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Research Article

Multicriteria Evaluation-GIS Integration Framework for Landfill Site Selection in Limited Space Regions: A Case Study in the West Bank

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Unplanned solid waste disposal is a global challenge that has created severe environmental and health problems, especially in developing countries. The West Bank, a developing region in the Middle East, is an example of a limited space region that suffers dangerous pollution, hazardous odors, and contaminated plantations as consequences of unplanned solid waste dumping sites and landfills. Limited space allotted to the West Bank Palestinians, making it highly inhabited, is the main reason behind the current allocation of solid waste dumping sites that are close to the residential area. Multicriteria evaluation (MCE) method, integrated with geographic information system (GIS) software, is employed here to find optimal solid waste disposal locations in the West Bank. The model assumes the input of two-factor types, namely natural and artificial. These two types include nineteen criteria. Based on the MCE method, a hierarchy criteria scheme has been developed and used in data analysis by GIS. The hierarchy scheme divides each required criterion into subcriteria with rankings to be presented. Each criterion has been weighted and intersected by the weight overlaying process in GIS to provide the most suitable locations for regional landfills inside the West Bank. Each existing landfill location has then been examined for compliance with the criteria. The results show that all regional five landfills, including a future planned site, exist in the restricted area determined here. However, one landfill is close to suitable places and can be relocated easily. Moreover, about 323.57 km^2 can be sufficiently used for regional landfills inside the West Bank, mostly available in the Eastern parts. The findings confirm the applicability of the MCE-GIS integration strategy in future planning of landfill siting in areas of limited space.

1. Introduction

Solid waste disposal is a major global challenge, commonly in random dumping sites. To minimize the disposal problems, regional landfills are globally used [1–3]. These landfills are usually used as places to collect unsorted solid waste. They have some advantages as they help to minimize random dumping sites and can be used in producing power from produced gases. However, these locations have several disadvantages, especially if not planned and designed way sustainably. Living close to landfills is a threat to the health of the residents as waste disposal creates hazardous gases like methane, carbon monoxide, hydrogen sulfide, and ammonia in addition to carbon dioxide gases [4]. As mentioned in Vasarhelyi, living within a mile of hazardous landfills increased the risk of congenital malformations in children by 12% in New York [5]. Moreover, in Limpopo Province, South Africa, a study was conducted to evaluate the perception of people who live close (100–500 m) and far (1-2 km) from landfill sites. The results indicated that 78% of participants who live close to landfills complained of bad odors and bad air quality. In addition to that, they reported illnesses such as flu and weakness in their bodies. And 56% indicated their fear of having landfills close to residential areas [6].

Landfills demand careful planning together with effective design. Planning defines the criteria to select the optimal locations for new landfills that minimize the effects on the surroundings [7]. Design, on the other hand, defines how the landfill should be built while avoiding contaminant leaching, by various methods. Landfill site planning is difficult and complex to achieve, as it deals with various social, cultural, economic, environmental, and physical factors that need to be evaluated [8–10]. The economic factors focus on the cost of moving wastes from their production places to landfills [8]; the environmental factors focus on possible pollution and how to minimize its negative effects [11]; and the health, social, and cultural factors focus on how to protect the communities from different harms of landfills [11].

In the West Bank, the challenge is more epidemic, due to small available space and political disputes. The need for carefully planned landfills is thus imperative. There are two types of solid waste disposal sites in the West Bank including 156 unplanned dumping sites, 4 used regional landfills, and 1 planned landfill [12]. Figure 1 describes all currently used and future planned landfills. According to Badawi, Zahrat Al-Finjan landfill has an area of about 240 dunom in Jenin Governorate. It was designed to fit two governorates (Jenin and Tubas) only. However, it is now used for 6 governorates (Jenin, Tubas, Tulkarem, Nablus, Qalqilia and Ramallah, and Al-Bireh). This landfill has been allocated within 1 km distance of four villages of Jenin Governorate. Munia landfill is located in the Beit-Lahem Governorate at the boundaries of Munia and Kisan communities. This landfill serves Beit-Lahem, Hebron, and some of Jerusalem governorate's communities with an area of 204 dunom. Jericho landfill to the east of Jericho city within less than 1 km of the residential area has an area of 38 dunom. It serves Jericho governorate and some of the Nablus and Tubas communities. Bait Anan landfill serves the northern and northwestern communities of Jerusalem governorate. This landfill is about 1 km distance from a residential area. Ramon landfill is a suggested location for future landfill projects. This location is within 3 km distance from Ramon community with an area of 208 dunom.

Random dumping sites are local locations used to collect solid waste temporarily before periodic transporting to regional landfills, as explained in Table 1. In 2015, the Palestinian Central Bureau of Statistics reported that the daily solid waste amount generated in the West Bank is 1835 tons [13]. In 2019, Atallah [12] reported that in the West Bank which has a limited space area of 2260 km^2 for 3×106 people, waste production was 1.58 million tons. Additional solid waste coming, from Israeli-West Bank settlements, and other Israeli cities, is dumped in various places in the West Bank. Therefore, the challenge has not been overcome yet. Random dumping sites and regional landfills still cause serious problems to the public health of the residential areas, the environment, water bodies, soil, plantations, animals, land value, and tourism. Moreover, various surface and groundwater resources have been affected by contaminants leaching from existing landfills [14]. The sites and the landfills are closely located near residential areas which expose people to hazardous gases.

Israel controls more than 60% of the West Bank (including areas classified as C and Israeli settlements). This limits the ability to do any safe planning for solid waste dumping. In 1991, the Oslo accord divided the West Bank lands into area "A 18%" under Palestinian control, area "B 21%" partially under Palestinian control, and area "C 61%" totally under Israeli control [15]. Only 39% of the West Bank, which accounts for 2260 km^2, is under Palestinian control and is available to use for living, commercial activity, transport, agriculture, open spaces, landfills, and other activities of all 3 M West Bankers. This makes the area one of the most heavily inhabited regions (with 0.08 km^2 per 100 people) in the world, even denser than overall Egypt (1 km^2 per 100 people).

A geographic information system (GIS) is one of the best approaches that help in siting landfills along with

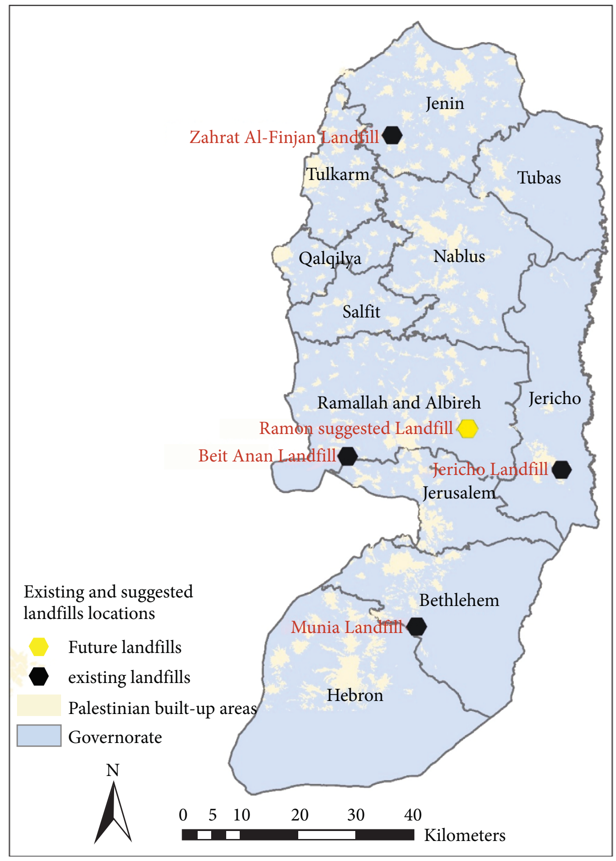

Figure 1: Existing and suggested landfills in the West Bank, prepared by researcher, data source: GeoMoLG.

Table 1: Some facts about dumping sites in the West Bank [4].

Condition	Number of solid waste sites	Percentage of the total number
Unused dumping sites	37	23.7
Dumping sites for more than one community	35	22.4
Dumping sites in the West Bank used by Israel	3	2
Gated dumping sites	10	6.4
Employees working on the sites	13	8.3
Covered by soil	32	20.5
Dumping sites within less than 500 m from main roads	126	81

implementing the multicriterion evaluation [16]. GIS can handle and simulate the necessary social, cultural, physical, economic, and even political constraints using different analytical tools. The multicriteria evaluation method (MCE) helps decision-makers in handling complex amounts of information. Nas defined MCE as "the principle of the method is to divide the decision problems into smaller understandable parts, analyze each part separately, and then integrate the parts in a logical manner" [11].

The integration between MCE and GIS helps decision-makers in the proper selection of landfill sites, by understanding all available information, and then formulating a hierarchy scheme of criteria to divide them into levels [17, 18]. This integration has been used in many case studies such as in Turkey and Greece. All studies proved the efficiency of using this integration [19]. The findings of Alkaradaghi et al. for landfill site selection in the Sulaymaniyah Governorate in Iraq were that the existing landfill sites do not fulfill the environmental requirements of landfill siting. So, they used the integration between GIS and MCE to find where landfills can be allocated. The final results pointed to 80% of the governorate as places suitable for landfills while 20% as nonsuitable places. The used criteria are urban area, villages, groundwater, slope, elevation, soil, geology, road, oil and gas, land use, archaeology, and powerlines.

In the West Bank, only a few similar studies have been made. An earlier study [4] used GIS for proposing suitable landfills based on several criteria in the West Bank. The earlier study referred to the existence of three landfills at the time. This study aims to show how the MCE method, together with GIS software, can be used to assess, and reallocate, the existing and future landfill sites, in regions with limited space. The West Bank, an over-inhabited area, with a long-lasting political dispute, is being studied here as a model case for other places. The study will evaluate all four existing and future planned regional landfill sites in the West Bank for the first time to our knowledge. The study will also come out with proposed sites for additional landfills and relocating existing ones to more suitable sites. Using GIS and MCE integration to achieve these goals has not been used in the West Bank, as an example of limited space areas, before. To our knowledge, this strategy has not been reported earlier specifically for limited space regions.

To achieve the stated objectives, different new criteria have been used to find the most suitable locations for solid waste disposal. Each criterion has been divided into subcriteria as the MCE works, and each subcriterion has been given a rank. After ranking, each subcriterion has been inserted into GIS as a subcriterion rank. Each criterion has then been given a weight according to its importance in allocating the landfills. This study is based on the following assumptions: countries with limited space have a severe challenge to find safe solid waste landfills. MCE-GIS integration can evaluate current landfill locations based on various criteria specifically human safety. MCE-GIS integration can bring new recommendations to relocate the existing landfills. Moreover, the MCE-GIS integration is useful in planning and site selection of additional future fill-sites. All such assumptions will be tested in this study. While the results will be useful to environmentalists and planners in future landfill siting, decision-makers will find the results useful in their negotiating strategies related to daily human life and land usage in the West Bank.

2. Materials and Methods

To present the most suitable locations for landfills in the West Bank and to evaluate the five regional landfill locations in terms of their suitability, spatial analysis tools in GIS (ArcMap) have been used to prepare nineteen different criteria as layers covering the study area. These criteria have been defined using the multicriteria evaluation (MCE) method.

According to Malczewski, the MCE method combines defined geographical data (defined as input data) into an output decision by combining the inputs throughout a mathematical process [20]. The findings appear as a collection of multidimensional data projected in one parameter-output map, namely the decision. Apart from geographical data, the process includes the decision-maker's preferences together with data manipulation in addition to preferences based on decision-specific rules.

In terms of planning, the MCE method helps to investigate the land's suitability for specific uses according to various priorities and preferences of stakeholders. This method creates a schematic hierarchy that distributes the main problem into main objectives (called criteria) [21]. It then subdivides each main objective into attributes (called subcriteria). According to the stakeholders, each criterion should be assigned a weight out of 100%, and each subcriterion should be assigned a rate according to specific parameters.

In this study, an integration between GIS and MCE is used. The MCE method is used to define the objectives and attributes to create the theoretical base. The GIS then spatially reflects all criteria into geographic datasets with spatial analysis [22]. The methodology of this study follows the flowchart shown in Figure 2.

In this study, all used datasets followed the following principal steps according to Figure 2:

(i) After defining the problem of this study in the Introduction, the second step is to define the objectives of this study which are the criteria here.

(ii) A hierarchal scheme has been prepared here for the datasets to define two levels of factors that are general topics of criteria and subcriteria according to MCE. The ranks have been given to each subcriterion based on literature, expert opinions, environmental guidelines, and regulations.

(iii) Digital GIS databases have been collected from the Palestinian Ministry of Local Government (MoLG) in the West Bank. The ministry uploaded all the databases on its online website GeoMoLG (https://geoMoLG.ps/).

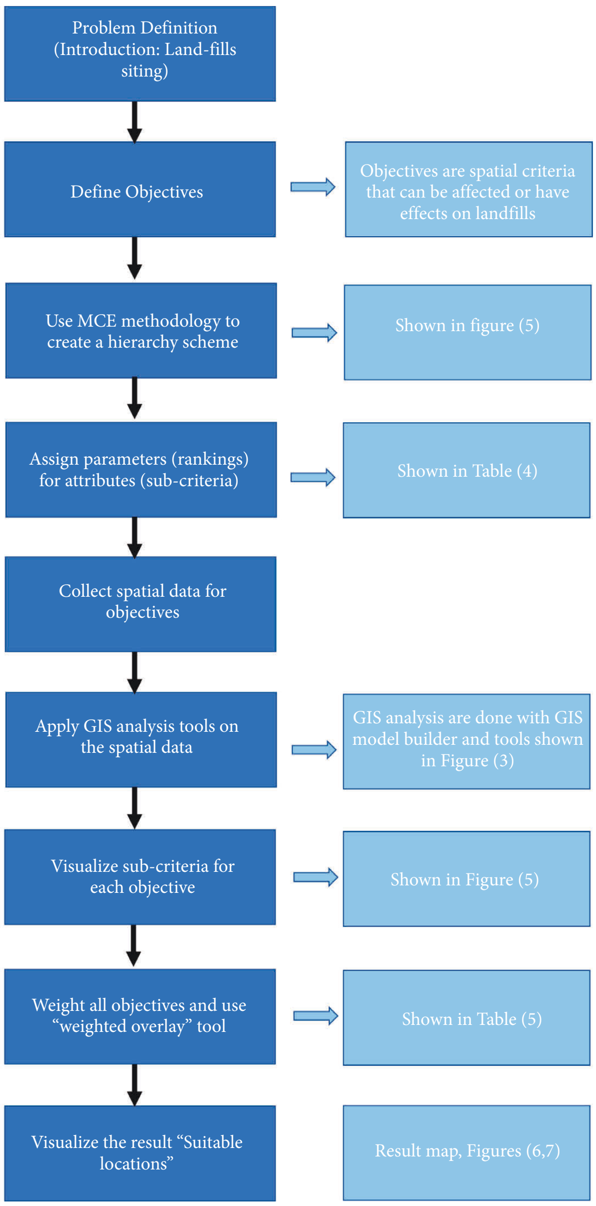

Figure 2: Methodology flowchart.

(iv) Appropriate buffer zones or special limitations around significant regions have been created to fit the required subcriterion map.

(v) A weight has been given to each general criterion according to their importance in the process.

(vi) All maps have been overlapped (using a weighted overlay tool) to prepare a suitability map for landfill locations.

The GIS modeling process is summarized in Figure 3. This GIS model shows how the spatial layers (shapefiles of objectives (criteria) and attributes (subcriteria)) are used here. The analysis tools, applied on each spatial layer, have been aggregated as overlapped spatial data to perform a spatial analysis that defines the most suitable locations for landfills. The ellipse shape designates the shapefile while the rounded rectangular shape designates the analysis tools. The analysis tools in this model have been chosen depending on

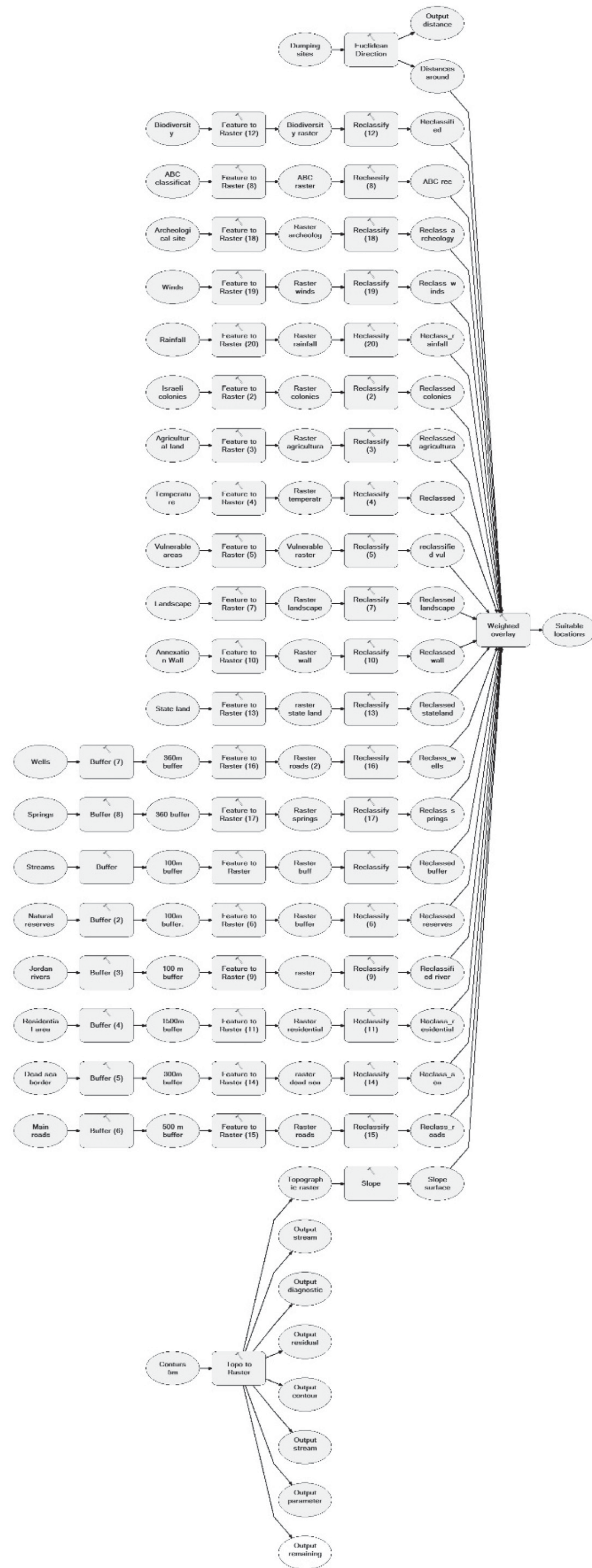

Figure 3: GIS modeling of the methodology used to find the most suitable locations for landfills.

Table 2: Subcriteria ranking value.

Criteria	Subcriteria	Rating values
Wells	0–360 m	0
	<360 m	10
ABC areas	Area A	0
	Area B	7
	Area C	10
Agricultural value of land	Forests	0
	High value	3
	Medium value	7
	Low value	10
Biodiversity	0–100	0
	>100	10
Israeli settlements	0–500	0
	>500	10
Streams	0–100 m	0
	>100 m	10
Natural reserves	0–100 m	0
	>100 m	10
Landscape	0–100 m	0
	>100 m	10
Jordan River	100 m	0
Israeli wall	Areas totally closed by the wall (western side of the West Bank)	0
	Other areas	10
Palestinian residential built-up areas	0–1500 m	0
	>1500 m	10
Land ownership	State land	10
	Private ownership	5
Soil (land vulnerability for damages and water contamination)	Extreme	0
	High	6
	Medium	8
	Low	10
	Not sensitive	10
Archaeology	0–300 m	0
	>300 m	10
Dead sea	0–300 m	0
	>300 m	10
Dumping sites	0–500 m	10
	500–1500 m	5
	>1500 m	3
Roads	0–500 m	7
	500 m–1000 m	7
	1-2 km	10
	>2 km	5
Springs	0–360 m	0
	>360 m	10
Slope	0–5%	10
	5–10%	9
	10–15%	8
	15–25%	7
	25–30%	2
	30–35%	1
	>35%	0
Separated areas by the wall	Closed areas	0
	Unclosed areas	10

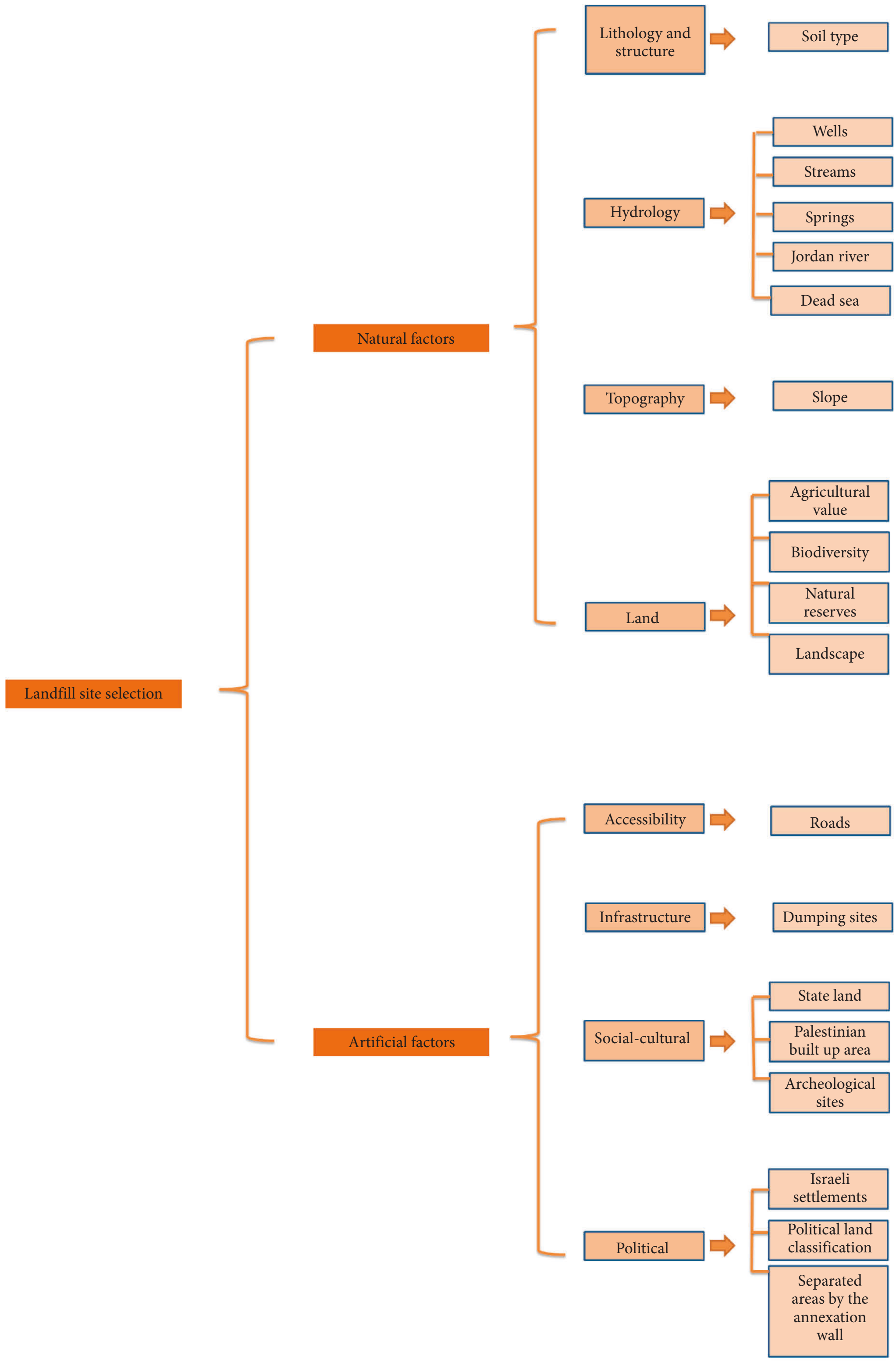

FIGURE 4: Hierarchical scheme of the decision process for landfill site selection.

Table 2 which defines the rankings of each subcriterion to create spatial analysis around each objective (criterion).

Detailed MCE-GIS integration procedures used here are explained as follows:

(1) Hierarchy scheme: a hierarchy scheme for suitable landfill locations has been constructed depending on the MCE method (Figure 4). The suitable landfill locations in the West Bank have been projected

through a hierarchal scheme to define the required data based on literature [19] and to define factors affecting the landfill siting process. This scheme involves three main levels as presented in the figure.

The first level is divided into natural and artificial factors. The second level is divided into eight main categories: land, topography, hydrology, lithology, accessibility, infrastructure, social culture, and political factors. Each of these eight categories involves several criteria. These criteria have been taken from literature review and field experience, as described below. All water bodies in the study area, including wells, springs, and streams, must be protected from any possible contamination that may result from landfills. These water bodies are sources of drinking water for people [4, 14]. Moreover, the Jordan River and the Dead Sea should be protected from contamination resulting from landfills. Landscapes, natural reserves, biodiversity areas, and forests should not also be used for landfills and should be kept away to avoid any pollution to wildlife and plantations. In terms of the agricultural value of land, forests and agriculturally high-value lands should be excluded from the landfill siting to protect the limited land available for plantation as earlier reported [11]. The soil type should have low permeability and should not allow liquid waste to go underground or to leak to other places [23–25].

As for the slope, the landfill plot is preferred to be on a slight to moderate slope enough to allow waste trucks to have easy access [11, 19]. Steep slopes should also be excluded to avoid waste slides. The road criterion is required to enable accessibility to the landfill location, without affecting the air quality around the main roads [4, 11]. The landfills should also be as far as possible from the archaeological sites and the residential built-up areas [11]. In this context, there are two criteria due to the dual authority in the West Bank, involving Palestinian residential built-up areas, and the Israeli settlements. All these are considered criteria here. Moreover, some areas, like the Western regions of the West Bank, are inaccessible and separated by the Israeli wall. This is used as a separate criterion. State lands are the lands owned by the government. This criterion is used here to avoid the high costs of land purchase. Random dumping sites, defined above, give an idea about the places with large amounts of waste production [4]. This is considered as another criterion.

(2) Dataset criteria map: after defining all the criteria required for this study, nineteen datasets have been obtained, from the MoLG in the West Bank, to be used as input parameters for the landfill suitable site selection model. The datasets were prepared by different governmental sources and then compiled into one online website. They have been converted into online data sources that can be downloaded as GIS shapefiles, Table 3.

Table 3: Criteria GIS shapefiles sources.

Criteria	Source
Wells Agricultural value of land Biodiversity Israeli settlements Streams Natural reserves	Ministry of Local Government (MoLG), Ministry of Agriculture, Ministry of Environment, Ministry of Water, hydrology group—taken from GeoMoLG website
Landscape Jordan River Wall Palestinian residential built-up areas State land Soil and geology Archaeology Dead sea Dumping sites Slope Springs ABC areas	MoLG—taken from GeoMoLG website
Roads	MoLG, Ministry of Transportation—taken from the GeoMoLG website

(3) Criteria restrictions: in defining suitable locations for landfills in the West Bank, each criterion has been studied to define the necessary restrictions while avoiding any future harm or damage. This is because each criterion has different spatial features such as the agricultural value of the land. By itself, this criterion can be divided into four subcriteria each of which has different relations with landfill sites. For example, forests and high agricultural value lands are very sensitive to landfill sites, while the low-value lands are less sensitive. Therefore, each subcriterion must be treated as a separate factor. Both buffer zones and Euclidean distances have thus been used to define the exclusionary areas for each criterion. The buffer zones have been created using the buffer tool. The buffer tool creates an area named a polygon around a spatial feature by offsetting a line around each part of the feature. For example, it creates a circle around a point feature and a polygon around a line feature. The distance between the feature and its offset can be defined by the user according to specific criteria. The Euclidean distance tool has been used in the same way as the buffer zones, with the difference that the Euclidean distance gives levels of distances. Each buffer zone, or Euclidean distance, has been prepared according to the recommended distance required to prevent environmental risks and excessive cost. All governmental regulation requirements have been considered. Table 4 shows that each criterion has exclusionary criteria taken from the literature [26, 27].

(4) Subcriteria ranking value: To define the most suitable locations, each criterion has been classified into

Table 4: Exclusionary criteria for landfill sites.

Criteria	Exclusionary criteria (buffer zone)		Reference
Wells	360 m	Landfills are better to be as far as possible from the wells to protect them from waste contamination. There should not be any landfill within 360 m from the wells.	[6]
ABC areas	Area A	The political classification of land in the West Bank should be considered. The limited "A" area for Palestinians should not be used as places for landfills. Areas with a classification form a small percentage of the West Bank where Palestinians are allowed to build and are concentrated within the existing residential areas.	This work
Agricultural value of land	Exclude forests	The land in the West Bank is divided into four categories in terms of land agricultural value. These are as follows: Forests: landfills should never be within High value: landfills should be avoided Medium value: it is acceptable to put the landfill within Low value: most recommended for landfills siting.	[23]
Biodiversity	100 m	All the areas classified as biodiversity areas must be excluded from the landfills siting and with a buffer of at least 100 m to protect all the wild lives.	[6]
Israeli settlements	500 m	These are residential or industrial Israeli settlements where Palestinians are not allowed to build within or to enter. All the colonies must be excluded from the siting and with a buffer of 500 m	This work
Streams	100 m	No landfills should be sited within 100 m from the streams to protect the water flows from contamination and to protect the waste from reallocation due to water movement.	[6]
Natural reserves	100 m	All the natural reserves must be excluded from the landfill allocation process and with a buffer zone of 100 m.	This work
Landscape	All inside	All landscaping areas in the West Bank must be excluded as they shape beautiful places for people and they mostly have high slopes which are not suitable for landfills.	This work
Jordan River	100 m	The river is shrinking currently; however, the original boundaries should be protected and a buffer of 100 m is required to protect the water from contamination	Reference [16] and this work
Israeli wall	Areas closed totally by the wall	Palestinians have no control over these locations despite that their residents are Palestinians.	This work
Palestinian residential built-up areas	1500 m	Landfills must be as far as possible from the residential areas. These are the most affected places from the existing dumping sites and landfills. A buffer of at least 1500 m is required to protect people from bad odors. These areas are the existing built-up areas with the planned expansion for each community.	[6]
State land	Nothing	It is preferred to have a state land for the landfills to minimize the costs.	This work
Soil and geology	Sensitive and permeable soil	Landfills should not be allotted on sensitive soil nor on permeable land that allows waste leachate goes underground	[16]
Archaeology	300 m	All the archaeological sites should be protected with a buffer of 300 m.	[16, 24, 25]
Dead sea	300 m	The dead sea should be protected with a buffer of at least 300 m	This work
Dumping sites	300 m	The existing dumping sites can be described as the centers of the most productive waste areas. The lower the distance to them, the lower the costs will be.	Reference [6], this work
Roads	500 m, 3 km	The landfills are required to be accessible; however, they also must be far from main roads. The distance to the close main road should be more than 500 m. The preferable distance is between 1 and 2 km. A distance of more than 3 km is so far.	[16, 23]
Slope	>35%		
Springs	360 m		

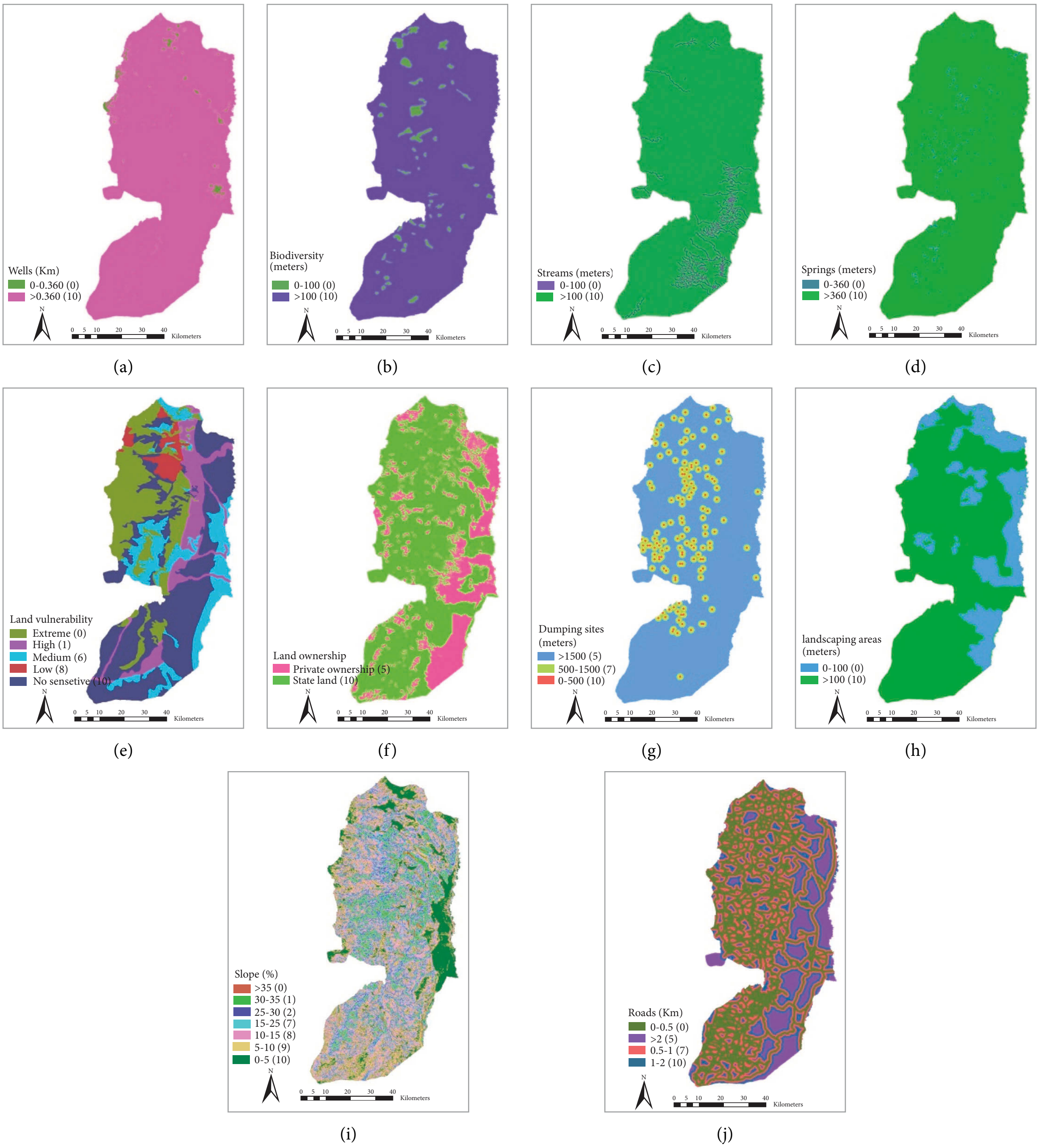

Figure 5: Subcriteria ranks (maps prepared by researcher, dataset source: GeoMoLG). (a) Map 1. (b) Map 2. (c) Map 3. (d) Map 4. (e) Map 5. (f) Map 6. (g) Map 7. (h) Map 8. (i) Map 9. (j) Map 10.

subcriteria with values from "0" to "10," as summarized in Table 2. Information from literature, scientific expert opinions, and the researcher's field experiences have been used to define the subcriteria ranking values. This is to prioritize different categories in each criterion in detail since each criterion has different categories with different effects on landfill siting. A higher-ranking value indicates a higher recommendation. For instance, the value "0" means that landfills must not be allocated within the area (restricted), while the value "10" is given to subcriteria where landfills are strongly preferred. Figure 5 shows a sample of the mapping for some of the subcriteria used in this work with a detailed ranking.

(i) As for wells, described in the first map, the given subcriteria value is 0 for lands within 360 m distance. The value 10 is given to lands of distances more than 360 m and indicates allowed landfill allocation.

(ii) The second map shows biodiversity. All places within 100 m distance from the boundaries of each biodiversity land are restricted for landfill location. Lands with distances of more than 100 m are allowed to be chosen as landfill locations.

(iii) The third map shows the streams of water. Lands within 100 m from the streams are restricted areas and are allotted the value of 0, while farther lands have the value of 10.

(iv) The fourth map shows the springs. The value of 0 is allotted to lands within 360 m from the springs, while the value 10 is given to lands farther than 360 m.

(v) The fifth map shows the ranking of lands according to their vulnerability to damage and water contamination. If the land is extremely vulnerable then it must be restricted (value = 0). If the land has a high vulnerability to damage, then it is given the value of 6. If the land has a medium vulnerability, then the value is 8, and lands with low vulnerability have a value of 10.

(vi) The sixth map shows land ranking according to ownership. Lands with public ownership are preferred for landfill locations, with a value of 10. Private lands are less preferred for landfill locations with a value of 5.

(vii) As for the random dumping sites, the seventh map shows the rankings as follows: lands within 500 m distance from the random dumping sites are preferred with a value of 7, lands within 500–1500 m are less preferred with a value of 5, and lands with distances more than 1500 m are least preferred with a value of 3.

(viii) The eighth map shows the landscaping areas. Lands within 100 m from the boundaries of landscaping areas are restricted lands with a value of 0, while farther lands have a value of 10.

(ix) The ninth map shows the lands ranking according to their slope. Lands with a slope less than 5% are preferred with a value of 10, lands with a slope from 5% to 10% are given a value of 9, lands with a slope of 10%–15% are given a value of 8, lands with a slope of 15–25% are given a value of 7, lands with a slope of 25%–30% are given a value of 2, lands with a slope of 30%–35% are given a value of 1, and lands with a slope more than 35% are given a value of 0.

(x) The tenth map shows the locations of roads. Lands with a distance of 0.5 km from road boundaries are given a value of 0. Lands with a distance between 1 km and 2 km from roads are given the value of 10. Lands with a distance from 0.5 km to 1 km are given the value of 7. Lands with a distance of more than 2 km are given the value of 5.

Table 5: Criteria weights.

Criteria	Weight (100%)
Wells	4
ABC areas	4
Agricultural value of land	10
Biodiversity	4
Colonies	4
Streams	4
Natural reserves	4
Landscape	4
Jordan River	4
Areas closed by the wall	4
Palestinian residential built-up areas	4
State land	4
Soil (land vulnerability for damages and water contamination)	10
Archaeology	4
Dead sea	4
Dumping sites	4
Rainfall	4
Winds	4
Roads	4
Springs	4
Slope	4
Temperature	4

(5) Weighting and overlapping criteria: after ranking the subcriteria, each criterion has been appointed a weight out of 100%. These weights were defined in terms of the level of impact or influence each criterion has on the landfill or vice versa. These weights were assigned by the researcher's experience with some help from urban planners in Palestine. It should be noted that earlier researchers did not have commonly agreed on values, since their criteria varied [4]. Table 5 shows the allotted weight for each criterion here.

(6) Overlapping criteria for best locations: The weight given to each criterion has been inserted in a GIS tool called weighted overlay that overlaps the subcriteria to find the most suitable places for landfill siting in the West Bank. According to Environmental Systems Research Institute (ESRI), this tool combines the following steps: it reclassifies the subcriteria raster datasets into restricted areas (with rate 0) or preferred areas (with rate 9). Then it multiplies the cell values of each criteria raster by the weight assigned to it. Finally, it adds the resulting values for each cell from each criterion together to produce the result.

3. Results and Discussion

New results have been acquired by the adopted methodology in this work. The acquired results, by integration between MCE and GIS software analytical tools, are summarized in Figure 6.

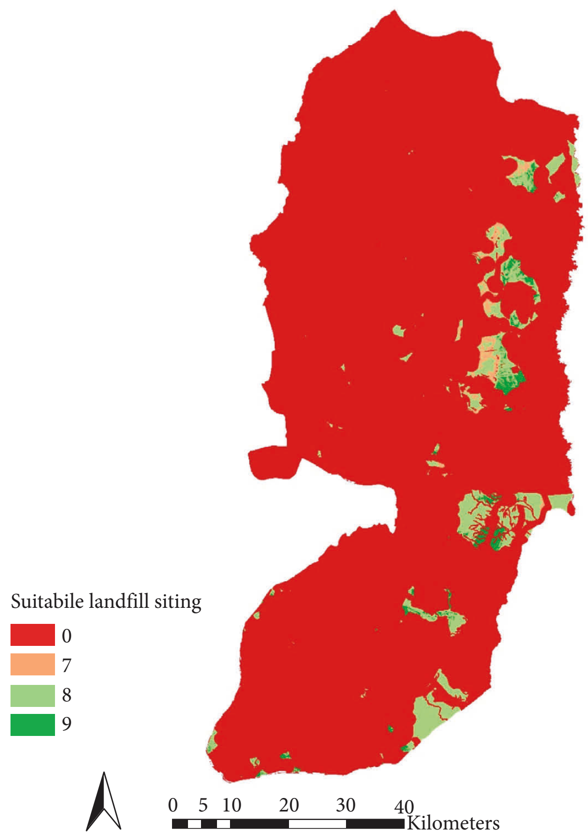

Figure 6: Suitable landfill siting areas (map prepared by researcher, dataset source: GeoMoLG).

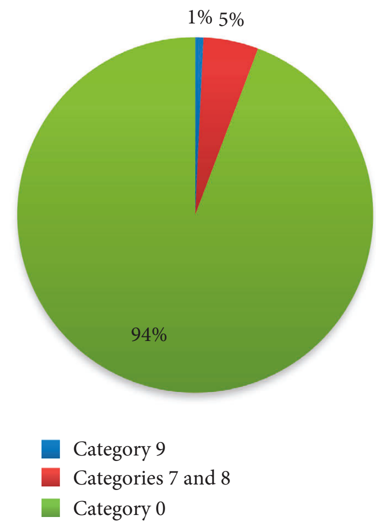

Figure 7: Landfill siting process results.

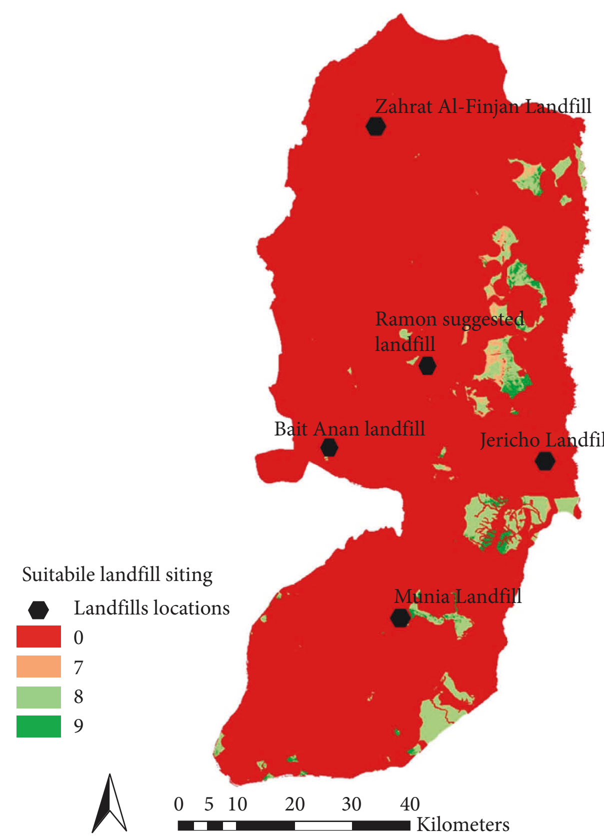

Figure 8: Existing regional landfill locations on the suitability landfill siting map.

Figure 6 map provides four categories for landfill allocation suitability: 0, 7, 8, and 9. Category 0 indicates the restricted areas where regional landfills or dumping sites should never be allocated in. Category 9 includes the most preferable areas where landfills should be allocated in. Categories 7 and 8 include areas where landfill siting is acceptable. These categories result from the categorization process used for each criterion. It can be seen that no results occur within the range 1–6 because nineteen criteria have been used, each of which has restrictions in some places. Most restrictions have been also concentrated in areas 0 such as residential areas, areas politically classified as "A," and roads. The eastern West Bank area has more space than other areas. The results show that 98% of the allowed places are concentrated in the east. Additionally, there are places in the middle and west, with a total area of 24.07 km^2 that are suitable to temporarily dump solid waste before transporting it to other eastern landfills. The proposed landfills can be considered for additional future recycling activities. For categories 9, 7 (and 8), and 0, the area values are 42.75, 280.82 (280.82), and 5306.10 km^2, respectively. This means that only about 6% of the West Bank are suitable places for landfill siting, as shown in Figure 7. This is a small area (6% of the West Bank) for landfill siting which can be considered a problem since these areas can be necessary for other uses within the limited spaces because not all suitable places are owned by the state.

Moreover, the results indicate that all five regional landfills (existing and planned) were improperly allocated in restricted areas. One regional landfill (Munia landfill) is located close to the allowed areas in the middle and the west (Figure 8). It can thus easily be reallocated to suitable places to eliminate negative impacts.

These results approve how unplanned our landfill's locations are—compared to the used criteria in this study—and how close to the residential areas they are. Which can help in understanding why serious and dangerous the current and future environmental problems that Palestinians in the West Bank have been and will be exposed to. The increases in temperature, bad odors, weak and poisoned plants, and new diseases can analyze some of the bad effects that the current landfills (close to residential areas) have created. The resulted suitable places—if used for landfills instead of the current places—can help in decreasing the environmental problems by protecting lands with high agricultural value, landscaping areas, natural reserves, and residential areas from the bad effects of landfills. This protection can play an important role in achieving sustainability within a limited space region for a growing population.

As a comparison between this study and Ghodieh and Shtayeh's study, their study resulted in 8 categories from 3 to 10 for suitable locations of landfill siting and no restricted areas have been defined. While this study provides only 6% as suitable places for landfills and 94% of the West Bank as restricted places. This study has taken the residential area as an important criterion to protect Palestinians and their lands from toxins and poisoning landfills. However, it had some limitations due to the limited information about Israeli landfills and the amounts of waste created by them inside the West Bank.

The spatial display of suitable places resulted from the integration between MCE and GIS software can help in future studies and future planning processes related to landfills or environmental issues. However, this is not the only use of this integration, the used methodology in this study can also be used for other projects' site selection processes by using different criteria. For decision-makers in the West Bank, it will be helpful to use this methodology in making their policies and plans to avoid possible environmental problems. For future studies, more criteria can be used to provide more suitable places for landfills. Suggested additional criteria can be the economic and social aspects of landfill locations and the Israeli landfills and dumping sites on the West Bank. An additional study can be prepared to prepare a plan for landfills according to the type of waste such as hazardous waste or medical waste.

4. Conclusion

Integration between GIS software and multicriteria evaluation (MCE) is a powerful tool in both evaluating and future recommendations regarding landfill sites. This work shows the most suitable alternative locations for landfill siting in limited and disputed lands, considering the West Bank as an exemplary case. The alternatives are proposed after providing evidence on how unsuitable the existing landfills and dumping sites are. Integration between GIS software and MCE has been used. MCE has been used to provide a hierarchy of criteria and subcriteria with weights and ranks to enhance the GIS modeling of these criteria. The used criteria include land vulnerability to damage and water contamination, streams, landscapes, natural reserves, biodiversity, wells, Jordan River, agricultural value of land, slope, roads, Palestinian residential built-up areas, Dead Sea, political disputes, Israeli settlements, political classification of land (OSLO accord A, B, and C), springs, land ownership, closed areas by the Israeli wall, archaeological areas, and existing dumping sites. The results have been acquired from overlaying the weighted criteria (with subcriterion ranks) using the "weighted overlay" tool in ArcMap (GIS). The suitable locations for the West Bank landfills represent about 6% of the West Bank, while all existing regional (and planned) landfills are located in the restricted areas based on this study. Therefore, it is strongly recommended to reallocate existing and future planned landfills to more preferable sites, while bringing the issue onto future negotiation agenda.

Data Availability

The data used to support this study are openly available in "GeoMoLG" as GIS shapefiles. GeoMoLG is a national website: https://geomolg.ps/L5/index.html?viewer=A3.V1.

Conflicts of Interest

The author declares there are no conflicts of interest.

References

[1] I. Carević, M. Sibinović, S. Manojlović, N. Batoćanin, A. S. Petrović, and T. Srejić, "Geological approach for landfill site selection: a case study of Vršac municipality, Serbia," *Sustainability*, vol. 13, no. 14, p. 7810, 2021.

[2] S. L Kareem, S. K. Al-Mamoori, L. A. Al-Maliki, M. Q. Al-Dulaimi, N. Al-Ansari, and S. L. Fegade, "Optimum location for landfills landfill site selection using GIS technique: Al-Naja city as a case study," *Cogent Engineering*, vol. 8, no. 1, Article ID 1863171, 2021.

[3] J. Mallick, "Municipal solid waste landfill site selection based on fuzzy-AHP and geoinformation techniques in Asir region Saudi arabia," *Sustainability*, vol. 13, no. 3, p. 1538, 2021.

[4] A. Ghodieh and R. Shtayeh, *Choosing the Best Sites that Use Western Waste Geographical Information (GIS)*, University of Jordan; and Department of Geography Department of Geography, Al-Najah National University, Palestine, 2012.

[5] K. Vasarhelyi, *The Hidden Damage of Landfills,* University of Colorado Environmental Center, Boulder, Colorado, 2021.

[6] L. Jarup, D. Briggs, C. De Hoogh et al., "Cancer risks in populations living near landfill sites in Great Britain," *British Journal of Cancer*, vol. 86, no. 11, pp. 1732–1736, 2002.

[7] N. B. Chang, G. Parvathinathan, and J. B. Breeden, "Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region," *Journal of Environmental Management*, vol. 87, no. 1, pp. 139–153, 2008.

[8] M. Z. Siddiqui, J. W. Everett, and B. E. Vieux, "Landfill siting using geographic information systems: a demonstration," *Journal of Environmental Engineering*, vol. 122, no. 6, pp. 515–523, 1996.

[9] T. D. Kontos, D. P. Komilis, and C. P. Halvadakis, "Siting MSW landfills on Lesvos island with a GIS-based methodology," *Waste Management & Research: The Journal for a Sustainable Circular Economy*, vol. 21, no. 3, pp. 262–277, 2003.

[10] E. Erkut and S. R. Moran, "Locating obnoxious facilities in the public sector: an application of the analytic hierarchy process to municipal landfill siting decisions," *Socio-Economic Planning Sciences*, vol. 25, no. 2, pp. 89–102, 1991.

[11] B. Nas, T. Cay, F. Iscan, and A. Berktay, "Selection of MSW landfill site for Konya, Turkey using GIS and multi-criteria evaluation," *Environmental Monitoring and Assessment*, vol. 160, no. 1-4, pp. 491–500, 2010.

[12] N. Atallah, "Palestine: Solid Waste Management under Occupation," 2020, https://ps.boell.org/ar/2020/10/07/palestine-solid-waste-management-under-occupation.

[13] PCBS, *Amount of Waste Generated Per Day (Tons), and the Average Daily Production of a Family (Kg) of Household Waste in Palestine by Region*, 2015.

[14] R. Badawi, "Management and Planning of Landfills in the West Bank," 2019, https://hdl.handle.net/20.500.11888/14510.

[15] O. Niksic, N. Nasser Eddin, and M. Cali, *Area C and the Future of the Palestinian Economy*, The World Bank, DC, USA, 2014.

[16] J. R. Eastman, "Multi-criteria evaluation and GIS," *Geographical information systems*, vol. 1, pp. 493–502, 1999.

[17] J. Malczewski, "Propagation of errors in multicriteria location analysis: a case study," in *Multiple Criteria Decision Making*, pp. 154-155, Springer, Berlin, Germany, 1997.

[18] A. Gemitzi, V. A. Tsihrintzis, and C. Petalas, "Use of GIS and multi-criteria evaluation techniques in environmental problems," in *Multimedia Services in Intelligent Environments*, pp. 5–59, Springer, Berlin, Germany, 2010.

[19] K. Alkaradaghi, S. S. Ali, N. Al-Ansari, J. Laue, and A. Chabuk, "Landfill site selection using MCDM methods and GIS in the Sulaimaniyah Governorate, Iraq," *Sustainability*, vol. 11, no. 17, p. 4530, 2019.

[20] J. Malczewski, *GIS and Multicriteria Decision Analysis*, John Wiley & Sons, NJ, USA, 1999.

[21] R. Janssen and P. Rietveld, "Multicriteria analysis and geographical information systems: an application to agricultural land use in The Netherlands," in *Geographical Information Systems for Urban and Regional Planning*, pp. 129–139, Springer, Berlin, Germany, 1990.

[22] L. G. J. B. D. Alkema, S. Ferlisi, and L. Cascini, "Spatial Multi-Criteria Evaluation, Web publication/site," http://www.charim.net/methodology/65.

[23] A. Allen and I. MacCarthy, "Geological aspects of waste disposal site selection," in *Proceedings of the 1st Irish Environmental Engineering Conference, Cork*, pp. 233–239, Seribia, July 1991.

[24] H. A Effat and M. N Hegazy, "Mapping potential landfill sites for North Sinai cities using spatial multicriteria evaluation," *The Egyptian Journal of Remote Sensing and Space Science*, vol. 15, no. 2, pp. 125–133, 2012.

[25] S. Orecchio, M. Fiore, S. Barreca, and G. Vara, "Volatile profiles of emissions from different activities analyzed using canister samplers and gas chromatography-mass spectrometry (GC/MS) analysis: a case study," *International Journal of Environmental Research and Public Health*, vol. 14, no. 2, p. 195, 2017.

[26] H. Ersoy and F. Bulut, "Spatial and multi-criteria decision analysis-based methodology for landfill site selection in growing urban regions," *Waste Management & Research: The Journal for a Sustainable Circular Economy*, vol. 27, no. 5, pp. 489–500, 2009.

[27] M. I. Yesilnacar, M. L. Süzen, B. Ş. Kaya, and V. Doyuran, "Municipal solid waste landfill site selection for the city of Şanliurfa-Turkey: an example using MCDA integrated with GIS," *International Journal of Digital Earth*, vol. 5, no. 2, pp. 147–164, 2012.