivation is 45,476 ha, and the total area under irrigated cultivation is 14,288 ha. The increase in economic and industrial development and population growth caused solid waste generation enhancement in these cities. It is estimated that solid waste production in the study area is 180 tons/day, as Javanrood, Paveh, and Ravansar have about 100-, 40-, and 30-ton production of waste per day, respectively [48].

Table 1. Statistics of three municipalities of case study.

	Population	Average Annual Temperatures (°C)	Precipitation (mm)	Forest Areas (ha)	Dryland Cultivation (ha)	Irrigated Cultivation (ha)	Solid Waste Production (ton/day)
Javanrood	75,169	16.5	590.9	47,925	19,064	2647	100
Paveh	60,431	15.6	803	46,875	384	1854	40
Ravansar	47,657	15.1	536.9	18,225	26,028	9784	30
total	183,257	-					180

2.2. Data Preparation

The first step in finding the best accessible location for the landfill site is to define the appropriate criteria. As it is a multi-criteria decision and has serious environmental, economic, and social impacts, they were chosen based on national regulations, standards and guidelines, local features, previous studies, expert assessments, and data availability [49–54]. By gathering the data layers from the National Geoscience Database of Iran, some factors and constraints were determined, as explained below (Table 2). Factors are indicators that increase or decrease the final suitability for a specific goal, and the constraint, which is usually based on the Boolean method (0 and 1), limits the goal. In this study, we do not consider the role of some criteria, such as land ownership, that can affect the final site selection or some criteria because there are no data on them. The reason is that such criteria cannot be entered into the model; however, we take into account these criteria at the stage of the site survey.

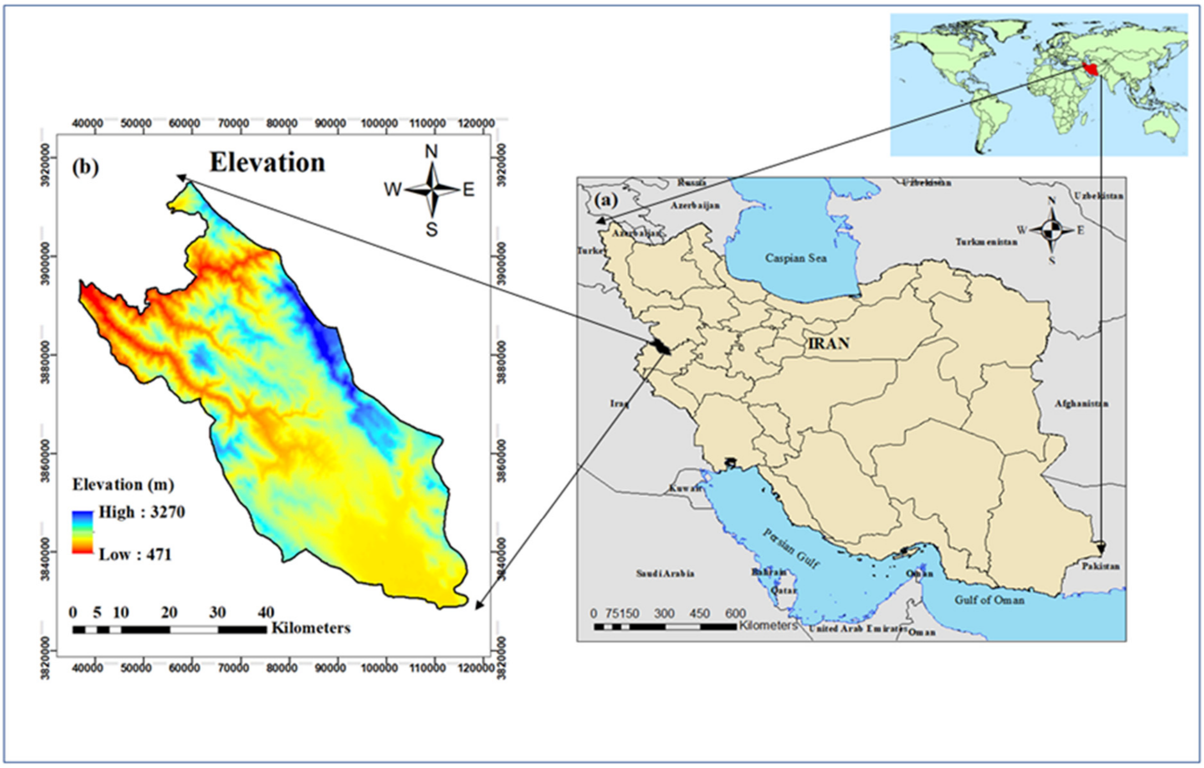

Figure 1. Location of the study area in Iran (**a**) and Kermanshah province (**b**).

Table 2. The criteria used for landfill site selection.

Criteria	Buffer Area	Rating	Reference
Slope	32°<	1	[41]
	24–32°	2	
	16–24°	3	
	8–16°	4	
	8°>	5	
Elevation	300 m>	1	[55]
	2500 m<	2	
	300–900 m	3	
	900–1500 m	4	
	1500–2500m	5	
River	0–1000 m	1	[56]
	1000–1500 m	2	
	1500–2000 m	3	
	2000–2500 m	4	
	2500 m<	5	
Well	0–500 m	1	[16]
	500–1000 m	2	
	1000–1500 m	3	
	1500–2000 m	4	
	2000 m<	5	
Road	0–300 m	1	[57]
	1500 m<	2	
	300–600 m	3	
	600–900 m	4	
	900–1500 m	5	

Table 2. *Cont.*

Criteria		Buffer Area	Rating	Reference
Fault		0–500 m 500–1000 m 1000–1500 m 1500–2000 m 2000 m<	1 2 3 4 5	[58]
Residential area	Urban area	0–1000 m 1000–2000 m 2000–3000 m 3000- 4000 m 4000 m<	1 2 3 4 5	[31]
	Rural area	0–500 m 500–1500 m 1500–2000 m 2000–2500 m 2500 m<	1 2 3 4 5	
Protected area		0–1000 m 1000–1500 m 1500–2000 m 2000–2500 m 2500 m<	1 2 3 4 5	[59]

Description of Factors and Constraints

Below is a detailed explanation of the most significant criteria that were chosen and assessed based on the literature review; also, this section describes how to create thematic maps of factors and constraints.

- Factors

Slope: The slope of a region is related to its topography, which determines elements such as surface flow velocity, runoff characteristics, soil water content, and erosion potential. The slope of the ground is important for transportation, constructing access routes, and managing the flow of surface water around the landfill site. Leachate may go great distances and pollute a broad region if the slope of an area is severe [46], particularly in places with large elevation fluctuations [1]. As a result, the landfill is built on a mild slope, preferably less than 6°.

Elevation: The higher elevation makes access difficult and results in higher transportation costs. In addition, the transfer of leachate to lower places becomes easier in the case of elevated sites. As a result, sites at higher elevations receive less weightage [46].

River: Due to the risk of leachate pollution, the landfill site should not be located near surface water bodies. The generation of leachate endangers not just surface water, but also groundwater. It is a significant issue for sanitary landfills. A 500 m buffer zone must be established around the city's water bodies [16,46].

Well: Wells are critical for preparing water sources for activities and drinking water, and they are impacted by a variety of circumstances, including agricultural and landfill responses. To avoid pollution, the landfill must be 40 m away from the wells. The distance between 0 and 40 m is given with a value of 0, and the higher the distance, the bigger the value of 1 [41].

Road: To prevent transportation costs, which also increase environmental pollution and the expense of creating new roads, the landfill site should not be too far from the road. It should not be too close to the road either because of visual impacts, terrible smells and waste dispersion [1,46]. As a result, a 300 m buffer was given on both sides of the road's centerline.

Fault: Distance to faults in situations such as earthquakes has a significant function in reducing contamination and site deconstruction [41]. The greatest distance from the fault was awarded the highest value.

Residential area: The location of a landfill near residential areas may create public issues, such as air pollution, visual pollution, noise pollution, fire hazards, and disease outbreaks. For these reasons, landfills should be positioned at a reasonable distance away from residential areas [46]. The residential area is used as both a factor and a constraint. First, there must be no landfill within a one-kilometer radius of the residential area (constraint), second, the farther from the residential area, the more suitable for the landfill (factor) [60]. A buffer of 500 m was supplied for high-density regions in this research, and a buffer of 300 m was provided for low-density areas.

Geology: Geology is a criterion that gives us information about groundwater. The landfill site should be geologically suitable and resistant to earthquakes, volcanos, landslides, and erosion. Because Iran is positioned in the earthquake belt of the world, the occurrence of earthquakes in different regions is natural and unavoidable [1]. Landfills should be located at least 200 m away from potentially hazardous regions.

Land use: According to Iran's Environmental Protection Organization (IEPO) laws on landfill site selection, the landfill must not be selected for certain land uses, such as agricultural and forest, wetlands, plant and animal habitats, riverbeds, farmlands, groves, and pastures [41]. In the event of unavoidable negative consequences, the least valued land can be utilized as landfills by classifying and assessing the degree of quality of each site [1].

- Constraints

Protected area: National parks and historical sites, according to IEPO, must not be used as a landfill. So, the landfill must be at least 1000 m in distance from these areas [41]. Bozin area, Quri Qale Cave, and Sarab Yavari area are three protected areas that are located in our study area. Bozin area, which is located in the northwest of Kermanshah province, was registered as a protected area in 1999 to conserve the valuable and endangered species of Iranian deer (Capreolus capreolus) and habitat values with an area of 23 thousand ha. Quri Qale Cave is the largest water cave in the Middle East, which was first registered as a national natural monument of Iran by the Department of Environment and then introduced as a natural heritage of Iran. This cave is located 25 km from Ravansar city and in the neighborhood of a village of the same name. Sarab Yavari is a beautiful limestone spring that is a significant ecosystem and is one of the destinations for migratory birds. The plants and trees that grow next to it are essential for the natural balance of the region. This area is located 21 km from the Kermanshah–Ravansar Road.

3. Methodology

3.1. Research Framework

Furthermore, as the factors used in the site selection have different units, it is necessary to standardize the factors before combining them [61]. The fuzzy membership function, and also linear and S-shape functions were utilized for standardization in this study. After applying AHP to weight each criterion, WLC and OWA selected functions to prioritize the alternatives of landfill sites based on minimum area and maximum suitability. GIS is a powerful tool that can manage large volumes of data from different sources, and simulate and manage social, economic, and environmental parameters. In the present study, WLC and OWA were applied in a GIS environment (ArcGIS10.5) to evaluate the suitability of selected landfill sites by using tools such as buffer, clip, intersect, union, merge, dissolve, identify, and weighted overlay eras. A flowchart of the methodology followed throughout the study is illustrated in Figure 2.

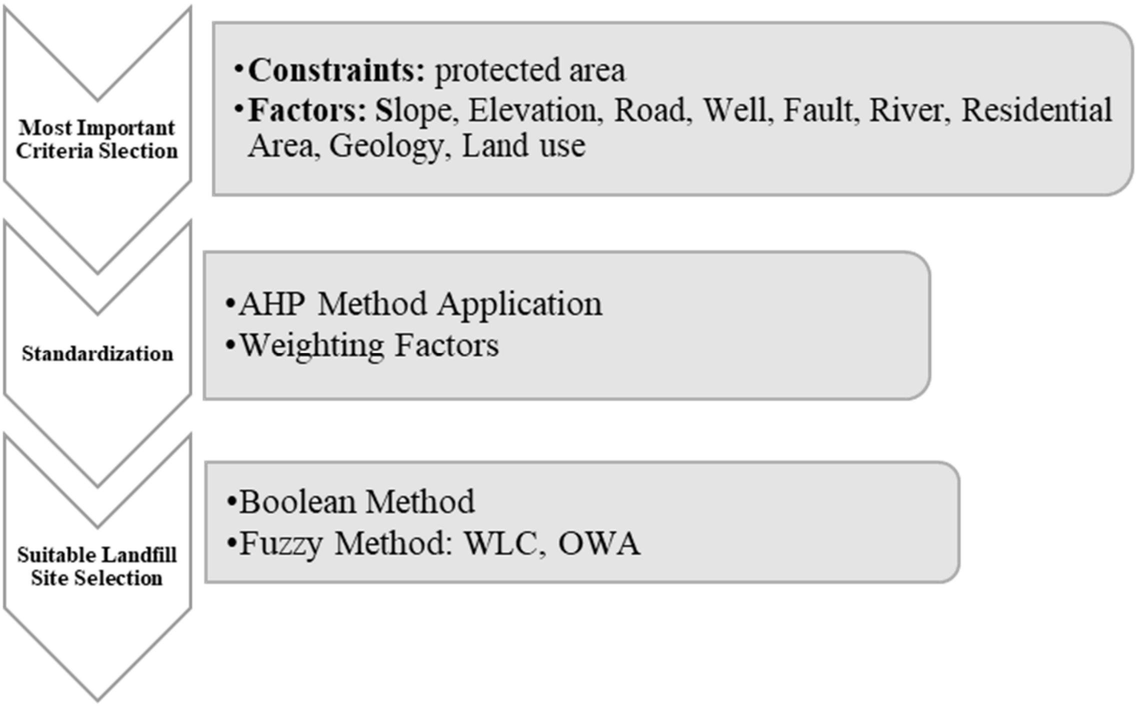

Figure 2. Flowchart of the methodology adopted in the study.

S shape and linear membership function are the most prevalent indices that show the gradual changes to the complete membership. The linear membership function is calculated with Equation (1) [62]:

$$x_i = \frac{(R_i - R_{min})}{(R_{max} - R_{min})} \times standardized\ range \tag{1}$$

In Equation (1), R_i is the first value (raw score) of the factor, R_{min} is the minimum score, and R_{max} is the maximum score.

The sigmoidal membership function is applied with the use of Equation (2) [63].

$$\mu = cos^2\alpha \tag{2}$$

If the membership function is of the reduction type, α will be calculated by Equation (3), and if it is of the increasing type, Equation (4) will be used to calculate α [64].

$$\alpha = \left(1 - \frac{(x - control\ point\ a)}{(control\ pointb - control\ point\ c)}\right) \times \frac{\Pi}{2} \tag{3}$$

$$\alpha = \frac{(x - control\ point\ c)}{(control\ point\ d - control\ point\ c)} \times \frac{\Pi}{2} \tag{4}$$

In Equations (2)–(4), a, b, c, and d are control points.

First, in the Boolean method, all criteria were converted to (0,1), and finally, they were combined with intersection (AND) and union (OR) operators. In this study, we used the "AND" operator because the Boolean is a method that cannot stand any risk. In this method, all criteria have maximum suitability [61]. Figure 3 shows the effective criteria used for site selection and the criteria used in the Boolean method.

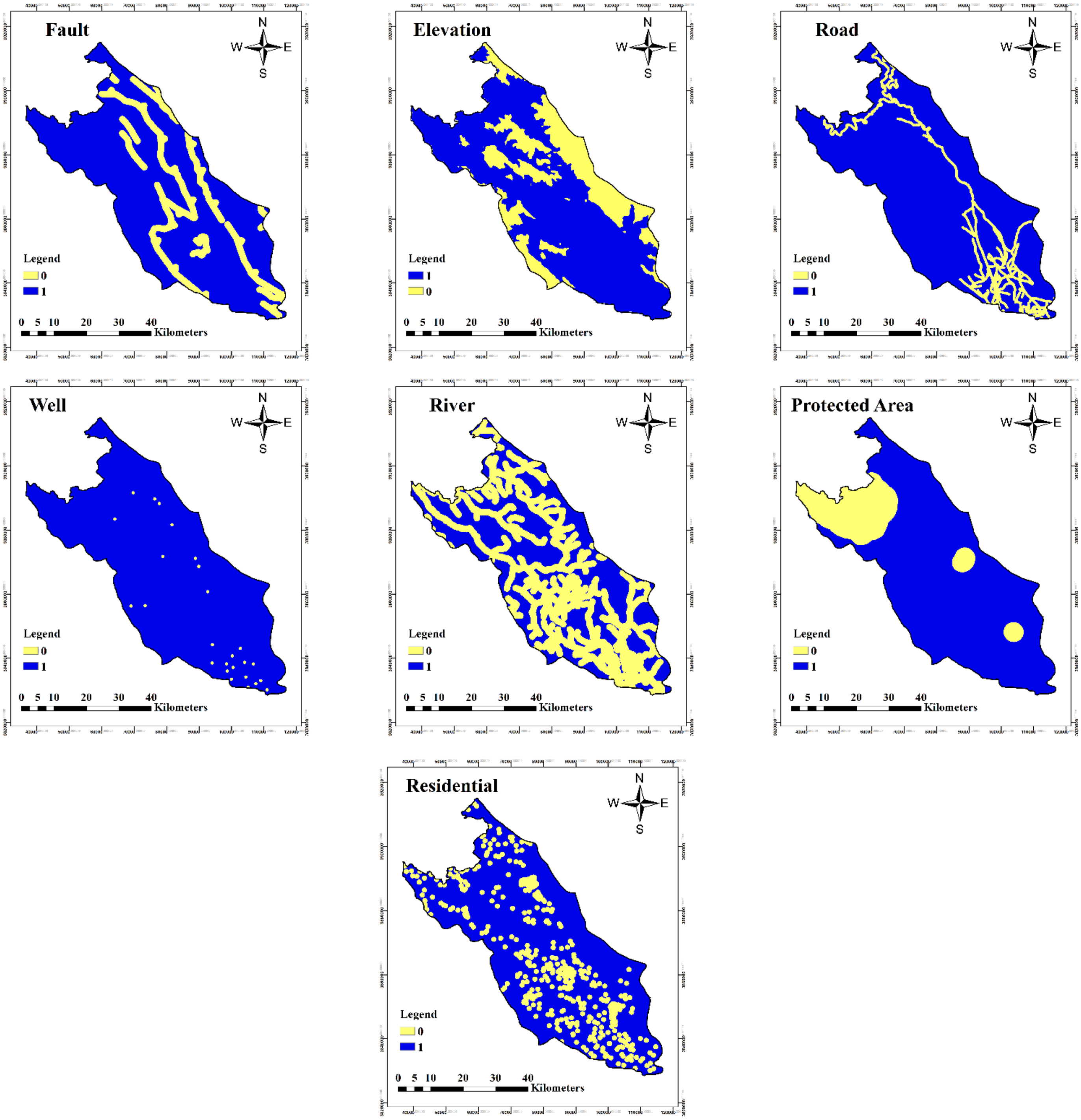

Figure 3. The criteria used in the Boolean method.

3.1.1. Weighted Linear Combination

Weighted linear combination (WLC) or simple additive weighting (SAW) is the most common method in analyzing multi-criteria evaluation. Factors were combined by assigning a weight to each of them, followed by a summation of the results to yield a suitability map [62]. In the WLC method, the final suitability was obtained with the use of Equation (5).

$$S = \sum w_i x_i \tag{5}$$

where S is the final suitability, w_i is the weight of factor i, and x_i is the criterion score of factor i. Based on this equation, the alternative that has the maximum weight is more suitable for our goal. Equation (6) is used when constraints are applied as criteria [65].

$$S = \sum w_i x_i \times \Pi\, c_j \tag{6}$$

where c_j is the criterion score of constraint j, and Π is the product of the constraints.

The fundamental tools for evaluating such models are provided by all GIS software systems. In this study, the AHP method was utilized to weigh the criteria and compare effective factors by pairwise comparison (and the total amount of all weights of factors equal 1). For this method, the consistency ratio (CR) is a coefficient that shows the weight accuracy credit; this amount must be less than 0.1 [62]. Suitable site selection was performed based on two attributes: minimum area and maximum suitability. After selecting a suitable landfill site, the WLC method was used to prioritize the place by environmental criteria ([58]; Figure 4).

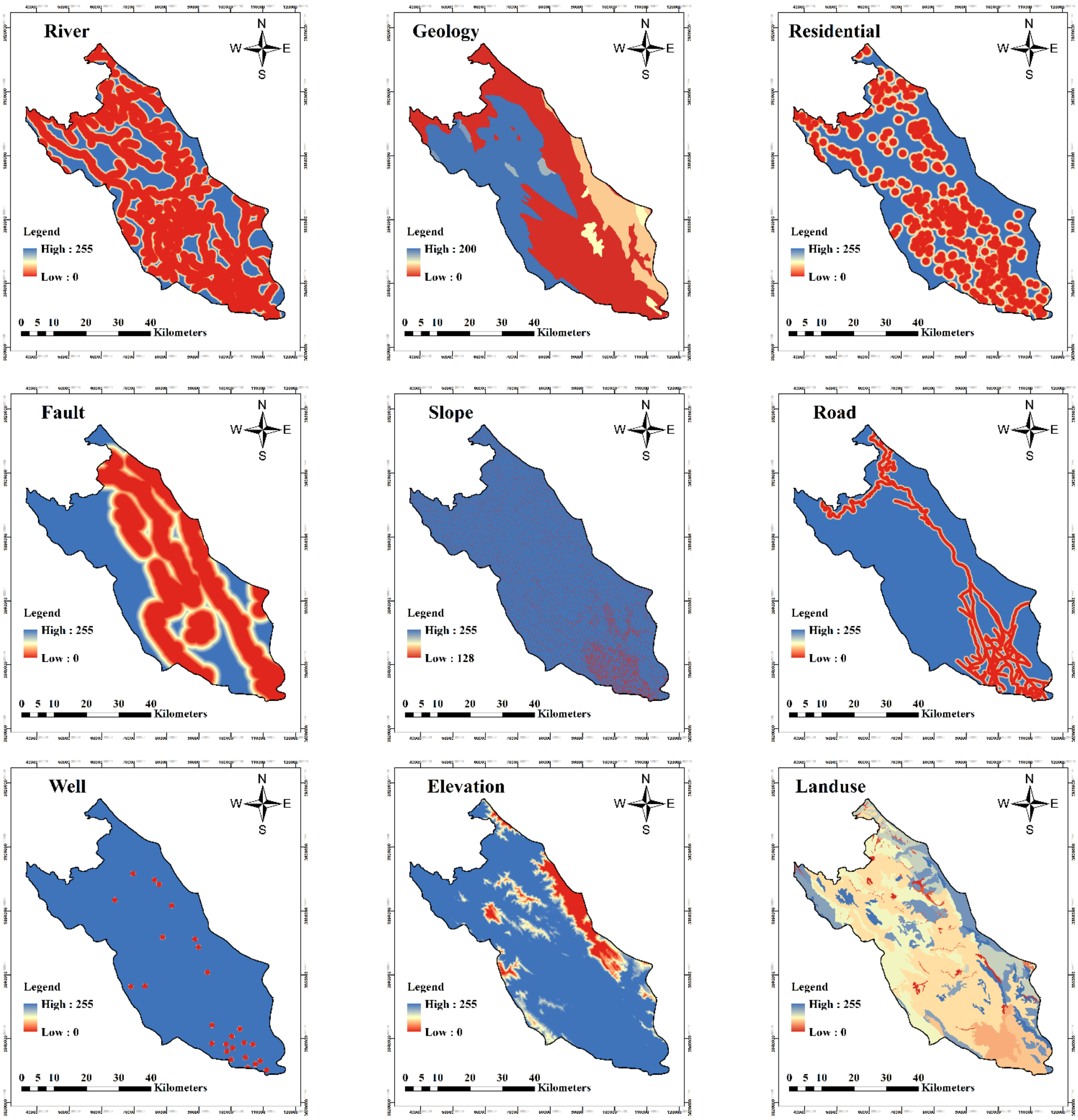

Figure 4. The criteria of the fuzzy factor.

3.1.2. Ordered Weighted Averaging

The ordered weighted averaging (OWA) operator is a technique for ranking criteria and addressing the uncertainty from their interaction. This method employs a continuous scaling scenario with local and global weights between risk taking and risk averse. The OWA method was developed by [66] as a generalization of the Boolean coverage operations and WLC. The weighted averaging method is a complete spectrum of spatial strategic decisions that delivers the primary gradation dimensions in an extension between the involved criteria and risk measurement in the solution [62,67]. One of the abilities of the WLC method is that it has maximum compensation or trade-off. According to this feature, the criteria with more weight compensate for the criteria with less weight, and the WLC method facilitates the Boolean tough decision [62]. The OWA method calculates the amount of risk in the final site selection. This method is a combination of multi criteria evaluating (MCE) that includes two groups; the first one controls the role of the specific criteria, and the second one controls the total weight [68].

4. Results and Discussion

The results from the application of the presented methodology were zones of varying regional land suitability. To facilitate decision making, the zones were rated in decreasing order based on the value of their regional land suitability. In the case of fuzzy membership, after the determination of the effective criteria layers in the site selection, the criteria were standardized with the use of the fuzzy membership function (Table 3).

Table 3. Control point and fuzzy membership function to standardize the used factors.

Factor	Control Points a, b	Control Point c, d	Function	Function	Boolean Logic	Environmental Condition
Slope	11	30	Sigmoidal	decreasing	-	-
Elevation	1800	3000	Linear	decreasing	1800–3000	-
Distance from river	1000	2000	Sigmoidal	increasing	1000	500–800
Distance from road	300	1000	Sigmoidal	decreasing	400	300
Distance from well	600	900	Sigmoidal	increasing	500	400
Land use	0	0.8	Linear	increasing	-	-
Geology	0	0.8	Linear	increasing	-	-
Distance from fault	2000	5000	Linear	Increasing	1000	200
Distance from residential areas	1000	2000	Linear	increasing	1000	1000

According to the AHP method weighting, the maximum weight was related to the slope (0.2936), distance from the fault, and elevation (0.1705), and the minimum weight was related to the geology (0.0312), which may be why geology overlaps with another Boolean factor (Table 4).

Table 4. AHP pairwise comparison and their weights.

		1	2	3	4	5	6	7	8	9	Weights of Factors	Consistency Ratio
1	Geology	1									0.0312	CR = 0.01
2	Elevation	5	1								0.1705	
3	Distance from river	2	1.3	1							0.0571	

Table 4. *Cont.*

		1	2	3	4	5	6	7	8	9	Weights of Factors	Consistency Ratio
4	Distance from road	2	1.3	1	1						0.0571	
5	Distance from well	2	1.3	1	1	1					0.0571	
6	Land use	4	1.2	2	2	2	1				0.1058	
7	Slope	7	2	5	5	5	3	1			0.2936	
8	Distance from fault	5	1	3	3	3	2	1.2	1		0.1705	
9	Distance from residential areas	2	1.3	1	1	1	1.3	1.5	1.3	1	0.0571	

Due to the fact that land use and geology maps have no units, their classes were scored separately, which were quantified according to the amount of suitability and were standardized based on the increasing fuzzy function (Tables 5 and 6).

Table 5. Value of different land uses in fuzzy and Boolean methods.

Land Use	Fuzzy Value	Boolean Value
Agriculture	102	1
Garden	55	1
Dense forest	128	1
Dryland farming	128	1
Good range	178	1
Low forest	153	1
River	0	0
Mix(agriculture-garden)	76	1
Mix (agriculture-dryland farming)	115	1
Mix (dryland farming-x)	128	1
Mix (low forest_ x)	165	1
Mix (moderate forest_ x)	140	1
Mix (moderate range_ x)	216	1
Mix (poor range_ x)	242	1
Mix (urban-x)	0	0
Moderate forest	128	1
Moderate range	229	1
Poor range	255	1
Rock	0	0
Urban	0	0
Water	0	0
Woodland	0	1

Table 6. Value of different geologies in fuzzy and Boolean methods.

Geology	Fuzzy	Boolean
Bangestan formation	200	1
Shely limestone	170	1
Sandstone	100	1
Biston limestone	75	1
Traces/Deposit	25	0

The OWA method can rank the "AND" scenario and "OR" scenario, and here, this ranking was performed by global and local weighting. Global weighting was determined according to the decision-maker's judgment, or by paired comparison to compensate control for another criterion, while the local weight was based on the pixel rank of a weighted factor and the AHP ranking [68,69]. One of the advantages of the OWA method is that researchers can produce a lot of maps and solve the problems related to them by reordering and changing criteria. This method shows a scenario between "AND" and "OR" against the Boolean method that only shows the "AND" scenario [70]. The level of the trade-off between criteria is directly controlled by the ordered weights [71]. The degree of dispersion of weight is controlled by the trade-off that shows the amount of compensation. Below, tables show the level of compensation and risk control (Figure 5).

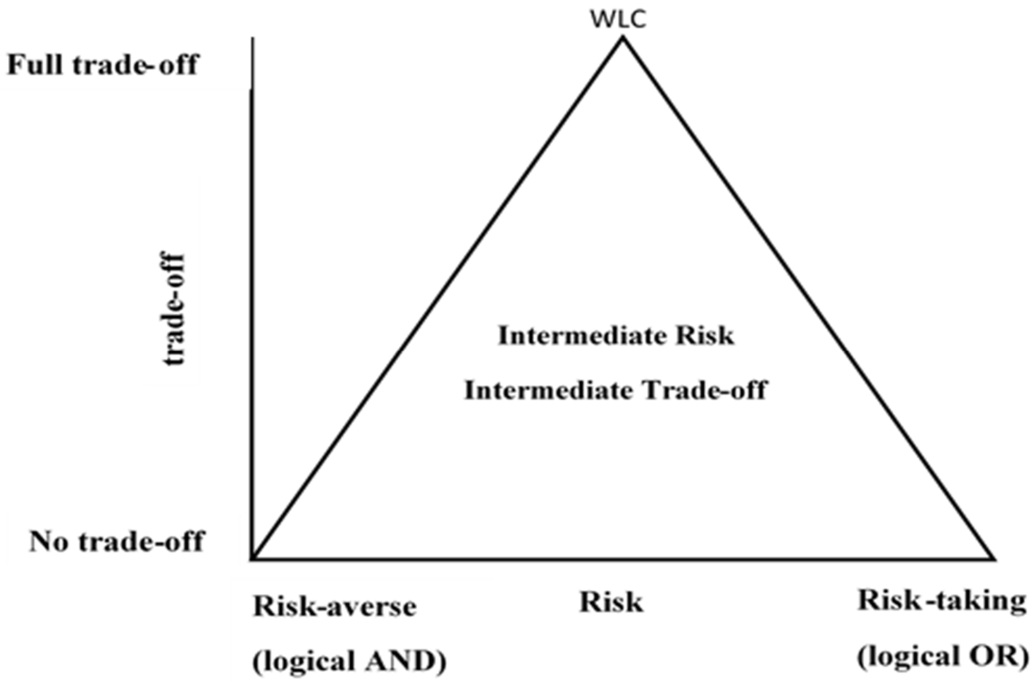

Figure 5. Decision strategy space: the Boolean trend and WLC position.

The effective criteria in the Boolean method show that maximum constraints were related to distance from the residential area, distance from rivers, and distance from protected areas (Figure 3). The result of the criteria overlay using the Boolean method shows that 0.096 percent of the study area (26593 ha) has suitable landfill conditions (Figure 6, Table 7).

Table 7. Weight of OWA for compensation of risk.

Method	Order	Trade-Off	ORness	ANDness
AND	(1, 0, 0, 0, 0, 0, 0, 0, 0)	0	0	1
LRST (MIDAND)	(0.5, 0.2, 0.1, 0.06, 0.05, 0.04, 0.03, 0.02, 0)	0.61	0.165	0.835
WLC	(0.0909, 0.0909, 0.0909, 0.0909, 0.0909, 0.0909, 0.0909, 0.0909, 0.0909,)	1	0.5	0.5
HRST (MIDOR)	(0, 0.02, 0.03, 0.04, 0.05, 0.06, 0.1, 0.2, 0.5)	0.61	0.8375	0.1625
OR	(0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1)	0	1	0

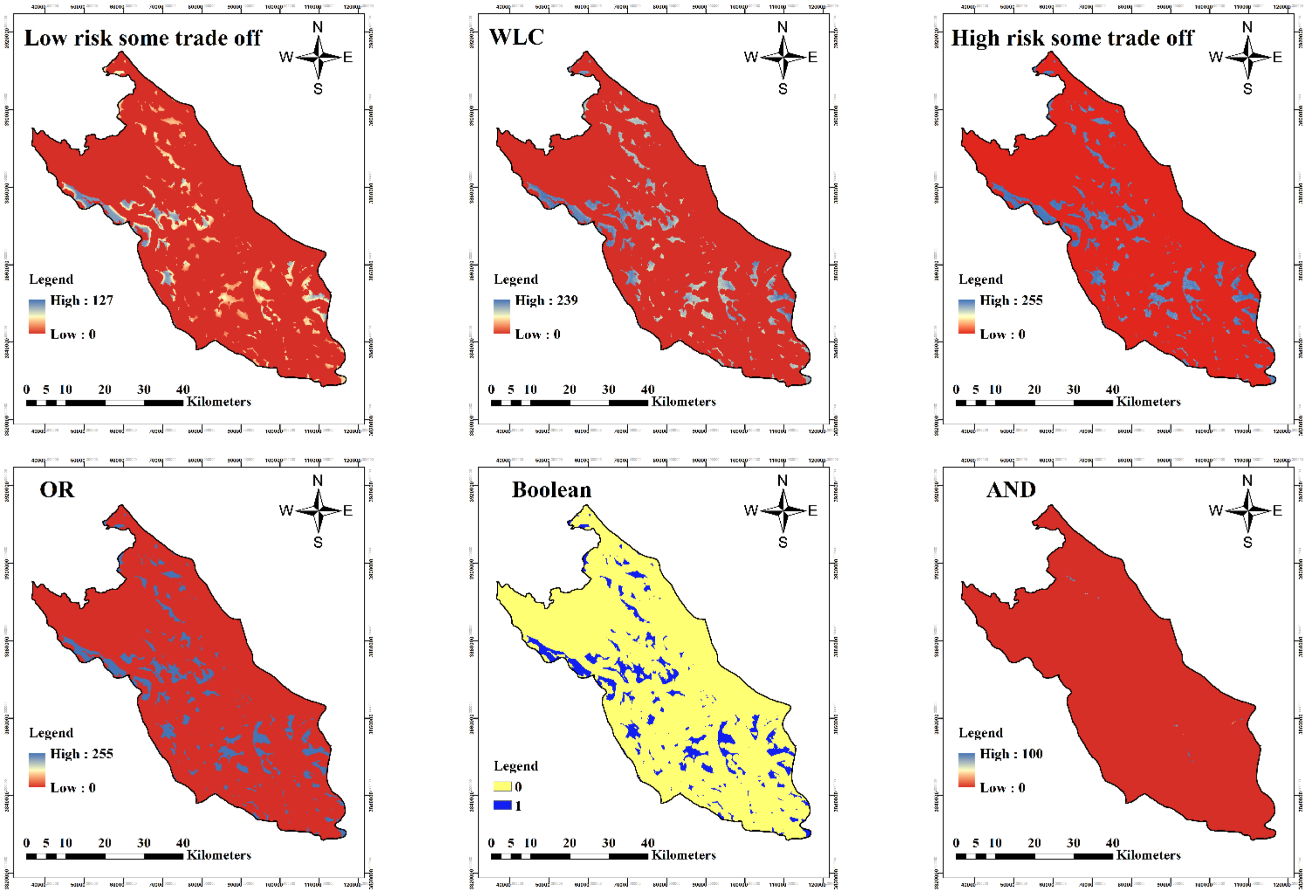

Figure 6. Suitability maps derived by Boolean, OWA, and WLC methods.

The result from the WLC method illustrates that about 95.5 percent of the study area does not have any suitable site for landfill. The final output amount of suitability was 112,690 ha. Based on slope, geology, land use, elevation, and distance from the river, road, fault, protected areas, and residential areas, the OWA and WLC methodologies identified 15 sites for landfill, whose zonal land suitability ranged from 98 to 253 (Tables 8–10). This study attempted to evaluate the general suitability of all available regions for landfilling in order to assist in the selection of restricted sites in subsequent investigations. At this point, it is critical to note that the actual availability of landfill areas may be significantly lower than what is expressed in Tables 8–10. Other considerations of the land should be taken into account, such as more analysis of present and future land uses, the land's economic benefits, and so on. In terms of proximity to the three cities, 2 of the 15 selected sites that met the environmental criteria (a, b) received the highest score (Figures 7 and 8). Site (a) was acquired through the WLC, and site (b) was acquired using OWA-low risk trade-off (LRST) techniques.

Table 8. Shows result from WLC site selection.

New ID	Hectare	Average	Max Value	Min Value	Old ID
1	48	233	235	227	1547
2	136	231	235	225	1552
3	115	230	232	225	1687
4	1963	228	236	225	2
5	40	228	232	225	1627

Table 9. Shows the result of (LRST) site selection.

New ID	Hectare	Average	Max Value	Min Value	Old ID
1	42	106	119	80	13
2	65	100	110	80	31
3	58	99	110	80	129
4	98	98	110	80	206

Table 10. Shows the result of high risk some trade-off (HRST) site selection.

New ID	Hectare	Average	Max Value	Min Value	Old ID
1	633	253	253	253	2
2	47	253	253	253	150
3	152	253	253	253	546
4	75	253	253	253	687
5	117	253	253	253	725
6	40	253	253	253	780

After small areas are selected by general criteria, the procedure is implemented because most of these criteria require extensive field surveys. The investigation of the suitability level at which the sites were selected during the allocation process revealed that there was little eligible land for landfilling. This has an impact on the waste treatment system's costs as well as the health of the environment and the residents. In particular, using places with inadequate soil or those close to rivers will result in low suitability. On these occasions, it is supposed to apply more advanced techniques and tools to improve environmental protection, which raises expenses. In addition, using land in proximity to residential areas may result in low appropriateness, which might cause a lot of public contention. Based on fundamental problem solving, planning and management are founded. Beginning with the definition and description of the problem, they then move on to different types of analyses, such as simulation and modeling, and then progress to prediction, prescription, and eventually design, which frequently comprises assessing potential solutions to the problem [72]. The large number of methods provided to help decision makers with planning tasks, according to Khan et al. [73], contain modeling tools. The methodology described in this study exhibits the use of GIS as a decision support system and combines the assessment capabilities of the MCDM with the analytical tools of GIS. Combining all of the criteria (factors and constraints) for landfill along with the minimum area desired restriction (20 ha), the model's initial phase evaluates if there is available land for landfills.

According to the land-use factors, site (a) is in a poor pasture, and site (b) is located in dryland farming; therefore, based on the economic factors, site (a) is a better choice than site (b). Another point that should be taken into consideration is the distance from the road; site (b) is near the road, but site (a) is far from the main road, which needs a new one to be constructed to reach the main road. The area of site (a) is 136 ha, and the area of site (b) is about 42 ha; consequently, site (a) is better than site (b). Site (a) is nearer to three cities, compared to site (b), so (a) is more suitable.

Figure 7. Location of the site (a).

Figure 8. Location of the site (b).

5. Conclusions

The ability of GIS and remote-sensing techniques to handle large volumes of data from various sources and their usage in an organized and systematic manner makes them very useful in the site-selection process, where multi-criteria evaluation can be effectively applied to address the issues related to municipal solid waste management due to its low cost and rapid implementation. This study sought to demonstrate how the combination application of AHP and the fuzzy logic-WLC and OWA methods based on MCDM succeeds in municipalities with the conditions of these three cities. The most important results of this research include the following:

- The location of the case study is in a mountainous area with steep slopes which decreases the final suitability. By surveying the current landfills in these three cities, it was concluded that some criteria are not regarded, such as site area for future, distance from the residential area, well, fault, river, and agriculture.
- Due to the different criteria units used in the site selection, the final data were standardized by weighting the criteria, and then the suitability map was produced. Therefore, in the Boolean method, there is a limit to the selection of places that have little area. Among these methods, OWA and WLC showed better efficiency, due to the constraint in the Boolean method.
- Out of 15 sites that were chosen based on the required criteria, two sites were considered the most suitable candidates since they matched all the requirements. Ultimately, only one site was introduced in this research based on land use, economics, social criteria, and other factors.

It is advised for future studies that the choice of parameters and even methods be based on climate, vegetation type, and other considerations affecting the type of landfill. In this research, 10 parameters were used, which could be expanded in the future to lead to more accurate results, such as groundwater depth and dominant wind direction of the study area.

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