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Investigation of Landfill Site Location Using GIS and Ranking Method: Pirmam District—A Case Study

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ABSTRACT

Urban waste management raises serious environmental issues, especially in light of the stresses of growing industrialization and urbanization, with a lack of contemporary infrastructure and the adoption of outdated landfill methods. This study aims to identify the proper landfill siting location by incorporating the ranking method with the Geographic Information System (GIS) tools for the Pirmam district in the Erbil governorate. The relevant factors included elevation, aspect, slope, soil type, land use/land cover, and distance to roads, wells, and settlements, and a pairwise matrix with different relative weights was constructed for implementing the Analytical Hierarchy Process (AHP). A final map illustrating all the locations that are compatible with the dump site has been established. The map shows that 2.67% of the study area is "most suitable", 48 percent is "suitable", 47.75% is "moderately suitable", and 1.57% is "unsuitable". The Area under Curve (AUC) analysis provides a reasonable validation of the landfill map, showing a high forecast accuracy of 92.8%. Furthermore, this study demonstrates the value of GIS and a rating approach in selecting optimal landfill sites.

1. INTRODUCTION

Waste management is one of the top sustainability issues humans face globally; therefore, selecting appropriate landfill sites is important to reduce the negative environmental impacts of groundwater contamination and on human health. Because the landfill impacts the nearby ecosystem and hydrological environment, environmental considerations are crucial [1-3]. Vast population growth, fast urbanization, and more industrial activity have all contributed to a large increase in waste output, which has raised serious concerns about pollution, ecological degradation, and public health [4-6]. Geographic Information System (GIS) and Multi-Criteria Decision-Making (MCDM) approaches, among them the Analytic Hierarchy Process (AHP), have emerged as important instruments to choose landfill sites in recent years [7-11]. GIS and AHP integration are becoming increasingly known as an excellent instrument to determine the efficacy of landfills, minimizing personality and boosting the exactitude of decision-making [12-19]. A dozen researchers computed the landfill fill siting using a GIS-based multi-criteria evaluation method to examine several criteria to select appropriate landfill sites, as slope, wells, groundwater, rivers, roads, land use/land cover (LULC), precipitation, soil type, and elevation among them [20-27]. The goal of this work is to demonstrate the AHP ranking method to assess, modify, and display geographical criteria to determine the best sustainable waste location under a GIS environment for the Pirmam district in Erbil province of Iraq, which lacks such studies. For this purpose, eight decision criteria have been considered to map the suitable locations for waste. Subsequently, the Receiver Operating Characteristic (ROC) methodology was applied to determine the model's accuracy. The findings will be crucial for sustainable waste management.

2. MATERIALS AND METHODS

2.1 Case study

The Pirmam district is about 30 km northeast of Erbil province, Kurdistan Region, Iraq. Since its altitude is over 1,000 meters above sea level, the city retains a substantially cooler temperature than Erbil, the capital. Because of its semi-arid climate, it has hot, dry summers and chilly, rainy winters. Most rain falls between November and April. Having a total land area of 486.5 km², it ranges from latitude 36° 31' 37.2"N to 36° 14' 55"N and longitude 43° 59' 49.5"E to 44° 23' 53.6"E. Figure 1 shows the study area.

2.2 Data sources

Landfill site selection is an important procedure that must take into account various environmental, topographical, and socioeconomic parameters to reduce potential problems [28]. Among the most significant criteria to consider for landfill location is the affordability and clarity of geographic data in the research area. In this study, numerous factors impacting landfill site selection were chosen for analysis: elevation, aspect, slope, LULC, soil type, proximity to settlements, groundwater, and roads. These features have been picked due to their significance in providing secure functioning of landfills, then manipulated as thematic layers using Digital Elevation Model (DEM) and Landsat imagery, and integrated into ArcGIS 10.6 software. Table 1 provides an overview of the data sources utilized in this study.

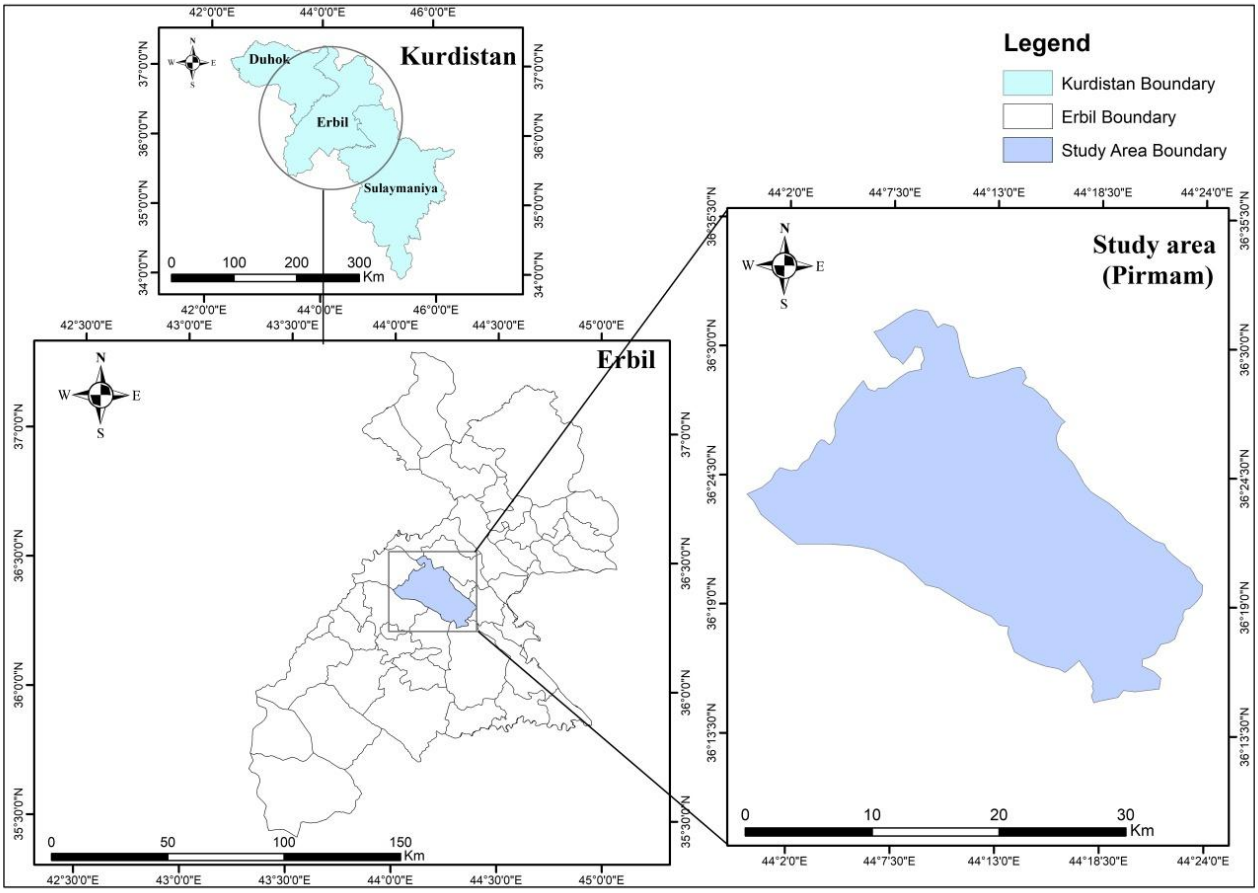

Figure 1. The location of the study area

Table 1. An overview of the data sources utilized in this study

Data Type	Description	Sources	Resolution
Landsat 8 Images	LULC classification	USGS Earth Explorer	30 m
DEM	Elevation, slope analysis, and aspect	USGS Earth Explorer	30 m
Soil Data	Soil texture	FAO Digital Soil Map of the World	1:5000000
Road Network Data	Proximity to roads	OpenStreet Map	Vector data
Groundwater Data	Proximity to groundwater	Directorate of Erbil Groundwater	Point locations
Settlement Data	Proximity to settlements	General Directorate of Dams and Water Reservoirs	Point locations

3. RANKING METHOD

Table 2. Comparison matrix scale [29]

Intensity of Importance	Definitions
1	Equal
3	Moderate
5	Strong
7	Very strong
9	Extreme
2,4,6,8	For compromises between the above

AHP is an accurate and adaptable multi-criteria decision-making methodology for tackling complicated issues demanding qualitative as well as quantitative analysis [30]. In the current investigation, the AHP tool was used to determine the site for the landfill in the study area, depending on the above-mentioned criteria. The technique allows for ranking or organizing elements about their perceived value or usage in a specific circumstance. The comparisons are demonstrated in an Excel spreadsheet as a matrix. For pairwise comparison, a scale from 1 to 9 is used, which has been developed by Saaty [29], as shown in Table 2. It means that two criteria are equally important, while 9 means extreme importance [29, 31, 32]. After creating the pairwise comparison matrix, it needs to be normalized. Each matrix element undergoes normalization by dividing it by the sum of all the associated columns. The normalized matrix's row scores are added up to figure out each factor's weight. To ensure the consistency of judgment, the Consistency Ratio (CR), which should be less than 0.1, is calculated. Eventually, all layers were entered into the corresponding (GIS) files for analysis and creating the map of landfill sites.

3.1 CR

The consistency ratio is a single numerical statistic that is used to assess the consistency of PWCM. It was calculated as a ratio of the Consistency Index (CI) and the Random Index (RI), as shown in Eq. (1).

$$R = \frac{CI}{RI} \tag{1}$$

According to the study by Saaty [29], the *RI* can take values listed in Table 3, which depend on the number of factors being compared, while *CI* is calculated using Eq. (2).

$$CI = \frac{\lambda_{\max} - N}{N - 1} \tag{2}$$

λ_{max} is the largest eigenvalue. The eigenvalue is calculated as the product of the pairwise comparison matrix and the weight vector divided by the respective weights, and then the ratios are averaged. *N* is the number of criteria in the pairwise compression matrix. If CR exceeds 0.1, the pairwise comparison matrix must be revised to improve consistency. Finally, the weighted parameters are combined using the Weighted Overlay Tool in ArcGIS to create the landfill suitability (LS) map using Eq. (3).

$$LS = \sum_{i=1}^{n} w_i * x_i \tag{3}$$

where, *LS* represents landfill suitability, *n* represents the number of components, w_i represent the weight of each criterion, and x_i represent the factors of priority rating.

Table 3. Values for RI [29]

N	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51

3.2 Thematic layers and weights

3.1.1 Distance to roads

According to the study by Randazzo et al. [33], the road network or accessibility is the most crucial consideration when selecting a landfill location. Administration costs, transit performance, and possible threats to neighboring towns are all impacted by road accessibility. Well-connected locations lower administrative and transportation expenses while reducing traffic congestion and environmental risks. Firstly, the road networks, including main and secondary roads and highways, were developed from OpenStreet Map, and to guarantee that specific places are suitably accessible, buffer zones were constructed around these roadways in ArcGIS using Euclidean distances.

3.1.2 LULC

The selection of landfill sites is greatly influenced by LULC, which has an impact on social, economic, and environmental aspects. Landfills must be sited away from agricultural grounds, woods, and densely populated regions to avert ecological degradation and social discord. ERDAS IMAGINE 2014 was used to categorize Landsat 8 OLI data (2021, 30-m resolution) using the maximum likelihood approach to build the LULC layer for the Pirmam district.

3.1.3 Land slope

The slope of the soil increases discharge through the land's surface, which may carry impurities from the waste site to a larger region. At the same time, it is a key component in landfill building prices, as steep slopes increase excavation expenses [34]. As a result, flatter slopes produce more stability and less leachate movement, thereby being appropriate for landfill placement.

3.1.4 Land elevation

Elevation is regarded as the fundamental selection factor for landfill sites. This property has a reverse correlation with disposal suitability for the position, which means that as elevation increases, an area's suitability for a waste site will decline. On the other hand, excavation expenses will be higher for land with a high elevation than on flat ground [35].

3.1.5 Land aspect

Aspect dictates the orientation of a slope, influencing its exposure to wind. Thus, wind direction and aspect must both be taken seriously when trying to shield households against dumping debris and pollutants [36]. The slope, elevation, and aspect spatial distribution for this work were generated from the DEM (DEM-30 m resolution).

3.1.6 Soil texture

While creating a landfill at a particular location, the amount of infiltration is an essential factor for assessing the danger of groundwater pollution [37, 38]. Low-permeability soils perform well, whereas high-permeability soils are not effective due fine-grained soils can hold greater quantities of water than soils with coarser grains [39]. The Food and Agriculture Organization's (FAO) digital soil map of the world (DSMW), which has a scale of 1:5000000, is used to obtain the texture of the soil map for the research site [40].

3.1.7 Distance to settlements

Distance to populated regions is considered an important consideration when choosing a landfill location. Landfills close to populated areas pose several environmental issues. Landfills should not be established in cities, towns, or villages due to the unpleasant noise and odor. In this study, data regarding settlements received from the General Directorate of Dams and Water Reservoirs in Erbil and processed as a point layer in ArcGIS. Buffer zones around these settlements were generated in ArcGIS utilizing Euclidean distances, using thresholds specified by expert advice.

3.1.8 Distance to groundwater

Groundwater pollution is a major environmental hazard because of landfill leachate and toxins that are transported [41, 42]. Landfills should not be placed on or near aquifers to prevent groundwater contamination. In this research, a distance to groundwater map was created using the location of wells map from the Directorate of Erbil groundwater, and buffer zones were generated around the wells in ArcGIS using Euclidean distances.

3.2 Landfill map assessment accuracy

An essential component of landfill mapping is predictive landfill site validation, which uses the ROC model to confirm the outcome of the landslide hazard assessment [43]. Plotting the false positive rate (FPR) on the x-axis and the true positive rate (TPR) on the y-axis, the ROC method offers a diagnosis that can be applied to differentiate between the two classes of events and to exhibit the classifier's performance [44, 45].

$$X = FPR = 1 - \left[\frac{TN}{TN + FP} \right] \tag{4}$$

$$Y = TPR = \left[\frac{TP}{TP + FN} \right] \tag{5}$$

$$AUC = \frac{\sum TP + \sum TN}{P + N} \tag{6}$$

In this case, TN stands for true negative, FP for false positive, TP for true positive, and FN for false negative. AUC is the area under the curve, P is the landslide number (pixels), and N represents the non-landslide number (pixels). AUC displays the statistical accuracy of the model and the range of the area under the curve from 0 to 1. The values of the ROC method are classified into five categories as a result of the relationship between the AUC values and prediction accuracy: 0.9–1 is excellent, 0.8–0.9 is very good, 0.7–0.8 is good, 0.6–0.7 is average, and 0.5–0.6 is a poor result [46-48].

4. RESULTS AND DISCUSSION

4.1 Allocate weight criteria

The landfill site selection was performed with GIS-based MCDA and AHP. Eight criteria were used for this study in order to assess the viability of landfill sites in the Pirmam district. Using the AHP, their relative relevance was ascertained. Based on technical, social, and environmental factors, preference values were assigned using expert judgment. Each factor was compared with every other element in pairs Table 4. The value in each cell was then divided by the sum of the corresponding columns to normalize the pairwise comparison matrix. The final weights of each factor were represented by the row averages, which were computed following normalization Table 5. The findings showed that the most important parameters were distance to groundwater (0.31) and distance to settlements (0.21), emphasizing their function in avoiding contamination and lowering social tensions. Due to their impact on accessibility and the technical viability of landfill development, slope (0.1) and distance to roadways (0.19) also carried a significant amount of weight. In contrast, elevation (0.03) and aspect (0.02) received the lowest weights since their impact on landfill suitability in the research area was judged to be modest. To determine the reliability of the assigned weights, a consistency analysis was conducted. First, the values in Table 5 were multiplied by the weights to generate the weighted sum vector, which yielded the consistency measure (CM) values displayed in Table 6. The maximum eigenvalue (λ_{max} = 8.71) was calculated by taking the average deviation of each CM value from its corresponding weighted sum. After that, the consistency of factors was determined using Eqs. (1) and (2) and Table 3. The results showed a CR of 0.07, which is less than 0.1, indicating that the weights are suitable.

Table 4. Table of comparison

Factors	DG	DS	ST	Slope	LULC	DR	Elev	Aspect
Distance to Groundwater (DG)	1	2	3	4	5	6	7	7
Distance to Settlements (DS)	0.5	1	2	3	4	5	5	6
Soil Texture (ST)	0.33	0.50	1	3	5	6	7	7
Slope	0.25	0.33	0.33	1	2	3	4	5
LULC	0.20	0.25	0.20	0.50	1	3	5	5
Distance to Roads (DR)	0.17	0.20	0.17	0.33	0.33	1	3	4
Elevation	0.14	0.20	0.14	0.25	0.20	0.33	1	2
Aspect	0.14	0.17	0.14	0.20	0.20	0.25	0.50	1
SUM	2.74	4.65	6.99	12.28	17.73	24.58	32.50	37.00

Table 5. The normalized pairwise compression matrix

Factors	DG	ST	DS	Slope	LULC	DR	Elev	Aspect	Weight
DG	0.37	0.43	0.43	0.33	0.28	0.24	0.22	0.19	0.31
ST	0.18	0.22	0.29	0.24	0.23	0.20	0.15	0.16	0.21
DS	0.12	0.11	0.14	0.24	0.28	0.24	0.22	0.19	0.19
Slope	0.09	0.07	0.05	0.08	0.11	0.12	0.12	0.14	0.10
LULC	0.07	0.05	0.03	0.04	0.06	0.12	0.15	0.14	0.08
DR	0.06	0.04	0.02	0.03	0.02	0.04	0.09	0.11	0.05
Elevation	0.05	0.04	0.02	0.02	0.01	0.01	0.03	0.05	0.03
Aspect	0.05	0.04	0.02	0.02	0.01	0.01	0.02	0.03	0.02

Table 6. Consistency measure values

Factors	DG	ST	DS	Slope	LULC	DR	Elev	Aspect
CM	2.81	1.93	1.8	0.87	0.71	0.42	0.25	0.19
CM/wi	9.05	9.24	9.32	8.86	8.58	8.19	8.14	8.27
λ_{max} = 8.71		CI = 0.10115		RI = 1.41			CR = 0.07	

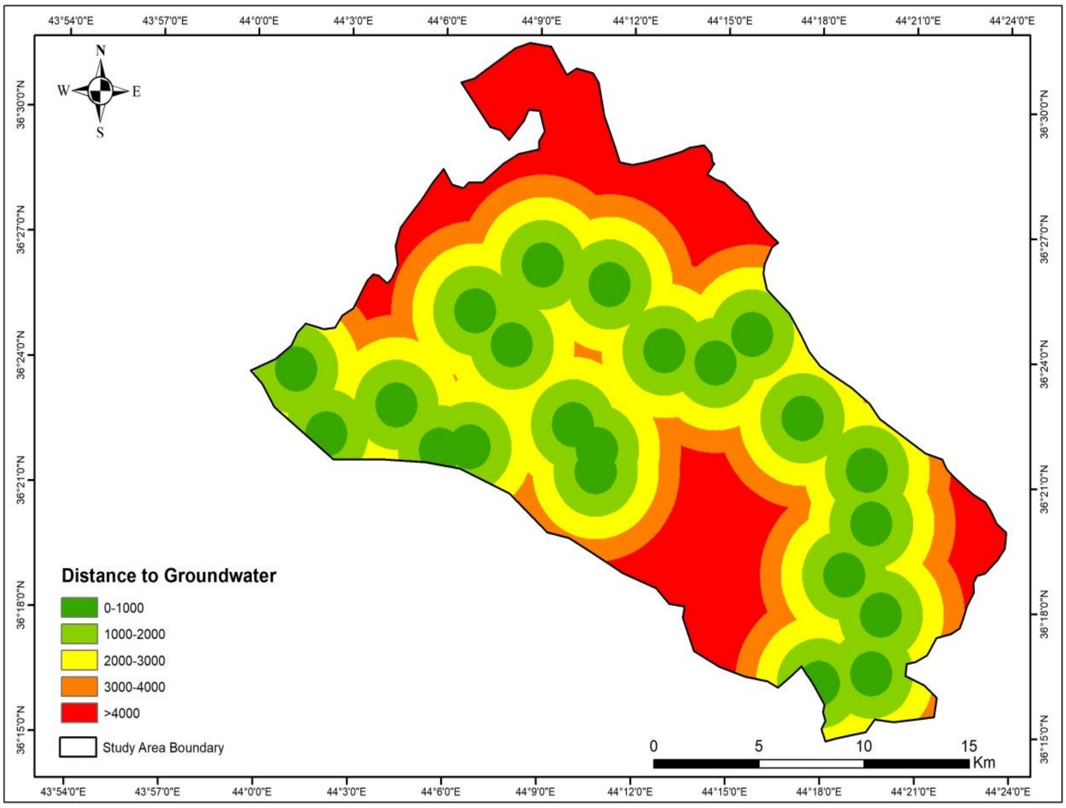

Figure 2. The distance to the groundwater of the study area

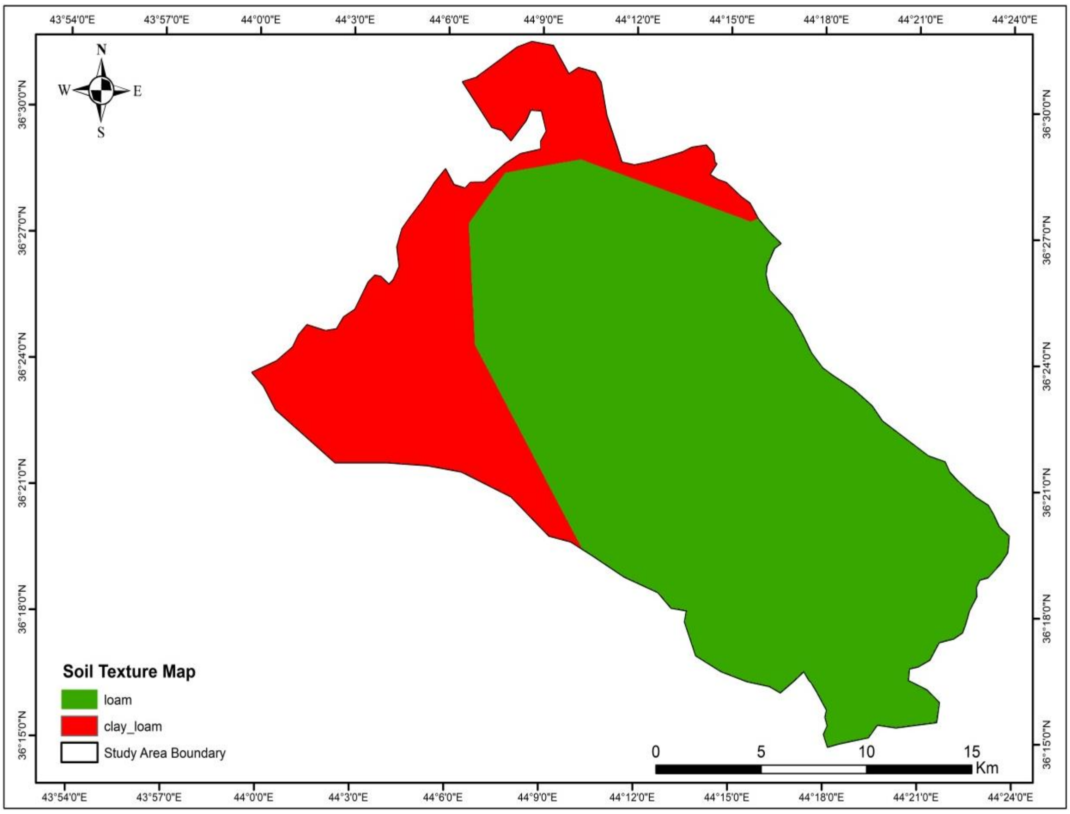

Figure 3. The soil texture of the study area

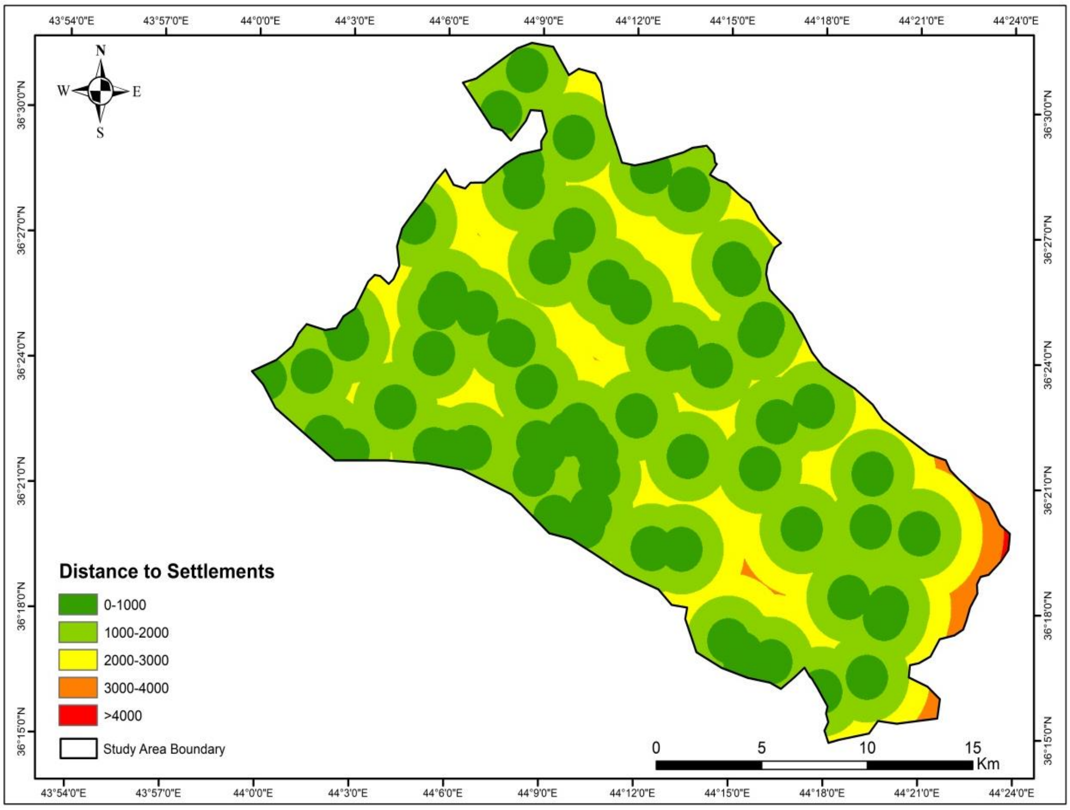

Figure 4. Distance to the settlement of the study area

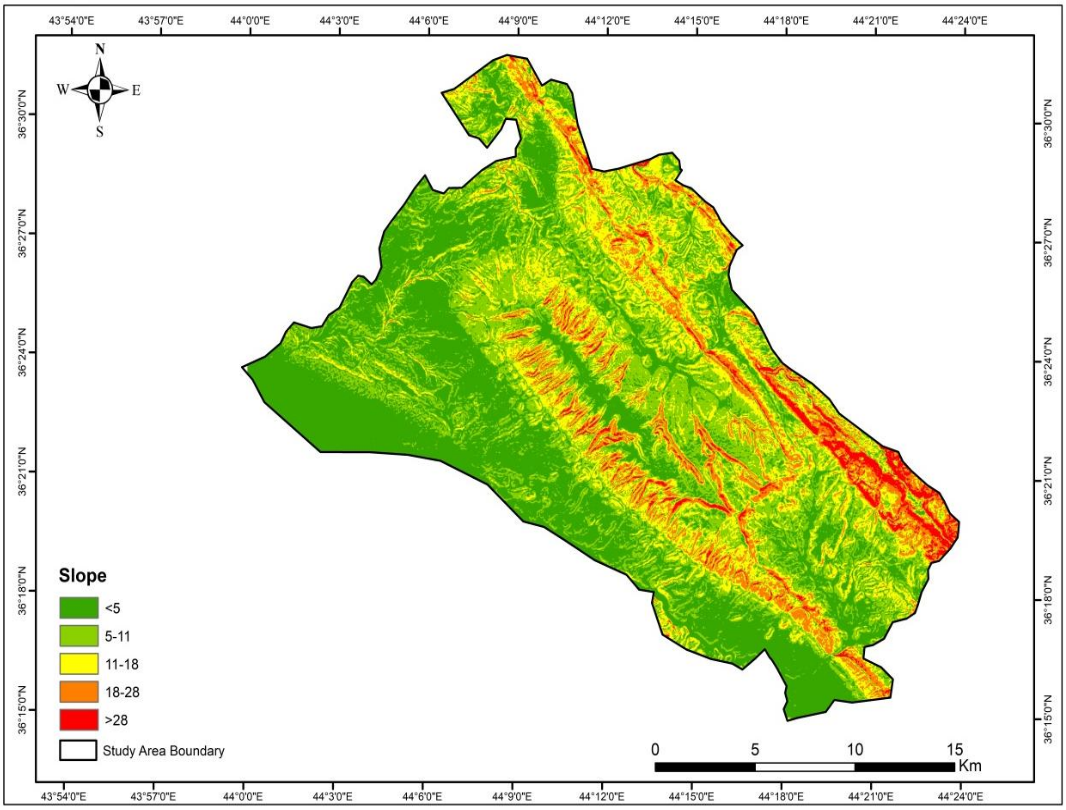

Figure 5. The slope of the study area

The landfill selection in the study area is based on various factors, and each of which is evaluated for its impact on site suitability. Table 7 summarizes the classification factors, class ranges, and assigned suitability ratings for each factor. Distance to groundwater (Figure 2) is considered the most important factor, holding the highest AHP weight of 31%. Areas that were more than 4000 meters away from groundwater wells (22.05% of the research area) were deemed to be extremely favorable for reducing the danger of contamination. Conversely, areas that were within 1000 meters (13.45%) were considered inappropriate. Site selection was heavily influenced by soil texture, as the study area was primarily composed of loam and clay-loam soils, as shown in Figure 3. Clay-loam, which makes up 26.23% of the land, was determined to be more appropriate because of its reduced permeability, which lessens the possibility of leachate seeping into groundwater. Depending on the distance to the settlement layer (Figure 4), more than 70% of the study area is within 2000 m, which is unstable to landfill development, while only 0.06% lies more than 4000 m away, which is considered most appropriate. The five slope categories in the region—from < 5, 5-11, 11-18, 18-28, and > 28—are depicted in Figure 5 with descending weights indicating their appropriateness for landfill construction.

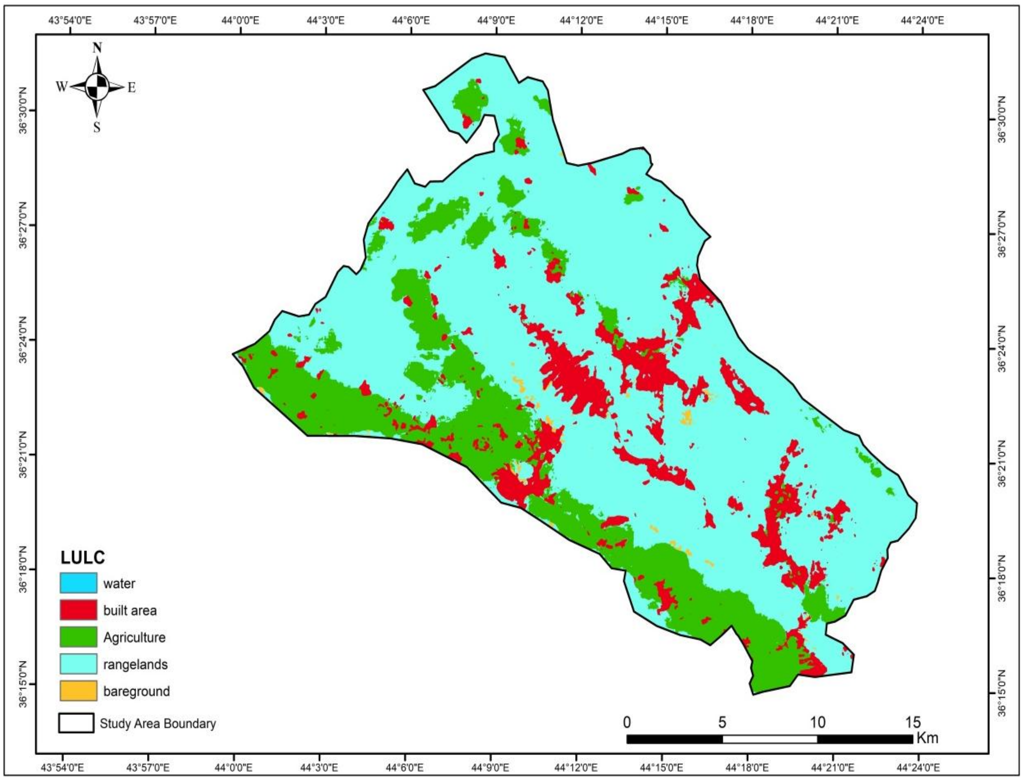

Figure 6. The LULC study area

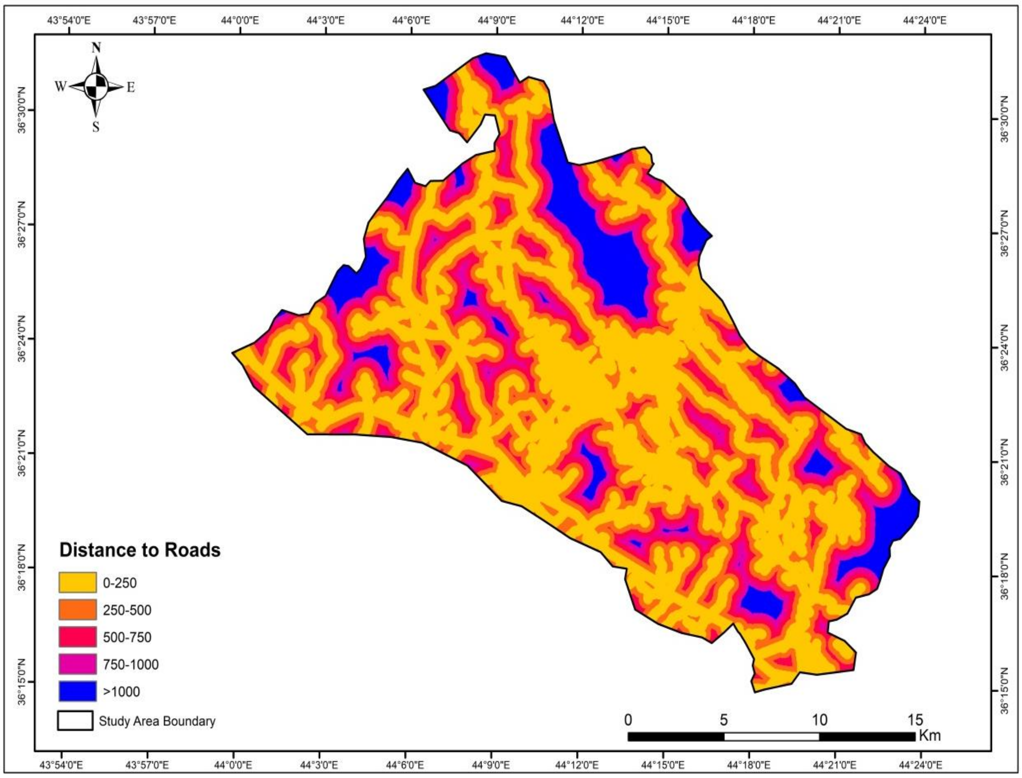

Figure 7. The distance to the roads in the study area

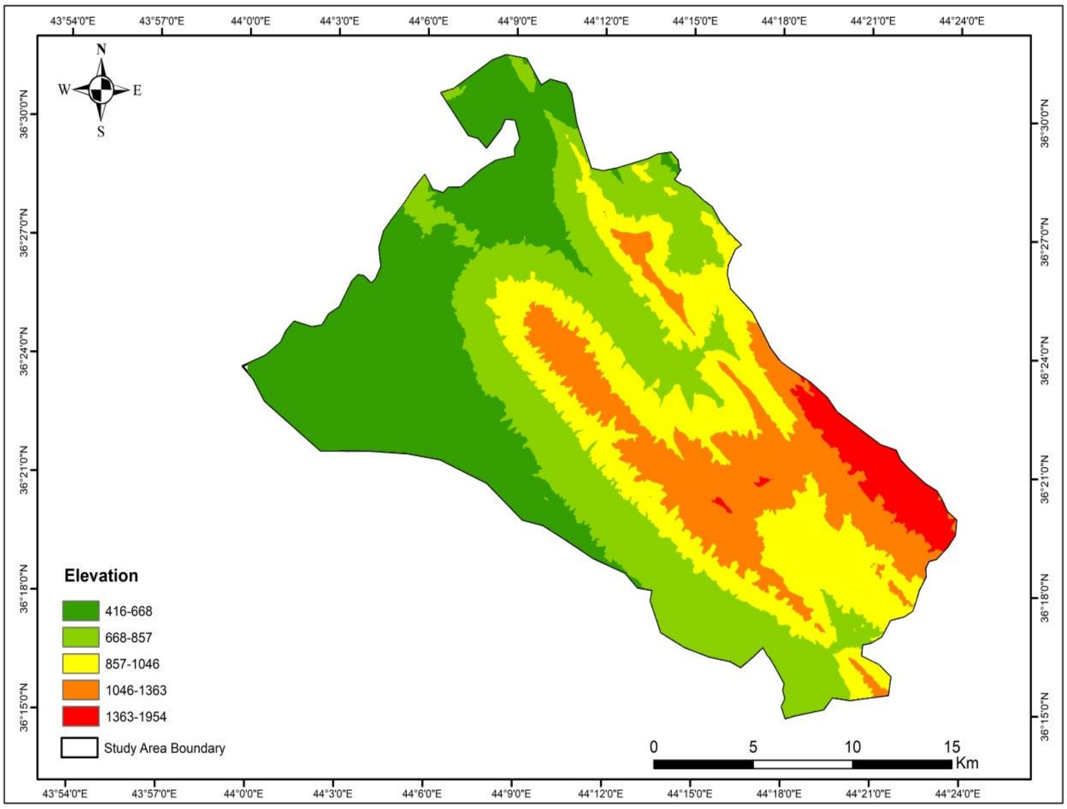

Figure 8. The elevation of the study area

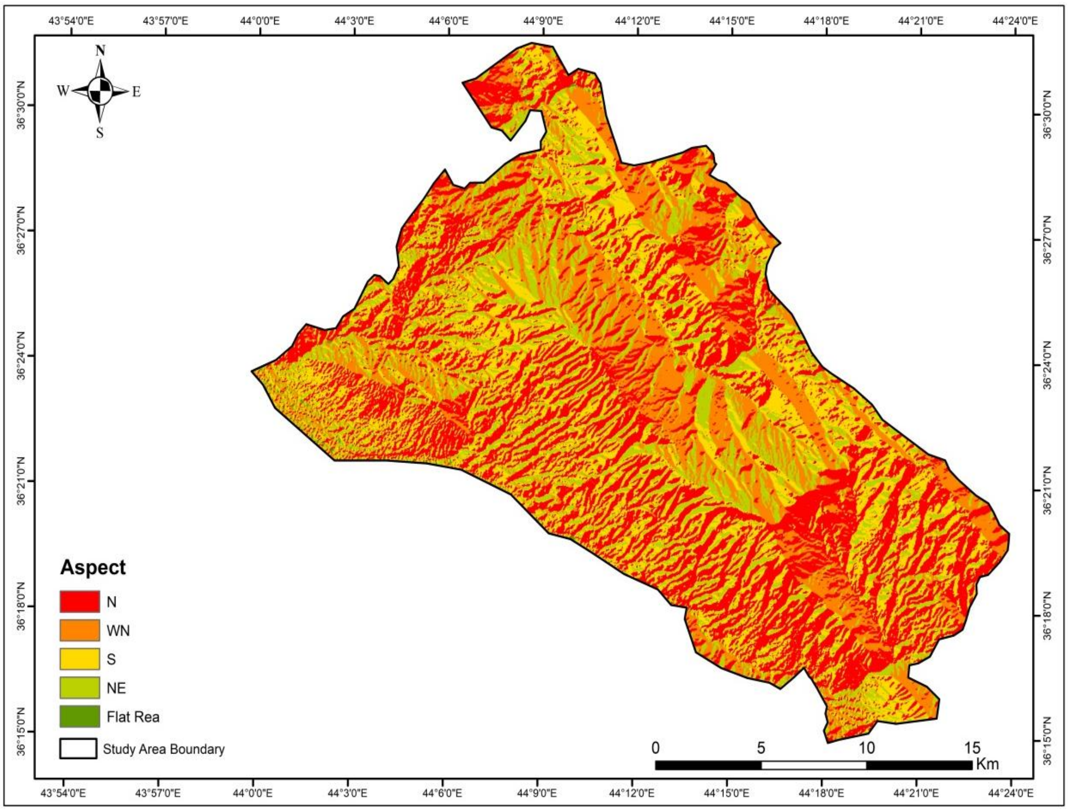

Figure 9. The aspect of the study area

Table 7 shows that more than 45% of the area is Low-slope areas under 5 degrees, which is ideal for landfill site selection. When it comes to the LULC layer (Figure 6), the results revealed that bare ground, which is considered the most favorable class for landfill site selection, covers only 0.45% of the study area. However, rangeland, which also has advantageous qualities for landfill construction, covers nearly 67.35% of the research area. Despite the limited availability of bare ground, rangeland provides a feasible and practical alternative for landfill site management due to its wide spatial dispersion.

Road accessibility is weighted at 5% since access and transit logistics are critical. While sites more than 1000 meters from roadways (9.10%) were deemed most appropriate, the majority of the research area (45.04%) is within 250 meters, presenting issues regarding accessibility vs. potential environmental disruption, as shown in Figure 7. Selection site for landfill and elevation are frequently shown to have in direct relationship. Higher elevations above 1363 m with 28.87% are considered less appropriate, while areas above 1046 were more favorable due to a balance in drainage and access, as illustrated in Figure 8. Finally, the aspect with the lowest weight of 2% had little impact on landfill suitability. Northeast- and northwest-facing slopes were marginally preferable due to superior wind dispersion, although flat areas (0.32%) were also deemed favorable due to their consistent terrain, as shown in Figure 9.

Table 7. Ranks and weights of different factors

No.	Factors	Buffer Zones	Ratings	Normalized Weight by AHP (%)	Area (%)
1	Distance to Groundwater (km)	0-1000	1	31	13.45
		1000-2000	2		29.02
		2000-3000	3		22.70
		3000-4000	4		12.78
		> 4000	5		22.05
2	Soil Texture	Loam	1	21	73.77
		Clay loam	2		26.23
3	Distance to Settlements (km)	0-1000	1	19	33.31
		1000-2000	2		49.53
		2000-3000	3		15.62
		3000-4000	4		1.48
		> 4000	5		0.06
4	Slope	> 5	1	10	45.03
		5-11	2		23.90
		11-18	3		14.27
		18-28	4		7.7
		> 28	5		9.10
5	LULC	Water	1	8	0.01
		Built Area	2		10.96
		Agriculture	3		21.23
		Rangelands	4		67.35
		Bare ground	5		0.45
6	Distance to Roads	0-250	1	5	45.04
		250-500	2		23.90
		500-750	3		14.27
		750-1000	4		7.69
		> 1000	5		9.10
7	Elevation	416-668	5	3	3.81
		668-857	4		16.29
		857-1046	3		23.58
		1046-1363	2		27.45
		1363-1954	1		28.87
8	Aspect	N	1	2	36.81
		WN	2		17.85
		S	3		25.33
		NE	4		19.69
		Flat Area	5		0.32

4.2 Landfill suitability map

The resulting map was categorized into four suitability classes: unsuitable, moderately suitable, suitable, and highly suitable areas, as shown in Figure 10. The landfill suitability map derived from selected factors reveals that the majority of the study area is either suitable (48%) or moderately suitable (47.76%) for landfill sitting, covering over 95% of the total study area. A small portion is identified as most suitable (2.67%); meanwhile, only 1.57% of the area is considered unsuitable, as detailed in Table 8.

4.3 Validation of landfill site map

The area under the AUC curve in this study is 0.928, as determined by the ROC approach using Eq. (6). This indicates a prediction accuracy of 92.8%, as illustrated in Figure 11. The area under the AUC curve in this study is 0.928, as determined by the ROC approach using Eq. (6). Considering the exceptionally high value, the AHP spatial modeling offers exceptional forecast accuracy in terms of identifying suitable disposal sites.

Table 8. Areas of the landfill suitability of the study area

No.	Landfill Suitability Classification	Area (km^2)	Percentage (%)
1	Unsuitable	7.74	1.57
2	Moderately suitable	234.69	47.76
3	Suitable	235.95	48
4	Most Suitable	13.11	2.67

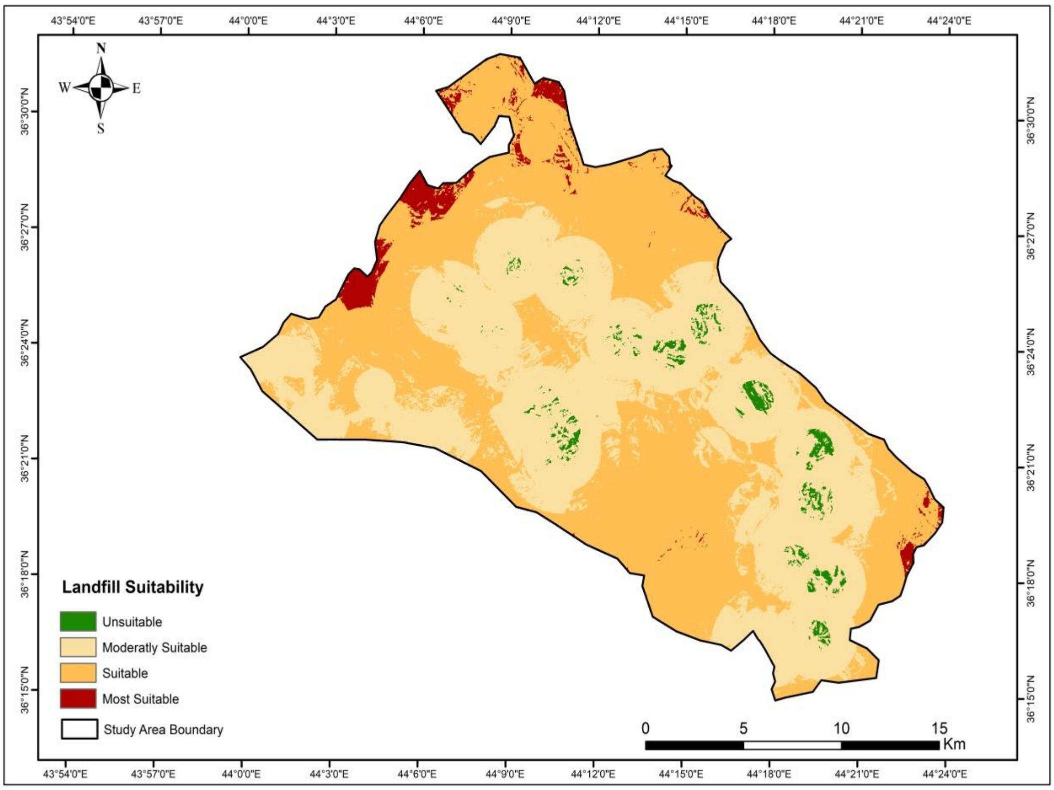

Figure 10. The landfill suitability of the study area

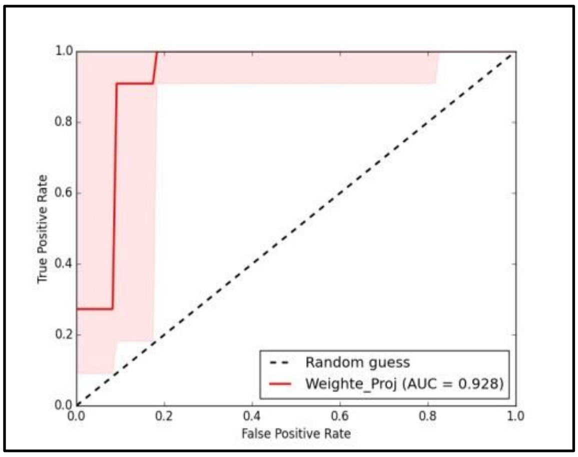

Figure 11. The ROC graph for the research area's landfill

5. CONCLUSIONS

This study shows the efficacy of combining GIS with the AHP for landfill site selection in Pirmam district, Kurdistan Region, Iraq. The model effectively detected and classified regions for landfill development by considering eight essential parameters: elevation, aspect, slope, soil texture, LULC, and proximity to roads, wells, and settlements. The results revealed that a large section of the study region is either suitable or moderately suitable for landfill siting, with just a small amount of land rated as unsuitable. The findings have important implications for sustainable urban design and environmentally responsible garbage management. The findings demonstrate that using GIS to find landfill locations is a practical and affordable strategy because it can quickly produce high-quality maps that are necessary for dump site selection.

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NOMENCLATURE

GIS	Geographic Information System
AHP	Analytical Hierarchy Process
MCDM	Multi-Criteria Decision-Making
LULC	Land use/Land cover
DEM	Digital Elevation Model
CR	Consistency Ratio
CI	Consistency Index
LS	Landfill Suitability
FAO	Food and Agriculture Organization
DSMW	Digital Soil Map of the World
DG	Distance to Groundwater
DS	Distance to Settlements
ST	Soil Texture
DR	Distance to Roads