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RESEARCH ARTICLE

Sanitary municipal landfill site selection by integration of GIS and multi-criteria techniques for environmental sustainability in Safita area, Tartous governorate, Syria

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Abstract

Urban waste disposal is a problem that poses a major challenge to city planners as a result of rapid population growth and urbanization. Finding suitable sites for solid waste is one of the most important solutions developed globally to manage this problem. In this regard, a set of physical, socio-economic and technological criteria must be considered to tackle the problem. Safita area (Tartous governorate) witnessed a rapid population growth during the decade of the war in Syria due to the onrush of internal refugees, which resulted in several environmental problems, including random waste dumps. After perusing the previous literature and considering expert opinions, a map of the spatial suitability of sustainable waste sites in the Safita area was developed by integrating the multi-criteria decision- making methodology (analytic hierarchy process) with the geographic information system. Thirteen criteria, including elevation, slope, permeability, distance to faults, distance to settlement, land use/land cover, distance to drainage, distance to water supplies, distance to lakes, distance to road, distance from tourist centers, distance from archaeological centers, and distance from religious centers, were used to achieve the goal of this study. The layer maps for these criteria were developed based on various data sources, including conventional and remote sensing data. Potential landfill sites were identified and divided into five categories: unsuitable (83.28%), less suitable (8.49%), moderately suitable (4.49%), highly suitable (2.57%), and very highly suitable (0.72%). The results of this study provide reliable spatial outputs that will help in suggesting new landfill sites that maintain environmental and socio-economic sustainability in the post-war phase. Moreover, the application of the methodology of this study can be generalized to the rest of the regions in Syria within the framework of the integrated management of the problem of random landfills.

Keywords Solid waste disposal · Landfill site selection · GIS-RS · MCDM · AHP · Spatial modeling · Syria

Introduction

The problem of solid waste constitutes one of the most contemporary environmental issues that threaten humans and the quality of ecosystems globally (Özkan et al. 2019; Bilgilioglu et al. 2021; Ahire et al. 2022). For the last two decades, economic and social developments have led to an increase in human requirements for services and goods, consequently, leading to a rise in the quantities of solid waste (Abdullah-Al-Mahbub et al. 2022; Babiker et al. 2005;

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Mohsenizadeh et al. 2020). The sensitivity of the solid waste problem grows as a result of poor management practices, acceleration in population growth, urban expansion, land use change, unplanned agricultural and social development, low technology, and low societal awareness (Khaliq et al. 2022; Aguilar et al. 2018; Kazuva and Zhang 2019).

Solid waste management is considered one of the difficult challenges facing local decision-makers and planners in developing countries (Yang et al. 2014; Orhan et al. 2020). This challenge requires the formulation of vital policies aimed at building a sustainable and effective environmental management system (Cheng and Urpelainen 2015; Bilgilioglu et al. 2021; Ahire et al. 2022). The concept of solid waste management can be defined as the process of waste disposal in the best method that promotes environmental and population health while supporting the local population, especially those affected by the existing solid waste sites (Balaban and Birdoğan 2010; Kazuva et al. 2021). However, the absence of solid waste management methods can cause serious environmental consequences (Kazuva and Zhang 2019; Tulun et al. 2021; Eghtesadifard et al. 2020).

Despite the presence of a number of methods and techniques that assist in reducing the amount of solid waste, including its recycling, transfer, and recovery, they hardly make the disposal foolproof (Kazuva et al. 2021). In this connection, organized storage of solid waste may be mentioned as among the most important means used globally to manage solid waste (Rahimi et al. 2020; Eghtesadifard et al. 2020). Determining the optimal sites for landfilling, however, is considered one of the critical environmental measures worldwide by decision makers in the framework of solid waste management within the comprehensive design of sustainable economic infrastructure (Bilgilioglu et al. 2021; Tulun et al. 2021). The best selection of these sites requires a comprehensive survey of all relevant physical, human, economic, health, and geographical criteria (Karasan et al. 2019; Kazuva et al. 2021; Ahire et al. 2022). Moreover, the traditional methods of selecting optimal landfill sites involve complex and long-term procedures with high costs. Multi-criteria decision-making is considered one of the most important modern tools used in choosing the most appropriate spatial options that can be exercised to bury household waste within the framework of urban, environmental, and regional planning procedures (Kareem et al. 2021). Furthermore, multi-criteria decision-based spatial appropriateness mapping in a geographic information system (GIS) environment determines the spatial dimensions of the distribution of optimal landfill areas. (Güler and Yomralıoğlu 2017; Orhan et al. 2020).

The integration of analytical hierarchy process (AHP) with GIS provides the best multi-criteria decision-building platform selecting the potential landfill site suitability. Previous literature has provided constructive results through that integration, including Aley and Chouf, Lebanon (Kamel and Hasan 2018); Sulaimaniyah Governorate, Iraq (Alkaradaghi et al. 2019); Aksaray, Turkey (Bilgilioğlu and Bilgilioğlu 2017); Dar es Salaam, Tanzania (Kazuva et al. 2021); Sicily, Italy (Randazzo et al. 2018); Sharjah, United Arab Emirates (Al-Ruzouq et al. 2018); Lahore, Pakistan (Asif et al. 2020); State of West Bengal, India (Ali et al. 2021); Savar upazila, Bangladesh (Islam et al. 2020); the Béni Mellal-Khouribga region of Morocco (Barakat et al. 2017); Paraiba do Sul river basin, Brazil (Senkiio et al. 2022); Songkhla, Thailand (Kamdar et al. 2019); Egyptian Suez Canal Corridor, Egypt (Monsef and Smith); and Gondar, Ethiopia (Sisay et al. 2021).

Syria generally lacks proper management of solid waste due to a rapid population growth and structural transformation in lifestyles, especially as the consequences of the current war (Rahmoun et al. 2016; Saghir 2019; Noufal et al. 2021; Khaddour 2021). Tartous governorate suffers from the accumulation of tons of solid waste in 10 random landfill sites, which led to the deterioration of the environment with a severe negative impact on various agricultural, economic, social, and cultural aspects oflifestyles (Noufal et al. 2020). Safita has seventeen main landfill sites, in addition to dozens of random landfill sites. These landfills collected waste in order to disposing presses in several methods, including burial, burning, and dumping.

During the period of war in Syria (since 2012), Safita area received thousands of displaced people from the war zones inside Syria. This massive inflation in the population of the area led to serious environmental consequences, including the accumulation of thousands of waste tons, especially in places of settlement and human activity, roads, rivers, and lakes. Based on the field surveys carried out, there is an urgent need to suggest suitable sites for landfilling as a critical part of formulating effective solid waste management policies for the Safita region. In this study, the optimal sites for landfills are suggested based on the integration between the AHP method and remote sensing data in a GIS platform. The outputs of this study include values of high importance to decision-makers and local planners in creating policies for managing the problem of solid waste in light of the consequences of the current war.

Material and methods

Study zone description (Safita area)

Safita is one of the six administrative regions in western Syria, including Tartous, Al-Draikish, Sheikhbadr, Al-Qadmous, Baniyas, in the Tartous governorate on the eastern coast of the Mediterranean. Study area lies between

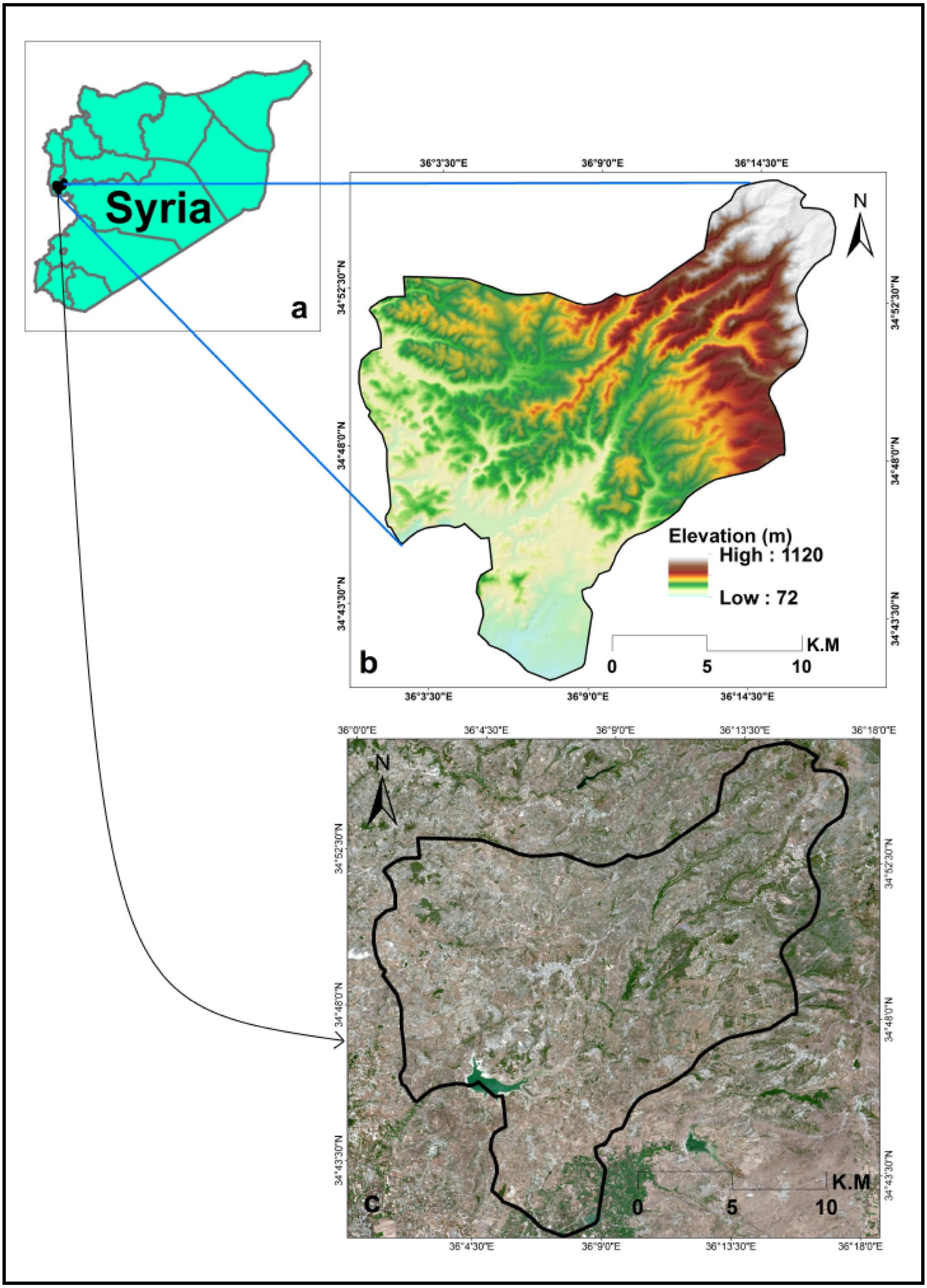


Fig. 1 Location of the study area: a—location for the Syrian governorates, b—location on the DEM, c—Landsat 8 OLI true image of the study area

35.8–36.1° E longitude and 34.41–35.3°N latitude (Fig. 1), with an area of 335 km^2 and a population of 22,145 (Abdo 2018). Study area is characterized by mountainous-hilly terrain with an elevation of 1120 m a.m.s.l. Safita is classified under the mountainous Mediterranean climate: the *Csa* and *Csb* patterns (*Köppen* climate classification), where the average annual temperature reaches 15.7 °C with a relative humidity of 68.4% (Mohammed et al. 2020). The rainy period extends for about eight months, from September to April, with the annual precipitation rate reaching to 1247 mm (Abdo 2020). Safita is one of the most important areas in Tartous governorate, which is characterized by economic activities such as agriculture and tourism. Moreover, Safita is part of the first agricultural stability zone in Syria (Abdo 2018). Olives and citrus are the most important agricultural crops.

Data used, processing and preparation

In order to map the spatial suitability of landfills, a set of multi-source data, especially remote sensing data, was relied on, as shown in the Table 1. However, data was entered and processed in a GIS environment using spatial analysis tools: *Resample*, *Resize*, *Euclidean Distance*, *Interpolation*, *Tabulation*, *Conversion*, *Raster Calculator*, and *Reclassification* tools at a resolution of 30 m. The considered criteria map layers were prepared and produced according to the spatial raster grid data format at a resolution of 30 m. Figure 2 shows the flow chart that represents the methodological framework used in this study. The digital elevation model (DEM) was used to derive the elevation, slope, and drainage layer maps. Slope degree layers were prepared using surface analysis tools in in the ArcGIS software. The drainage layer also was derived using the hydrological analysis tools, by applying the steps: fill, flow direction, flow accumulation, con, and streams. The spatial distribution of permeability values was mapped through the process of digitizing and converting to the Raster formula. A comprehensive spatial evaluation process was conducted for the faults, settlements, drainages , water supplies, lakes, roads, tourist centers, archaeological centers, and religious centers criteria using the Euclidean distance analysis (Eq.1) (Gonçalves et al. 2014).

$$d(p,q) = \sqrt{\sum_{i=1}^{n} (q_i - p_i)^2} \tag{1}$$

p, q: two points in Euclidean n-space, $q_i - p_i$: Euclidean vectors, starting from the origin of the space (initial point),n: n-space. Land use/land cover (LULC) map was created based on the analysis of Landsat 8 OLI Image using the maximum likelihood classifier supervised classification algorithm. The quality of the LULC classification was verified experimentally by using the method of comparison between the LULC layer and a set of randomly distributed reference points (Al Shogoor et al. 2022). In this regard, an error matrix was built, which is the basis for the accuracy evaluation process, as well as the kappa coefficient was used. The classification accuracy and kappa coefficient were 88% and 84.7%, respectively. Referring to a map of settlements, it was exported from LULC layer.

Exclusion assessment

The process of sanitary municipal landfill site selection is a necessity for sustainable spatial development in any region. Thus, the classification of criteria involved in the modeling process must be accurately determined through the evaluation of exclusion. In this study, new landfill site selection in the study area were identified based on several methodological justifications in the evaluation

Table 1 Thematic layers of factors used and sources of data

Parameter	Data source	Data format	Resolution
Slope Elevation Drainages	(https://earthexplorer.usgs.gov/) (accessed on 17 April 2022)	Spatial raster grid data	30 m
Permeability Faults	The General Corporation of Geology in Lattakia Governorate General Authority for Remote Sensing—Lattakia Governorate	Spatial vector data	-
LULC Settlement	Landsat OLI-TIRS, April 2022 (https://earthexplorer.usgs.gov/) (accessed on 22 April 2022)	Spatial raster grid data	30 m
Water supplies Lakes	Directorate of Water Resources in Tartous Governorate	Spatial vector data	-
Roads	Directorate of Transport and Public Roads – Tartous governorate	Spatial vector data	-
Tourist centers	Directorate of Tourism in Tartous Governorate	Spatial vector data	-
Archaeological centers	Directorate of Antiquities and Museums in Tartous Governorate	Spatial vector data	-
Religious centers	Awqaf Directorate in Tartous Governorate	Spatial vector data	-

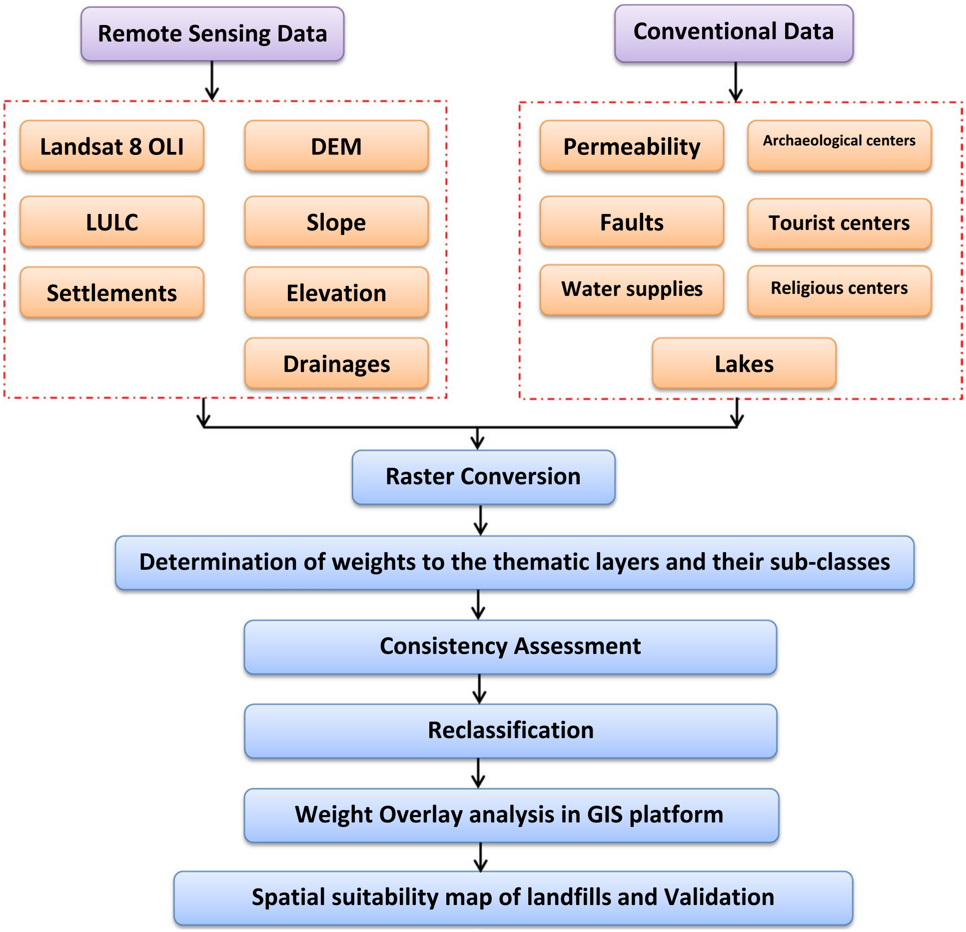


Fig. 2 Flowchart of methodology used in this study

of exclusion, including the regulations of the Ministry of Local Administration and Environment in Syria, expert opinions, and a review of the relevant literature. Table 2 refers to exclusion, threshold values, and references utilized in the current investigation.

Considered criteria

The determination of the criteria for spatial suitability is one of the most important and complex procedures, especially in a sensitive issue such as choosing the optimal sites for landfills. To this end, twelve experts (ecologists, geologists, geomorphologists, land use planners, and waste management practitioners) were surveyed with the aim of accurate identification of AHP criteria. Furthermore, a systematic survey of the relevant literature was conducted for the criteria used in mapping the spatial suitability of landfills, as shown in Table 3. Based on the expert opinions, the previous literature, the field study, and the specificity of the study area, thirteen factors were identified for modeling the spatial suitability of landfills establishment.

Elevation

Elevation is at the forefront of the topographical parameters in the selection process for optimal landfill sites. The relevant literature indicates that areas with high elevation values are not suitable for sustainable landfill construction due to high waste transportation costs, extreme climatic characteristics, and insufficient management. (Alkaradaghi et al. 2019). Moreover, areas with low elevation are considered unsuitable for landfills due to proximity to water sources and drainage constraints (Bilgilioglu et al. 2021). Thus, landfills should be established in areas with moderate elevation values to avoid related problems. In this study, the elevation layer map was categorized into five classes: <200, 200–400, 400–600, 600–800, and >800 m as Fig. 4a illustrates.

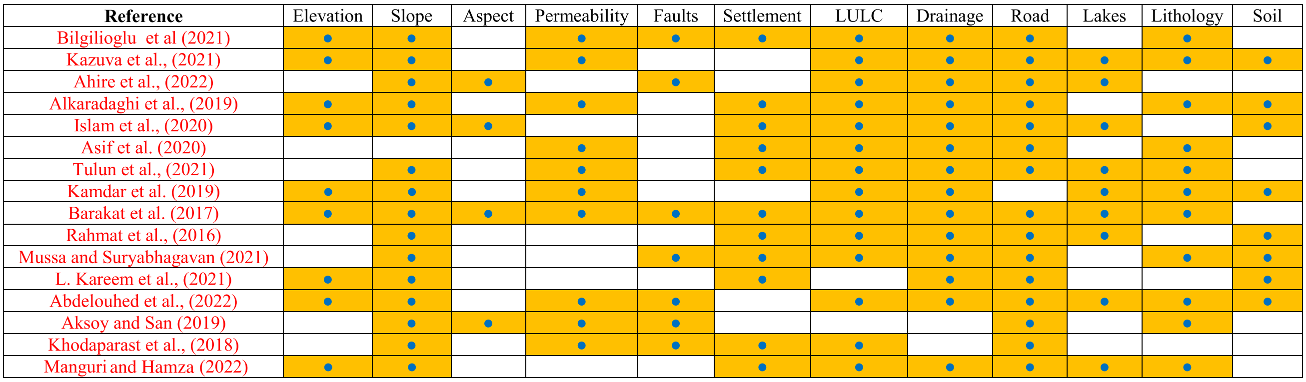
Slope

Slope is among the critical terrain factors that must be taken into account in the construction of sustainable

Table 2 Exclusion, threshold values, and references utilized in the current investigation

Criteria	Exclusion class	References
Elevation	< 800 m	Experts' opinions; Manguri and Hamza (2022)
Slope	> 20°	EO (2018); Jafar et al. (2016); Azem et al. (2021); Mussa and Suryabhagavan (2021);Manguri and Hamza (2022); Ersoy and Bulut (2009); Alsarayreh and Alsarayreh 2021)
Distance to faults	< 300 m	Jafar et al. (2016); Ersoy and Bulut (2009); Elahi and Samadyar (2014); Kamel and Hasan 2018
Distance to settlement	< 500 m	Jafar et al. (2016); EO (2018); Ghobadi et al. (2013); Alsarayreh and Alsarayreh (2021)
LULC	-	Experts' opinions
Distance to drainage	< 100 m	EO (2018); Jafar et al. (2016); Kamel and Hasan 2018; Experts' opinions
Distance to water supplies	< 500 m	EO (2018); Jafar et al. (2016); Ghobadi et al. (2013); Mussa and Suryabhagavan (2021)
Distance to lakes	< 500 m	Jafar et al. (2016); EO (2018); Manguri and Hamza (2022); Wang et al. (2009); Khan and Samadder (2015)
Distance to road	< 200 m	Jafar et al. (2016); Karimi et al. (2019); Uyan (2014); Bilgilioglu et al. (2021); Chabuk et al. (2017)
Distance from tourist centers	< 400 m	Jafar et al. (2016); Tercan et al. (2020); Experts' opinions
Distance from archaeological centers	< 1000 m	Jafar et al. (2016); Manguri and Hamza (2022); Kareem et al. (2021); Ersoy and Bulut (2009); Experts' opinions
Distance from religious centers	< 1000 m	Jafar et al. (2016); EO (2018); Kareem et al. (2021); Ersoy and Bulut (2009); Experts' opinions

Table 3 Literature review of several parameters for landfill site selection using AHP



Reference	Elevation	Slope	Aspect	Permeability	Faults	Settlement	LULC	Drainage	Road	Lakes	Lithology	Soil
Bilgilioglu et al (2021)	●	●		●	●	●	●	●	●		●	
Kazuva et al., (2021)	●	●		●			●	●	●	●	●	●
Ahire et al., (2022)		●	●		●		●	●	●	●		
Alkaradaghi et al., (2019)	●	●		●		●	●	●	●		●	●
Islam et al., (2020)	●	●	●			●	●	●	●	●		●
Asif et al. (2020)				●		●	●	●	●		●	
Tulun et al., (2021)		●		●		●	●	●	●	●	●	
Kamdar et al. (2019)	●	●		●			●	●		●	●	●
Barakat et al. (2017)	●	●	●	●	●	●	●	●	●	●	●	
Rahmat et al., (2016)		●				●	●	●	●	●		●
Mussa and Suryabhagavan (2021)		●			●	●	●	●	●		●	●
L. Kareem et al., (2021)	●	●				●		●	●			●
Abdelouhed et al., (2022)	●	●		●	●		●	●	●	●	●	●
Aksoy and San (2019)		●	●	●	●				●		●	
Khodaparast et al., (2018)		●		●	●	●	●		●			
Manguri and Hamza (2022)	●	●				●	●	●	●	●	●	

landfill sites. Steep slopes cause an increase in landfill construction and maintenance costs, a high potential for soil and water pollution due to increased movement of slope materials, and an increase in transportation costs (Babiker et al. 2005). Therefore, areas with slope values greater than 30 degrees are considered unsuitable for the establishment of landfills, as indicated by the previous literature (Dereli and Tercan 2021; Chabuk et al. 2017). The study area is characterized by high sensitivity to landslides due to several factors, especially severe slopes (Abdo 2018). In the current assessment, the slope degree map were categorized into five classes (Fig. 4b): <5°, 5–10°, 10–15°, 15–20°, and >20°.

Permeability

The hydrological permeability factor determines the susceptibility to soil and groundwater contamination by landfill output of highly toxic liquids. Thus, areas with low hydrological permeability should be selected in order to reduce hydrogeological pollution (Tulun et al. 2021). Geological investigations indicate that the study area consists of mainly Mesosoic (Jurassic and Cretaceous), Cenosoic (Neogene volcanic), and Quaternary (Holocene) formations (Fig. 3). According to several geological studies carried out in the Syrian coast, the Jurassic and Holocene formations

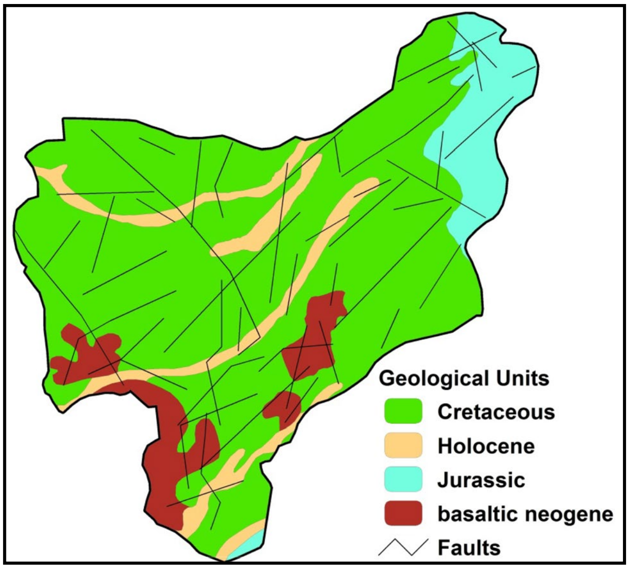


Fig. 3 Geological units in this study

are characterized by high permeability, followed by the Cretaceous formations. In this regard, basaltic neogene formations are described as having low permeability due to clay (Ponikarov 1966). The *Quaternary* formations were identified as unsuitable sites for landfill construction (sand and gravel) in contrast to the *Tertiary* volcanic formations with impermeable lithology (clay). However, Fig. 4c shows the spatial distribution of hydrological permeability according to three classes: permeable, impermeable, and semi-permeable.

Distance to faults (DF)

Fractured zones provide a critical indicator of the potential for landfill output into groundwater (Barakat et al. 2017). Moreover, geomorphological hazards increase in areas near faults that can cause irreversible environmental hazards. Thus, the areas near the faults are not suitable for the establishment of landfills. The study area is characterized by the density of faults as a result of tectonic complexity due to the influence of the huge African-Asian fault. The fault layer was derived on the basis of the geological maps 1/50000 (the maps of Safita and Tartous) issued by the General Corporation of Geology in Lattakia Governorate. Moreover, the fault layer was supported by data derived from the studies carried out by the General Authority for Remote Sensing—Lattakia Governorate. In the current analysis, the distance to faults in the study area was classified into four categories, including 100 < m, 100–200 m, 200–300 m, 300–400 m, and < 400 m, as Fig. 4d shows.

Distance to settlement (DS)

The establishment of landfills near settlement areas leads to catastrophic environmental and health consequences for the population, including the spread of diseases, emission of unpleasant odours, noise pollution, distortion of the aesthetics of the place, and the devaluation of the property (Rahimi et al. 2020). For these reasons, the criterion of distance from settlements is one of the decisive human criteria in the process of establishing landfills. In the current assessment, the distance to settlements was divided into five categories: <100, 100–200, 200–300, 300–400, and >400 m, as Fig. 4e shows.

Land use/land cover (LULC)

The integrated management of LULC reduces the negative environmental and social consequences of establishing landfills (Bilgilioğlu and Bilgilioğlu 2017). In addition, the LULC is one of the critical criteria for the mitigation of the land degradation susceptibility (Rahmat et al. 2017). In this regard, the establishment of landfill sites on lands with high biological values is an illegal issue. Unfortunately, LULC planning in the context of spatial management is almost missing in the study area (Abdo et al. 2022; Chaaban et al. 2022). Agricultural land, bare ground, forest, grass, scrub/shrub, settlement, and water are the types of LULC in study area, as Fig. 4f depicts.

Distance to drainage

The distance to drainage network is one of the most important hydrological criteria included in the modeling of land suitability for landfills. The output of landfills can enter the rivers, causing severe pollution to humans and the environment. Moreover, the sensitivity of this criterion is increased in humid and semi-humid environments that are characterized by high precipitation intensities and the density of the drainage network, as is the case in the study area (Mohammed et al. 2021). In the current analysis, the distance to o drainages was divided into five classes: 100 < m, 100–200 m, 200–300 m, 300–400 m, and < 400 m, as Fig. 4g shows.

Distance to water supplies

The spatial distribution of water supplies is a pivotal consideration when constructing landfills. In the study area, drinking water is secured through a group of wells that are scattered around. It is important to consider this distribution when establishing landfills in the context of continuous maintenance of surface water quality. Figure 4h classifies

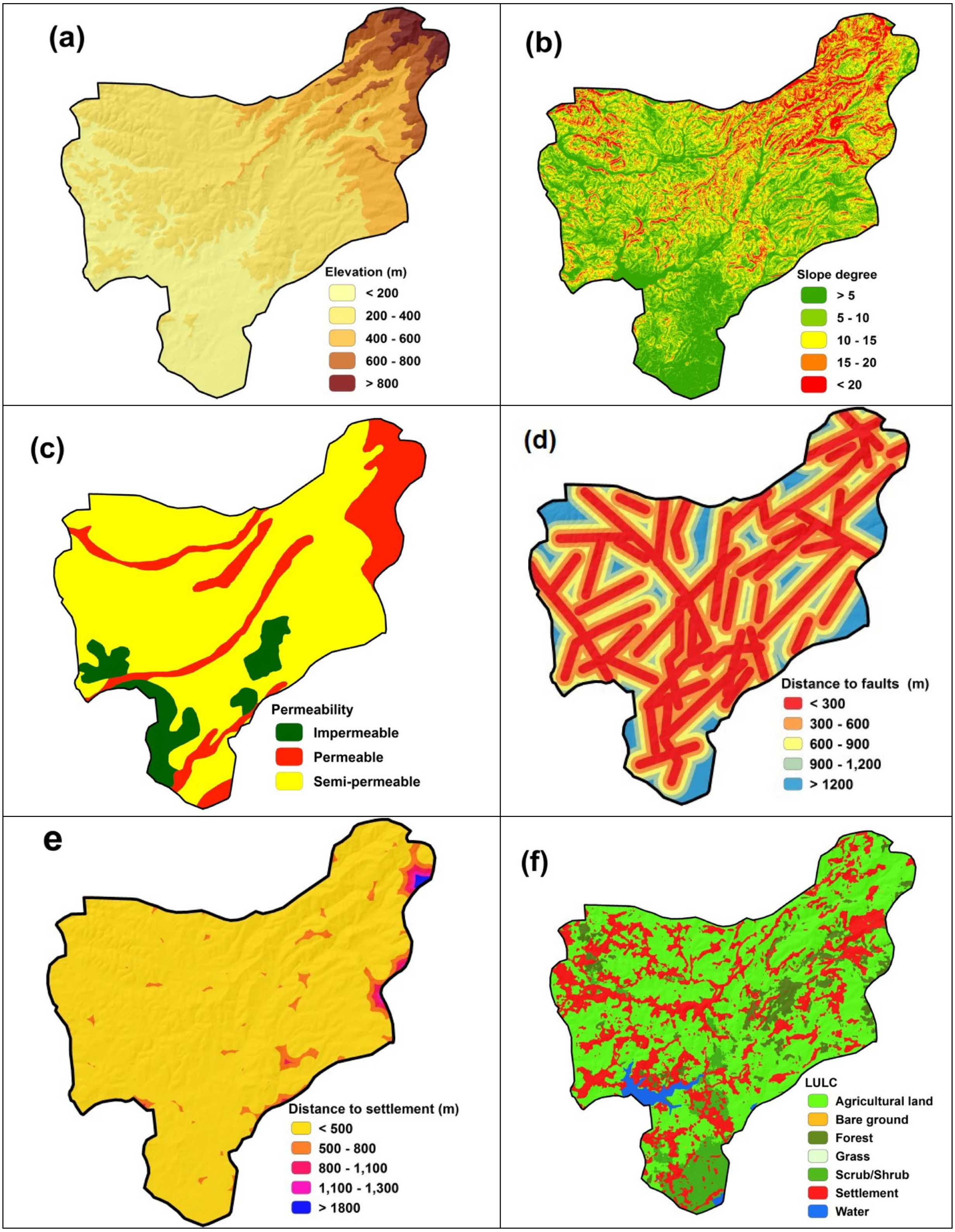


Fig. 4 Layers factors: **a** elevation, **b** slope degree, **c** permeability, **d** proximity to faults, **e** distance to settlement, **f** LULC, **g** distance to drainage, **h** distance to water supplies, **i** distance to lakes, **j** distance to road, **k** distance from tourist centers, **l** distance from archaeological centers, **m** distance from religious centers

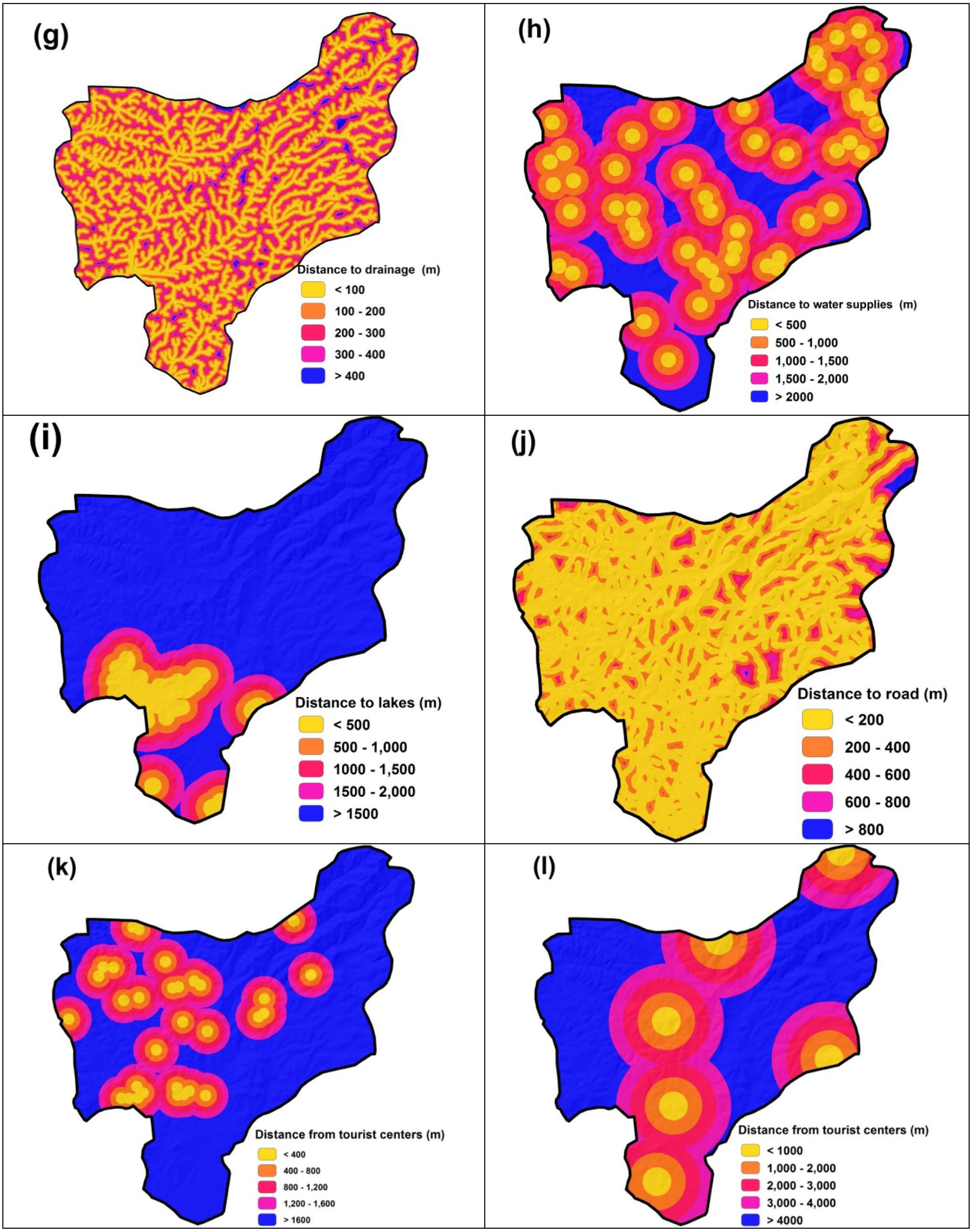


Fig. 4 (continued)

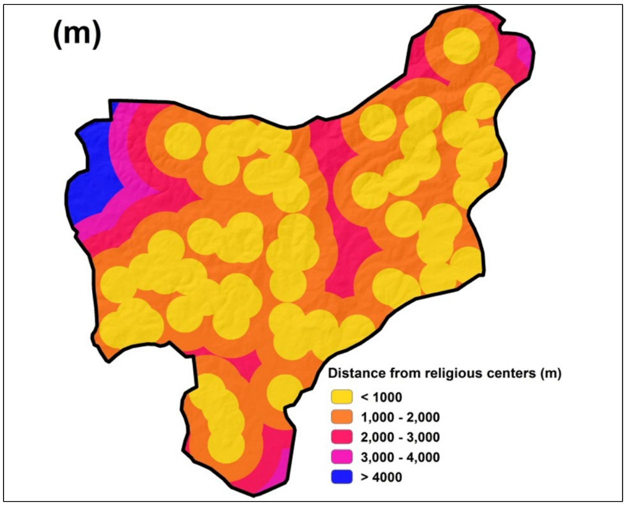


Fig. 4 (continued)

the distance to water supplies into five classes: 100 < m, 100–200 m, 200–300 m, 300–400 m, and < 400 m.

Distance to lakes

Lakes represent an important basis for the sustainability of humans, agricultural development, and wildlife conservation. Maintaining the quality of water bodies, including lakes and dams, is one of the most important criteria for sustainable environmental planning (Pasalari et al. 2019). However, continuous water surfaces are among the most polluted environmental components. The criterion of distance to lakes is decisive in the study area due to the presence of Al-Basel lake, which is the largest one in Tartuse Governorate. In the current assessment, the distance to lakes was divided into five classes: 100 < m, 100–200 m, 200–300 m, 300–400 m, and < 400 m, as Fig. 4i illustrates.

Distance to road

The distance to roads constitutes one of the most substantial economic criteria for choosing potential sites for the construction of landfills. Despite the financial ease of transporting waste owing to the proximity of the landfill site to the main road network, it distorts the general aesthetic appearance (Aksoy and San 2019). Thus, a balance must be struck between costs and the beauty of the landscape when planning the construction of landfills. At the present evaluation, the distance to road was divided into five classes: 100 < m, 100–200 m, 200–300 m, 300–400 m, and < 400 m, as Fig. 4j shows.

Distance from tourist centers

Tourism activity is considered one of the most important aspect of economic life in the study area. The proximity of landfills to tourist centers distorts the aesthetics of the urban environment, which leads to hitting one of the most important sources of local income. Thus, due consideration should be given to existing tourism infrastructure when constructing landfills (Ding et al. 2018). In this study, the distance from tourist centers was divided into five classes: 100 < m, 100–200 m, 200–300 m, 300–400 m, and < 400 m, as Fig. 4k shows.

Distance from archaeological centers

Preservation of archaeological sites is among the essential criteria that must be taken into account when planning the establishment of landfills (Chabuk et al. 2017). The study area possesses a cultural and historical heritage represented by many archaeological sites. Also, these sites support tourism activity in the study area. In this study, the distance from archaeological centers was divided into five classes: 100 < m, 100–200 m, 200–300 m, 300–400 m, and < 400 m, as Fig. 4l shows.

Distance from religious centers

The study area is characterized by rich religious heritage as it houses some important Christian and Islamic religious centers. These centers are places of great spiritual sanctity, and it should be borne in mind when conducting environmental and urban planning processes. Achieving distance to religious centers is one of the most important considerations when establishing landfills. In this study, the distance from religious centers was divided into five classes: 100 < m, 100–200 m, 200–300 m, 300–400 m, and < 400 m, as Fig. 4m shows.

Analytical hierarchy process

Analytical hierarchy process (AHP) is a well-known multi-criteria decision-making method evolved by Saaty in 1980 (Saaty 1980; Halder et al. 2022; Islam et al. 2020). In this method, criteria are ordered in a hierarchal approach targeting the quantification of relative preferences in a given set of alternatives on a ratio scale (Asfaw et al. 2022; Asif et al. 2020; Islam et al. 2020; Abdo 2022). In addition, a lot of scholars have reported the importance of analytical hierarchy process implementation in land suitability for landfills (Kamdar et al. 2019).

In order to produce a logical conclusion on the significance of chosen criteria, a decision matrix was constructed utilizing the analytic hierarchy process (AHP) by considering the expert views on the impact of each factor on the construction of potential landfill sites (Abdelouhed et al. 2022; L. Kareem et al. 2021; Manguri and Hamza 2022). This pairwise comparison matrix is composed in which aii = 1 and aij = 1/ai. The importance coefficients of the ranking criteria and the sub-criteria are computed utilizing the right eigenvector calculated from the maximum absolute eigenvalue ($\lambda_{\max}$, 1, 2). The estimating values of all the criteria are normalized to 1.

Step 1: Principal eigenvalue (λ) was calculated by the eigenvector technique (Kumar and Krishna 2018) which is expressed by the equation below (Eq. 2).

$$\lambda_{max} = \frac{1}{n}\sum\nolimits_{wi}^{n}\frac{(AW)i}{w} \qquad (2)$$

Step 2: Pairwise comparison matrix was built (Eq. 3) (Saaty 1980)

$$AW = \begin{pmatrix} a11 & a12 & ...a1n \\ a21 & a22 & ...a2n \\ a31 & a32 & ...a3n \\ . & . & . \\ . & . & . \\ . & . & . \\ an1 & an2 & ...ann \end{pmatrix} \times \left(w_{1,2,3....n}\right) \qquad (3)$$

where W is the corresponding eigenvector of $\lambda_{\max}$ and wi (i = 1, 2, 3,..., n) is the weight value for ranking. The rank of each pairwise comparison was specified from Saaty's pairwise scale to put the relative significance to the selected criteria taken for land suitability for landfills. The scale ranges from 1 to 9 point scale as proposed and developed by Saaty (1980) (Table 4).

Step 3: The consistency of the decision matrix should be tested with the computation of the consistency index (CI) which is expressed by the below equation (Eq. 4) (Saaty 1980).

Table 4 The random inconsistency value

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	
Rationales	Ratio arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

Table 5 The random inconsistency value

Number of criterion	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Random inconsistency	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{4}$$

where CI is the consistency index, $\lambda_{\max}$ is the maximum or principal eigenvalue of the decision matrix, and n is the order of the matrix.

Step 4: The consistency ratio (CR) coefficient is computed based on the approach suggested by Saaty (1980). The CR coefficient should be less than "0.1," representing the total consistency of the pairwise comparison matrix. If the consistency ratio exceeds "0.1," the matrix of the decision will be considered "inconsistent" and the matrix has to be evaluated again. Simultaneously, the value of the consistency ratio is totally equaled to "0" or ranging from 0 to 0.09 will be accepted only as consistent. The consistency ratio (CR), however, is expressed by the equation below (Eq. 5) (Saaty 1980).

$$CR = \frac{CI}{RI} \tag{5}$$

where CR is the consistency ratio, CI is the consistency index, and RI is the random index, whereas RI has been adopted according to Table 5.

Mapping the spatial suitability of landfill

The multi-criteria suitability map of landfills is a spatial dimensionless outcome that supports predicting the acceptable land sectors for sustainable sanitary municipal landfill sites in a specific area. In the current assessment, the weight overlay analysis in GIS platform method has been implemented to map the spatial suitability of landfills as follows (Eq. 6) (Abdelouhed et al. 2022)

$$S = \sum\nolimits_{t=1}^{m} \sum\nolimits_{f=1}^{n} (W_t + X_f) \tag{6}$$

where W_t represents the normalized weight of the t thematic layer, X_f represents the rank value of each class with respect to the f layer, m represents the total number of thematic layers, and n represents the total number of classes in the thematic layer. In this context, weights specified to the different thematic layers and derivation of the normalized weights using AHP are shown in Tables 5 and 6. The multi-criteria suitability map of landfills evaluating all the criteria in an integrated layer is computed utilizing Eq. 7

$$\begin{aligned} LM = {} & El_{wi} \times El_r + SL_{wi} \times SL_r + PE_{wi} \times PE_r + DF_{wi} \times DF_r + DS_{wi} \times DS_r + \\ & LULC_{wi} \times LULC_r + DD_{wi} \times DD_r + DW_{wi} \times DW_r + DL_{wi} \times DL_r + DR_{wi} \times DR_r + DT_{wi} \times DT_r + DA_{wi} \times DA_r + DG_{wi} \times DG_r \end{aligned} \tag{7}$$

where El_{wi} represents the weight index of elevation criteria and El_r is the rank of elevation criteria; SL_{wi} represents the weight index of slope criteria and SL_r is the rank of slope criteria; PE_{wi} represents the weight index of permeability criteria and PE_r is the rank of permeability criteria; DF_{wi} represents the weight index of distance to faults criteria and DF_r is the rank of distance to faults criteria; DS_{wi} represents the weight index of distance to settlement criteria and DS_r is the rank of distance to settlement criteria; $LULC_{wi}$ represents the weight index of LULC criteria and $LULC_r$ is the rank of

Table 6 Pairwise comparison matrix by AHP

Factors	EL	SL	PE	DF	DS	LULC	DD	DW	DL	DR	DT	AD	DG
Elevation (El)	1	1.00	2.00	3.00	3.00	1.00	3.00	1.00	3.00	5.00	6.00	8.00	9.00
Slope (SL)	1.00	1	3.00	4.00	2.00	4.00	5.00	3.00	4.00	5.00	6.00	6.00	7.00
Permeability (PE)	0.50	0.33	1	3.00	4.00	2.00	3.00	3.00	4.00	3.00	4.00	5.00	6.00
Distance to faults (DF)	0.33	0.25	0.33	1	3.00	2.00	2.00	3.00	2.00	3.00	4.00	5.00	5.00
Distance to settlement (DS)	0.33	0.50	0.25	0.33	1	1.00	3.00	2.00	4.00	3.00	4.00	5.00	5.00
Landuse/Landcover (LULC)	1.00	0.25	0.50	0.50	1.00	1	2.00	1.00	2.00	4.00	5.00	4.00	5.00
Distance to drainage (DD)	0.33	0.20	0.33	0.50	0.33	0.50	1	1.00	1.00	2.00	3.00	4.00	4.00
Distance to water supplies (DW)	1.00	0.33	0.33	0.33	0.50	1.00	1.00	1	1.00	4.00	5.00	6.00	6.00
Distance to lakes (DL)	0.33	0.25	0.25	0.50	0.25	0.50	1.00	1.00	1	2.00	3.00	4.00	4.00
Distance to road (DR)	0.20	0.20	0.33	0.33	0.33	0.25	0.50	0.25	0.50	1	1.00	2.00	2.00
Distance from tourist centers (DT)	0.17	0.17	0.25	0.25	0.25	0.20	0.33	0.20	0.33	1.00	1	3.00	4.00
Distance from archaeological centers (DA)	0.12	0.17	0.20	0.20	0.20	0.25	0.25	0.17	0.25	0.50	0.33	1	3.00
Distance from religious centers (DG)	0.11	0.14	0.17	0.20	0.20	0.20	0.25	0.17	0.25	0.50	0.25	0.33	1

LULC criteria; DD_{wi} represents the weight index of distance to drainage criteria and DD_r is the rank of distance to drainage criteria; DW_{wi} represents the weight index of proximity of distance to water supplies criteria and DW_r is the rank of distance to water supplies criteria; DL_{wi} represents the weight index of distance to lakes criteria and DL_r is the rank of proximity of distance to lakes criteria; DR_{wi} represents the weight index of distance to road criteria and DR_r is the rank of proximity of distance to road criteria;DT_{wi} represents the weight index of distance from tourist centers criteria and DT_r is the rank of proximity of distance from tourist centers criteria;DA_{wi} represents the weight index of distance from archaeological centers criteria and DA_r is the rank of proximity of distance from archaeological centers criteria; DG_{wi} represents the weight index of distance from archaeological centers criteria and DG_r is the rank of proximity of distance from archaeological centers criteria.

Validation

The process of accuracy evaluating of the final output of spatial modeling is a critical complementary procedure contributes in providing a reliable output that allows optimal use of the results of this study (Mohsin et al. 2022). The area under curve-receiver operating characteristic (AUC-ROC) was used in order to assess the accuracy of the final map of sanitary municipal landfill site selection in study area. To this end, several fieldworks were carried out in cooperation with the mayors across the study area to identify 100 sites, with 50 suitable sites and 50 unsuitable sites of landfills.

Result and discussion

The integration between spatial multi-criteria technology and GIS provided a reliable tool for developing a map of spatial suitability for optimal landfill sites. In this study, thirteen criteria, including geological, topographical, geomorphological, hydrological, and structural criteria, were used in selecting process the optimal sites for sustainable landfills. The selected criteria contribute to providing a correct spatial decision that helps in managing the problem of landfill sites in the context of reducing their negative effects on humans and the environment in the study area.

The AHP approach was based on evaluating the quantitative importance of the criteria involved in the spatial fit process to identify potential new landfill sites. At this stage, the importance of the criteria was compared by developing a pairwise comparison matrix according to the Saaty scale of 1 to 9. In this context, the opinions of 11 experts were based on the weighting of the criteria used. The consistency of this weighting performed in AHP approach was tested by CR index calculation. The value of CR is 0.061 ($CR < 0.1$), meaning that the criteria can be considered consistent and acceptable for modeling and classification in reliable spatial decision making. Final weights were assigned to all maps of the criteria layers used in the GIS environment (Fig. 5, Tables 7 and 8), and then, a spatial suitability map was produced.

Figure 6a shows the final output of the multi-criteria spatial modeling process for the potential landfill locations according to five suitability levels, i.e. unsuitable (83.28%), less suitable (8.49%), moderately suitable (4.49%), highly suitable (2.57%), and very highly suitable (0.72%) (Table 9). According to the current result, it was found that more than 80% of the study area is not suitable for establishing new landfill sites. It may be mentioned here that, this area is characterized by high environmental sensitivity, and consists mainly of forest masses and built-up lands; therefore, it is an area for forest conservation and urban and tourism development (Khodaparast et al. 2018; Bilgilioglu et al. 2021). Also, these areas are characterized by steep slopes measuring more than 50 degrees in some locations. Many ecologists indicate that slope enhances the risk of landfills, especially in humid areas (Şener et al. 2010; Pasalari et al. 2019; Barzehkar et al. 2019). The slope increases the runoff causing a greater spatial distribution of the landfill liquids. In sum, the establishment of

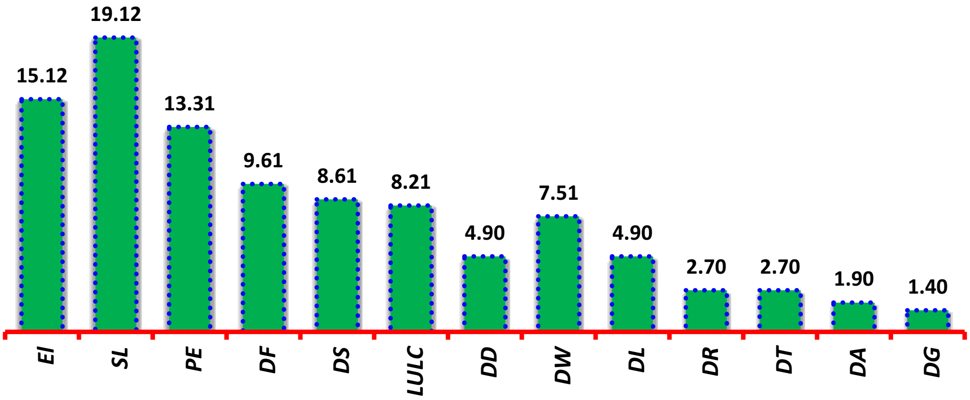


Fig. 5 Final weight ratio of sub-criteria based on AHP

Table 7 Normalized pairwise comparison matrix and computation of criterion weightage

Criteria	EL	SL	PE	DF	DS	LULC	DD	DW	DL	DR	DT	AD	DG	Weights	Rank
Elevation (El)	0.156	0.209	0.224	0.212	0.187	0.072	0.134	0.060	0.129	0.147	0.141	0.150	0.148	0.151	2
Slope (SL)	0.156	0.209	0.336	0.283	0.125	0.288	0.224	0.179	0.171	0.147	0.141	0.113	0.115	0.191	1
Permeability (PE)	0.078	0.069	0.112	0.212	0.249	0.144	0.134	0.179	0.171	0.088	0.094	0.094	0.098	0.133	3
Distance to faults (DF)	0.051	0.052	0.037	0.071	0.187	0.144	0.090	0.179	0.086	0.088	0.094	0.094	0.082	0.096	4
Distance to settlement (DS)	0.051	0.104	0.028	0.023	0.062	0.072	0.134	0.119	0.171	0.088	0.094	0.094	0.082	0.086	5
Land use/land cover (LULC)	0.156	0.052	0.056	0.035	0.062	0.072	0.090	0.060	0.086	0.118	0.117	0.075	0.082	0.082	6
Distance to drainage (DD)	0.051	0.042	0.037	0.035	0.021	0.036	0.045	0.060	0.043	0.059	0.070	0.075	0.066	0.049	8
Distance to water supplies (DW)	0.156	0.069	0.037	0.023	0.031	0.072	0.045	0.060	0.043	0.118	0.117	0.113	0.098	0.075	7
Distance to lakes (DL)	0.051	0.052	0.028	0.035	0.016	0.036	0.045	0.060	0.043	0.059	0.070	0.075	0.066	0.049	9
Distance to road (DR)	0.031	0.042	0.037	0.023	0.021	0.018	0.022	0.015	0.021	0.029	0.023	0.038	0.033	0.027	10
Distance from tourist centers (DT)	0.026	0.035	0.028	0.018	0.016	0.014	0.015	0.012	0.014	0.029	0.023	0.056	0.066	0.027	11
Distance from archaeological centers (DA)	0.019	0.035	0.022	0.014	0.012	0.018	0.011	0.010	0.011	0.015	0.008	0.019	0.049	0.019	12
Distance from religious centers (DG)	0.017	0.029	0.019	0.014	0.012	0.014	0.011	0.010	0.011	0.015	0.006	0.006	0.016	0.014	13
λ	14.16														
n	13														
CI	0.096														
RI: $n = 13$	1.56														
CR	0.061														
CR%	6.19														

λ, maximum eigenvalue; *CI*, consistency index; *CR*, consistency ratio; *CV*, consistency vector

Table 8 Weights of the criteria and scores of the sub-criteria

	Criteria	Sub-criteria	Suitability class	Rating	AHP weights
1	Elevation (El) m	<200	Highly suitable	5	0.151
		200–400	Suitable	4	
		400–600	Moderately suitable	3	
		600–800	Less suitable	2	
		<800	Unsuitable	1	
2	Slope (SL) degree	<5	Highly suitable	5	0.191
		5–10	Suitable	4	
		10–15	Moderately suitable	3	
		15–20	Less suitable	2	
		<20	Unsuitable	1	
3	Permeability (PE)	Permeable	Unsuitable	1	
		Impermeable	Highly suitable	5	
		Semi-permeable	Moderately suitable	3	
4	Distance to faults (DF) m	<300	Unsuitable	1	0.096
		300–600	Less suitable	2	
		600–900	Moderately suitable	3	
		900–1200	Suitable	4	
		<1200	Highly suitable	5	
5	Distance to settlement (DS) m	<1000	Unsuitable	1	0.086
		2000–3000	Less suitable	2	
		3000–4000	Moderately suitable	3	
		4000–5000	Suitable	4	
		<5000	Highly suitable	5	
6	Land use/land cover (LULC)	Agricultural land	Moderately suitable	3	0.082
		Bare ground	Highly suitable	5	
		Forest	Excluded	0	
		Grass	Suitable	4	
		Scrub/shrub	Suitable	4	
		Settlement	Excluded	0	
		Water	Excluded	0	
7	Distance to drainage (DD) m	<1000	Unsuitable	1	0.049
		2000–3000	Less suitable	2	
		3000–4000	Moderately suitable	3	
		4000–5000	Suitable	4	
		<5000	Highly suitable	5	
8	Distance to water supplies (DW) m	<2000	Unsuitable	1	0.075
		2000–4000	Less suitable	2	
		4000–5000	Moderately suitable	3	
		5000–6000	Suitable	4	
		<7000	Highly suitable	5	
9	Distance to lakes (DL) m	<500	Unsuitable	1	0.049
		1000–1500	Less suitable	2	
		2000–2500	Moderately suitable	3	
		3000–3500	Suitable	4	
		<3500	Highly suitable	5	
10	Distance to road (DR) m	<200	Unsuitable	1	0.027
		400–600	Less suitable	2	
		600–1200	Moderately suitable	3	
		1800–2400	Suitable	4	
		<2400	Highly suitable	5	

Table 8 (continued)

	Criteria	Sub-criteria	Suitability class	Rating	AHP weights
11	Distance from tourist centers (DT) m	< 3000	Unsuitable	1	0.027
		3000–6000	Less suitable	2	
		6000–9000	Moderately suitable	3	
		9000–12,000	Suitable	4	
		< 12,000	Highly suitable	5	
12	Distance from archaeological centers (DA) m	< 1000	Unsuitable	1	0.019
		2000–3000	Less suitable	2	
		3000–4000	Moderately suitable	3	
		4000–5000	Suitable	4	
		< 5000	Highly suitable	5	
13	Distance from religious centers (DG) m	< 1000	Unsuitable	1	0.014
		2000–3000	Less suitable	2	
		3000–4000	Moderately suitable	3	
		4000–5000	Suitable	4	
		< 5000	Highly suitable	5	

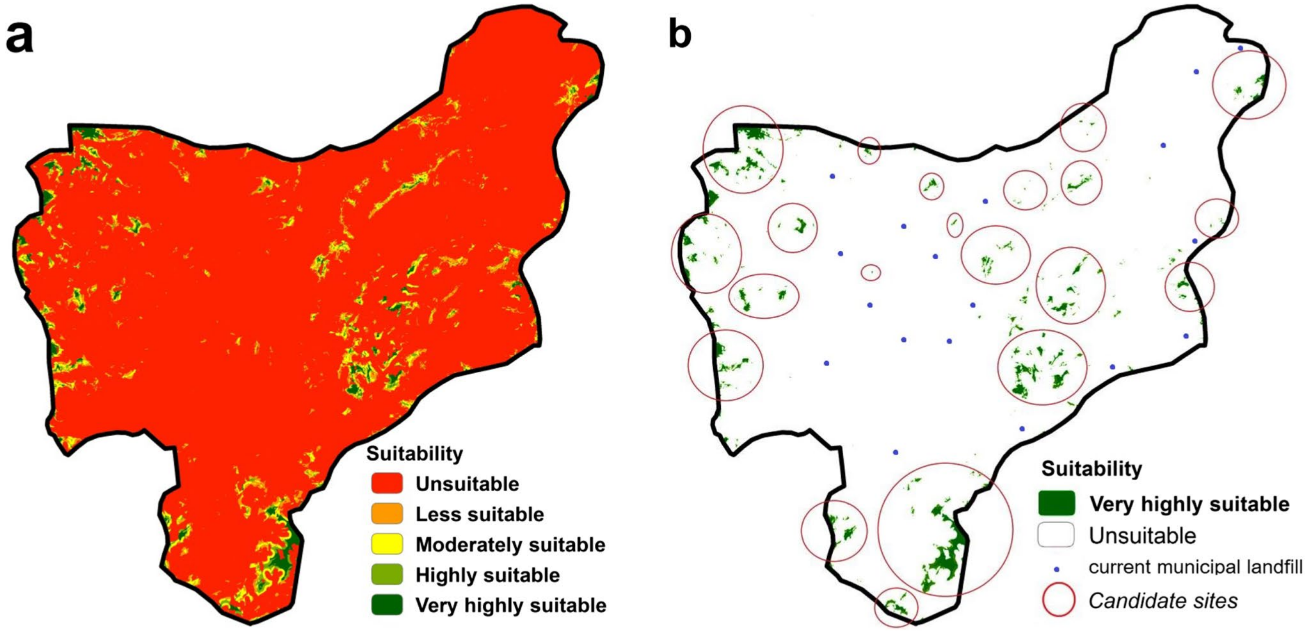


Fig. 6 Final outputs of landfilling suitability modeling: **a** suitability degrees map for the landfill sites, **b** candidate sites for landfilling according to AHP

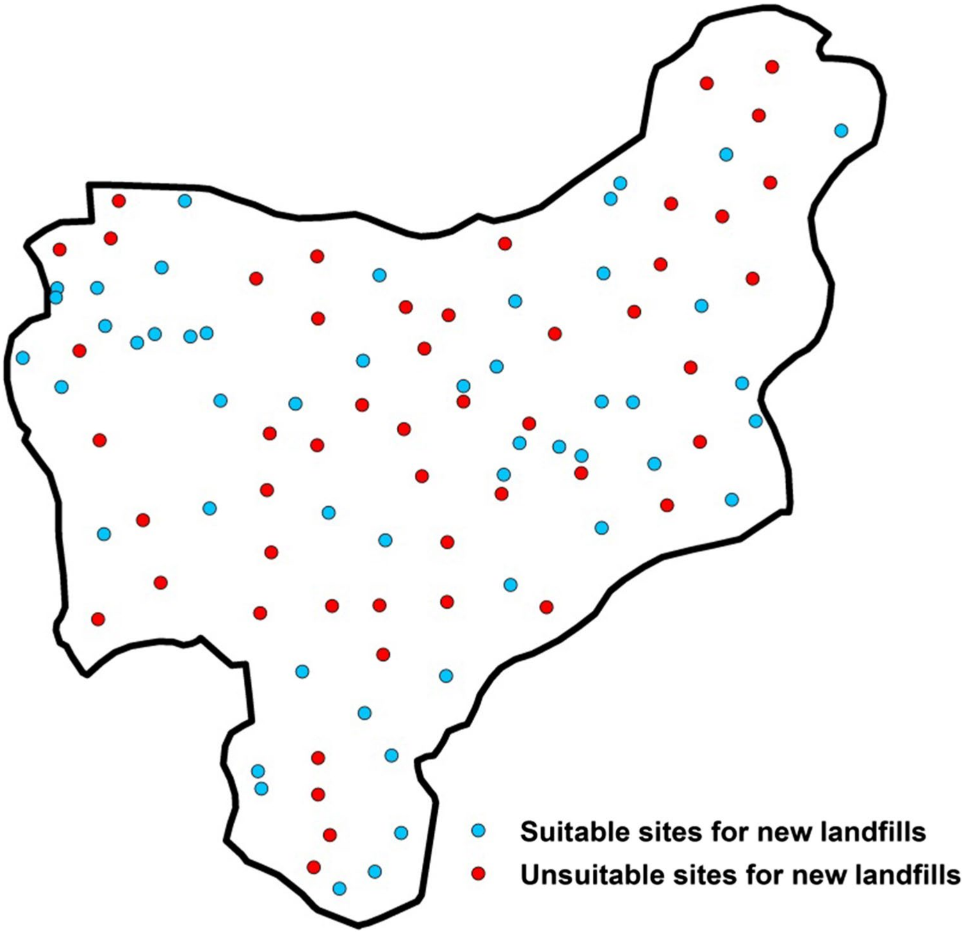
Table 9 Tabulate areas of landfills suitability degrees

Degree	Suitability degree	Area (km^2)	%
1	Unsuitable	280.02	83.59
2	Less suitable	30.17	9.01
3	Moderately suitable	15.47	4.62
4	Highly suitable	7.54	2.25
5	Very highly suitable	1.8	0.54

landfills in these areas will inevitably lead to catastrophic environmental consequences for various vital sectors in study area.

Simultaneously, it was found that only 0.72% of the study area is suitable for establishing new sustainable landfills. In this connection, Figure 6b shows the proposed sites for the establishment of landfills. The distribution of the proposed landfill sites, however, ensures the spatial balance between

Fig. 7 Determining suitable and unsuitable landfill locations



the distribution of population and settlements. It can be seen that the largest candidate sites for the establishment of new landfills were concentrated in the southern and southwestern regions. The proposed sites also provide important spatial horizons for achieving sustainable environmental conservation of natural resources in the study area with environmentally safe urbanization. Furthermore, it can be seen a spatial incompatibility between the existing dumps and the proposed ones. This indicates the environmental risk caused by the current landfills in destroying the local environment.

Figure 7 shows the spatial distribution of 100 landfill sites, including 50 suitable sites and 50 unfavorable sites. These sites, however, were used to assess the quality of the final map using ROC/AUC method. The AUC value of 88.01% indicates that the final map of the proposed landfill sites in this study is characterized by high accuracy (accuracy greater than 85%) according to Mohsin et al.'s (2022) study (Fig. 8). Thus, this final map can be used in the process of developing new landfill sites with environmental sustainability.

Despite the strict criteria presented in exclusion analysis based on national and methodological justifications in landfill site selection, it is important to note the great flexibility that characterizes the rigid integration of GIS and computers. In this regard, making any improvements or additions to these criteria based on the abundance of data will produce other final spatial outputs that have greater credibility and reliability.

In this regard, the national criteria adopted in this analysis are compatible with the regulations of the countries neighbouring Syria, especially if the national population growth is compared with the neighbouring countries. In this regard, many studies have been conducted based on strict environmental regulations similar to the Syrian environmental regulations, including in Turkey (Azem et al. 2021), Iraq (Manguri and Hamza 2022), Jordan (Alsarayreh and Alsarayreh 2021), and Lebanon (Kamel and Hasan 2018). Moreover, some regions of the neighboring countries are witnessing a demographic growth similar to the study area. In those regions, the integration of GIS and the MCDM was relied upon in selecting the best sites for landfills, such as Aley and Chouf, Lebanon (Kamel and Hasan 2018) and Al-Naja city, Iraq (Kareem et al. 2021).

Despite the catastrophic health consequences induced by the landfills in the western region of Syria, mitigation of this problem is still absent from the list of priorities of the local administrative authorities (Nasser and Ahmad 2019; Noufal

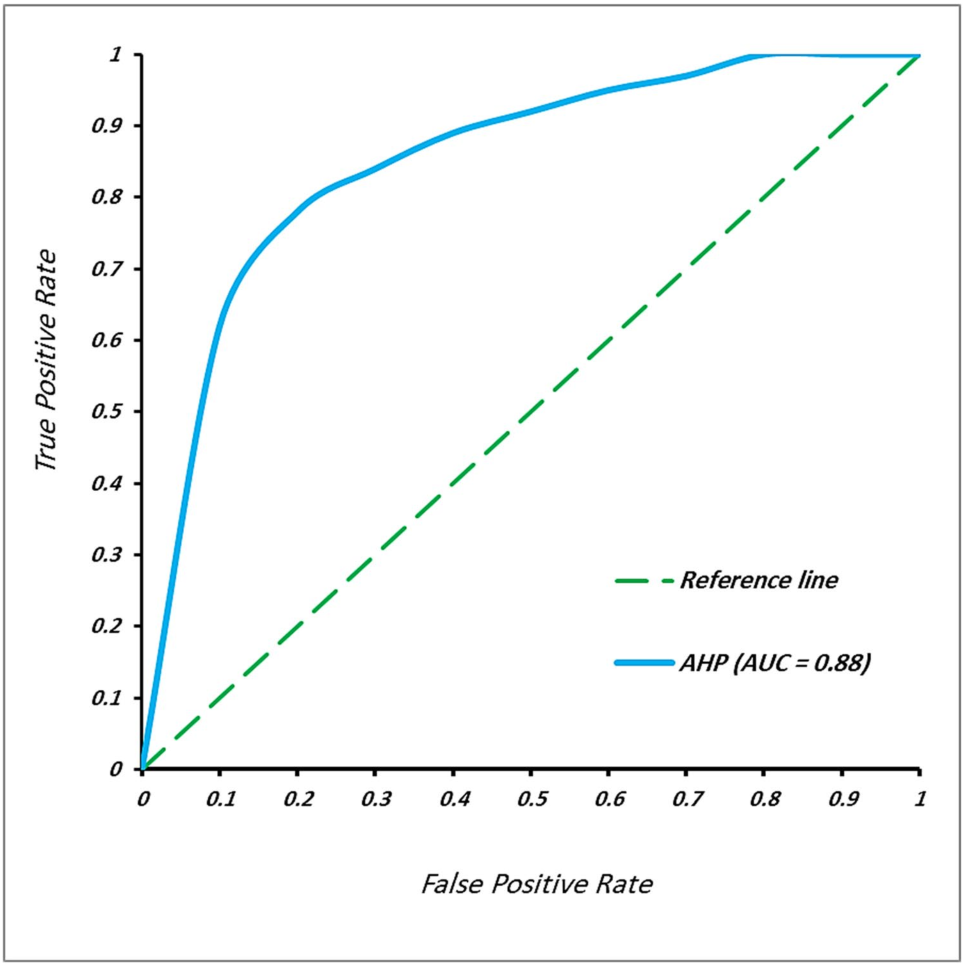


Fig. 8 AUC/ROC accuracy assessment of the final map

et al. 2021). During the last three decades, the rapid population growth and urbanization acceleration have led to an increase in the generation of solid waste which explains the massive spread of random landfills. This spread was not limited to the huge landfill for each administrative area in the study area, but almost every village has its own landfill. These landfills have negative impacts on the environmental quality, including soil degradation, pollution of water resources, population health, and distortion of the landscape. Incidentally, tourism is considered one of the most important sources of earnings in the study area due to the presence of some favorable factors including a moderate climate, the density of the river network, a dense forest cover, and the historical ruins. Consequently, the proliferation of landfills is a negatively impacts for the local economy and welfare. Similar observations can be reported by Chabuk et al. (2017) and Tercan et al. (2020) studies.

During the decade of war in Syria, the study area was among ones that received tens of thousands of displaced people from the places of hostilities inside Syria. The sudden and massive inflation in the population has caused an increase in the generation of solid waste, thus implying complete inability of the environmental authorities to manage the increase. In this study, a computerized hierarchical system incorporating a robust quantitative integration between AHP and GIS environment enabled the selection of sustainable landfill sites. The approach applied in this study helps in providing the basis for managing the pollution caused by random sites of landfills in the study area in the post-war environmental rehabilitation stage.

Conclusion

The spread of random landfills possesses catastrophic environmental consequences on public health and environmental quality. Despite the great complexity, choosing the optimal sites for landfills is one of the best urgent solutions applied globally. This selection process requires an understanding of many different criteria including physical, socio-economic, and technical ones. The robust integration of GIS and MCDM provides a creative platform which helps in proposing sustainable sites for landfills. In this study, the sustainable sites for sanitary landfills were determined through the integration of AHP and GIS techniques in the Safita area (western Syria). The study area, however, suffers from the indiscriminate spread of landfills, especially during the war period, which witnessed massive internal refugee waves. Based on national standards, previous literature, expert opinions, and the specificity of the study area, thirteen evaluation criteria were identified and used in the spatial suitability modeling process. These criteria are: elevation, slope, permeability, distance to faults, distance to settlement, land use/land cover, distance to drainage, distance to water supplies, distance to lakes, distance to road, distance from tourist centers, distance from archaeological centers, and distance from religious centers. A map of proposed sustainable landfills was generated and categorized using *Natural Breaks* into five classes: unsuitable (83.28%), less suitable (8.49%), moderately suitable (4.49%), highly suitable (2.57%), and very highly suitable (0.72%). The AUC value of this map, further, reached to 88.01%. The outputs of this paper provide high-value spatial insights into the problems of Safita area for local decision-makers and environmental planners. These insights will help manage the risk of random landfills in the post-war period in Syria.

Author contribution Hazem Ghassan Abdo, Taghreed Hamdi Dowiaan Aljohani, and Hussein Almohamad proposed the main concept and highly involved in write-up. Hazem Ghassan Abdo, Hussein Almohamad, Ahmed Abdullah Al-Dughairi, and Taghreed Hamdi Dowiaan Aljohani assisted in data analysis and preparation spatial map. Hazem Ghassan Abdo, Hussein Almohamad, and Motrih Al-Mutiry are involved to write-up and review. Hazem Ghassan Abdo, Motrih Al-Mutiry, Ahmed Abdullah Al-Dughairi, and Taghreed Hamdi Dowiaan Aljohani involved to review, editing, review, and English grammar correction. All authors read and approved the final manuscript.

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Data availability The datasets used and/or analyzed during the current study are available in the article/ from the corresponding author on request.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Abdelouhed F, Ahmed A, Abdellah A, Yassine B, Mohammed I (2022) GIS and remote sensing coupled with analytical hierarchy process (AHP) for the selection of appropriate sites for landfills: a case study in the province of Ouarzazate, Morocco. J Eng Appl Sci 69(1):1–23

Abdo HG (2018) Impacts of war in Syria on vegetation dynamics and erosion risks in Safita area, Tartous. Syria Reg Environ Change 18(6):1707–1719

Abdo HG (2020) Evolving a total-evaluation map of flash flood hazard for hydro-prioritization based on geohydromorphometric parameters and GIS–RS manner in Al-Hussain river basin, Tartous Syria. Nat Hazards 104(1):681–703

Abdo HG (2022) Assessment of landslide susceptibility zonation using frequency ratio and statistical index: a case study of Al-Fawar basin, Tartous, Syria. Int J Environ Sci Technol 19(4):2599–2618

Abdo HG, Almohamad H, Al Dughairi AA, Al-Mutiry M (2022) GIS-based frequency ratio and analytic hierarchy process for forest fire susceptibility mapping in the western region of Syria. Sustainability 14(8):4668

Abdullah-Al-Mahbub Md, Islam ARMdT, Almohamad H, Al Dughairi AA, Al-Mutiry M, Abdo HG (2022) Different forms of solar energy progress: the fast-growing eco-friendly energy source in Bangladesh for a sustainable future. Energies 15(18):6790. https://doi.org/10.3390/en15186790

Aguilar JAA, Aguilar HAN, Hernandez RFG, Valencia MNR (2018) Emplacement of solid waste management infrastructure for the Frailesca Region, Chiapas, México, using GIS tools. Egypt J Remote Sens Space Sci 21(3):391–399

Ahire V, Behera DK, Saxena MR, Patil S, Endait M, Poduri H (2022) Potential landfill site suitability study for environmental sustainability using GIS-based multi-criteria techniques for nashik and environs. Environ Earth Sci 81(6):1–15

Aksoy E, San BT (2019) Geographical information systems (GIS) and multi-criteria decision analysis (MCDA) integration for sustainable landfill site selection considering dynamic data source. Bull Eng Geol Env 78(2):779–791

Al Shogoor S, Sahwan W, Hazaymeh K, Almhadeen E, Schütt B (2022) Evaluating the impact of the influx of Syrian refugees on land use/land cover change in Irbid District. Northwestern Jordan Land 11(3):372

Ali SA, Parvin F, Al-Ansari N, Pham QB, Ahmad A, Raj MS, ..., Thai VN (2021) Sanitary landfill site selection by integrating AHP and FTOPSIS with GIS: a case study of Memari Municipality, India. Environ Sci Pollut Res 28(6):7528-7550

Alkaradaghi K, Ali SS, Al-Ansari N, Laue J, Chabuk A (2019) Landfill site selection using MCDM methods and GIS in the Sulaimaniyah Governorate, Iraq. Sustainability 11(17):4530

Al-Ruzouq R, Shanableh A, Omar M, Al-Khayyat G (2018) Macro and micro geo-spatial environment consideration for landfill site selection in Sharjah, United Arab Emirates. Environ Monit Assess 190(3):1–15

Alsarayreh HK, Alsarayreh DW (2021) Assessment and suitability study of landfills in Jordan, Al-karak using geographic information systems (GIS). Int J Geoinform 17(3):61–80

Asfaw H, Karuppannan S, Erduno T, Almohamad H, Al Dughairi AA, Al-Mutiry M, Abdo HG (2022) Evaluation of vulnerability status of the infection risk to COVID-19 using geographic information systems (GIS) and multi-criteria decision analysis (MCDA): a case study of Addis Ababa City Ethiopia. Int J Environ Res Public Health 19(13):7811. https://doi.org/10.3390/ijerph19137811

Asif K, Chaudhry MN, Ashraf U, Ali I, Ali M (2020) A GIS-based multi-criteria evaluation of landfill site selection in Lahore, Pakistan. Pol J Environ Stud 29(2):1511–1521

Azem KURU, Ezgi TOK, Aktas MG, Demir HH, Özcan HK, Demir G (2021) GIS and multicriteria decision analysis for landfill site selection in Edirne Province, Turkey. J Inst Sci Technol 11(2):969–981

Babiker IS, Mohamed MA, Hiyama T, Kato K (2005) A GIS-based DRASTIC model for assessing aquifer vulnerability in

Kakamigahara Heights, Gifu Prefecture, central Japan. Sci Total Environ 345(1–3):127–140

Barakat A, Hilali A, Baghdadi ME, Touhami F (2017) Landfill site selection with GIS-based multi-criteria evaluation technique. A case study in Béni Mellal-Khouribga Region, Morocco. Environ Earth Sci 76(12):1–13

Barzehkar M, Dinan NM, Mazaheri S, Tayebi RM, Brodie GI (2019) Landfill site selection using GIS-based multi-criteria evaluation (case study: SaharKhiz Region located in Gilan Province in Iran). SN Appl Sci 1(9):1–11

Bilgilioğlu SS, Bilgilioğlu BB (2017) Selection of suitable site for municipal solid waste disposal sites for the Aksaray (Turkey) using AHP and GIS methods. Int J Sci Eng Res Int 4(11):36–45

Bilgilioglu SS, Gezgin C, Orhan O, Karakus P (2021) A GIS-based multi-criteria decision-making method for the selection of potential municipal solid waste disposal sites in Mersin, Turkey. Environ Sci Pollut Res 1–17

Chaaban F, El Khattabi J, Darwishe H (2022) Accuracy assessment of ESA WorldCover 2020 and ESRI 2020 land cover maps for a Region in Syria. Journal of Geovisualization and Spatial Analysis 6(2):31. https://doi.org/10.1007/s41651-022-00126-w

Chabuk A, Al-Ansari N, Hussain HM, Knutsson S, Pusch R, Laue J (2017) Combining GIS applications and method of multi-criteria decision-making (AHP) for landfill siting in Al-Hashimiyah Qadhaa, Babylon, Iraq. Sustainability 9(11):1932

Cheng CY, Urpelainen J (2015) Who should take the garbage out? Public opinion on waste management in Dar es Salaam, Tanzania. Habitat Int 46:111–118

Dereli MA, Tercan E (2021) Comparison of GIS-based surrogate weighting methods for multi-directional landfill site selection in West Mediterranean Planning Region in Turkey. Environ Dev Sustain 23(3):3438–3457

Ding Z, Zhu M, Wu Z, Fu Y, Liu X (2018) Combining AHP-entropy approach with GIS for construction waste landfill selection—a case study of Shenzhen. Int J Environ Res Public Health 15(10):2254

Eghtesadifard M, Afkhami P, Bazyar A (2020) An integrated approach to the selection of municipal solid waste landfills through GIS, K-Means and multi-criteria decision analysis. Environ Res 185:109348

Elahi A, Samadyar H (2014) Municipal solid waste landfill site selection using analytic hierarchy process method for Tafresh Town. Middle-East J Sci Res 22(9):1294–1307

EO (2018) Environmental Observatory in Ministry of local administration and environment in Syria, Regulation No. 2117 on random landfill management (In Arabic)

Ersoy H, Bulut F (2009) Spatial and multi-criteria decision analysis-based methodology for landfill site selection in growing urban regions. Waste Manage Res 27(5):489–500

Ghobadi MH, Babazadeh R, Bagheri V (2013) Siting MSW landfills by combining AHP with GIS in Hamedan province, western Iran. Environ Earth Sci 70(4):1823–1840

Gonçalves DNS, de Morais Gonçalves C, de Assis TF, da Silva MA (2014) Analysis of the difference between the euclidean distance and the actual road distance in Brazil. Trans Res Procedia 3:876–885

Güler D, Yomralıoğlu T (2017) Alternative suitable landfill site selection using analytic hierarchy process and geographic information systems: a case study in Istanbul. Environ Earth Sci 76(20):1–13

Halder B, Banik P, Almohamad H, Al Dughairi AA, Al-Mutiry M, Al Shahrani HF, Abdo HG (2022) Land suitability investigation for solar power plant Using GIS AHP and multi-criteria decision approach: a case of Megacity Kolkata West Bengal India. Sustainability 14(18):11276. https://doi.org/10.3390/su141811276

Islam MA, Murshed S, Hasan M (2020) Selecting suitable landfill site with multi-criteria evaluation and GIS: a case of Savar upazila in Bangladesh. Arab J Geosci 13(18):1–15

Jafar R, Slman H, Hamod R (2016) Assessment of the dump sites in Tartous governorate by using GIS. Tishreen Univ J Res Sci Stud-Eng Sci Ser 38(3):513–528 In Arabic

Kamdar I, Ali S, Bennui A, Techato K, Jutidamrongphan W (2019) Municipal solid waste landfill siting using an integrated GIS-AHP approach: a case study from Songkhla, Thailand. Resour Conserv Recycl 149:220–235

Kamel A, Hasan B (2018) Sustainable geographic information system-based map for suitable landfill sites in Aley and Chouf, Lebanon. Int J Geol Environ Eng 12(6):436–460

Karasan A, Ilbahar E, Kahraman C (2019) A novel pythagorean fuzzy AHP and its application to landfill site selection problem. Soft Comput 23(21):10953–10968

Karimi H, Amiri S, Huang J, Karimi A (2019) Integrating GIS and multi-criteria decision analysis for landfill site selection, case study: Javanrood County in Iran. Int J Environ Sci Technol 16(11):7305–7318

Kazuva E, Zhang J (2019) Analyzing municipal solid waste treatment scenarios in rapidly urbanizing cities in developing countries: the case of Dar es Salaam, Tanzania. Int J Environ Res Public Health 16(11):2035

Kazuva E, Zhang J, Tong Z, Liu XP, Memon S, Mhache E (2021) GIS-and MCD-based suitability assessment for optimized location of solid waste landfills in Dar es Salaam, Tanzania. Environ Sci Pollut Res 28(9):11259–11278

Khaddour LA (2021) Life-cycle sustainability risk management a multi-stakeholder approach: the case of Damascus post-war residential projects. Environ Dev Sustain 1–31. https://doi.org/10.1007/s10668-021-01963-3

Khaliq MA, Javed MT, Hussain S, Imran M, Mubeen M, Nasim W, Fahad S, Karuppannan S, Al-Taisan WA, Almohamad H, Al Dughairi AA, Al-Mutiry M, Alrasheedi M, Abdo HG (2022) Assessment of heavy metal accumulation and health risks in okra (*Abelmoschus Esculentus* L.) and spinach (*Spinacia Oleracea* L.) fertigated with wastwater. International Journal of Food Contamination 9(1):11. https://doi.org/10.1186/s40550-022-00097-2

Khan D, Samadder SR (2015) A simplified multi-criteria evaluation model for landfill site ranking and selection based on AHP and GIS. J Environ Eng Landsc Manag 23(4):267–278

Khodaparast M, Rajabi AM, Edalat A (2018) Municipal solid waste landfill siting by using GIS and analytical hierarchy process (AHP): a case study in Qom city, Iran. Environ Earth Sci 77(2):1–12

Kumar A, Krishna AP (2018) Assessment of groundwater potential zones in coal mining impacted hard-rock terrain of India by integrating geospatial and analytic hierarchy process (AHP) approach. Geocarto Int 33(2):105–129

Kareem SL, Al-Mamoori SK, Al-Maliki LA, Al-Dulaimi MQ, Al-Ansari N (2021) Optimum location for landfills landfill site selection using GIS technique: Al-Naja city as a case study. Cogent Eng 8(1):1863171

Manguri SBH, Hamza AA (2022) Sanitary landfill site selection using spatial-AHP for Pshdar area, Sulaymaniyah, Kurdistan region/Iraq. Iran J Sci Technol Trans Civ Eng 46(2):1345–1358

Mohammed S, Abdo HG, Szabo S, Pham QB, Holb IJ, Linh NTT, ..., Rodrigo-Comino J (2020) Estimating human impacts on soil erosion considering different hillslope inclinations and land uses in the coastal region of Syria. Water 12(10):2786

Mohammed S, Hassan E, Abdo HG, Szabo S, Mokhtar A, Alsafadi K, ..., Rodrigo-Comino J (2021) Impacts of rainstorms on soil erosion and organic matter for different cover crop systems in the western coast agricultural region of Syria. Soil Use Manag 37(1):196-213

Mohsenizadeh M, Tural MK, Kentel E (2020) Municipal solid waste management with cost minimization and emission control objectives: a case study of Ankara. Sustain Cities Soc 52:101807

Mohsin M, Ali SA, Shamim SK, Ahmad A (2022) A GIS-based novel approach for suitable sanitary landfill site selection using integrated fuzzy analytic hierarchy process and machine learning algorithms. Environ Sci Pollut Res 29(21):31511–31540

Mussa A, Suryabhagavan KV (2021) Solid waste dumping site selection using GIS-based multi-criteria spatial modeling: a case study in Logia town, Afar region, Ethiopia. Geol Ecol Landsc 5(3):186–198

Nasser H, Ahmad S (2019) Estimation of the ionic content of the groundwater Surrounding the al-Bassa landfill, Lattakia, Syria. Tishreen Univ J-Basic Sci Ser 41(2):119–137 (In Arabic)

Noufal M, Maalla Z, Adipah S (2021) Households' participation in solid waste management system of Homs city, Syria. Geojournal 86(3):1441–1463. https://doi.org/10.1007/s10708-020-10139-x

Noufal M, Yuanyuan L, Maalla Z, Adipah S (2020) Determinants of household solid waste generation and composition in Homs City, Syria. J Environ Public Health 2020

Orhan O, Yakar M, Ekercin S (2020) An application on sinkhole susceptibility mapping by integrating remote sensing and geographic information systems. Arab J Geosci 13(17):1–17

Özkan B, Özceylan E, Sarıçiçek İ (2019) GIS-based MCDM modeling for landfill site suitability analysis: a comprehensive review of the literature. Environ Sci Pollut Res 26(30):30711–30730

Pasalari H, Nodehi RN, Mahvi AH, Yaghmaeian K, Charrahi Z (2019) Landfill site selection using a hybrid system of AHP-Fuzzy in GIS environment: a case study in Shiraz city, Iran. Methodsx 6:1454–1466

Ponikarov VP (1966) The Geology of Syria. Explanatory notes on the geological map of Syria, Scale 1: 200 000. Ministry of Industry, Damascus, Syrian Arab Republic

Rahimi S, Hafezalkotob A, Monavari SM, Hafezalkotob A, Rahimi R (2020) Sustainable landfill site selection for municipal solid waste based on a hybrid decision-making approach: Fuzzy group BWM-MULTIMOORA-GIS. J Clean Prod 248:119186

Rahmat ZG, Niri MV, Alavi N, Goudarzi G, Babaei AA, Baboli Z, Hosseinzadeh M (2017) Landfill site selection using GIS and AHP: a case study: Behbahan, Iran. KSCE J Civ Eng 21(1):111–118

Rahmoun T, Hassan M, Alhasan W (2016) Protection strategy for the coastal areas of climate change "Syrian Coast, Tartous City." Res J Appl Sci Eng Technol 12(3):264–271

Randazzo L, Cusumano A, Oliveri G, Di Stefano P, Renda P, Perricone M, Zarcone G (2018) Landfill site selection for municipal solid waste by using AHP method in GIS environment: waste management decision-support in Sicily (Italy). Detritus 2(1):78

Saaty TL (1980) The analytic hierarchy process: planning, priority setting, resource allocation, 1st edn. McGraw-Hill, New York, NY, pp 27–30

Saghir A (2019) Solid waste management in non-State armed group-controlled areas of Syria case study-Jisr-Ash-Shugur-district. Environ Res Technol 2(4):191–210

Şener Ş, Şener E, Nas B, Karagüzel R (2010) Combining AHP with GIS for landfill site selection: a case study in the Lake Beyşehir catchment area (Konya, Turkey). Waste Manage 30(11):2037–2046

Senkiio CS, Ramos APM, Simões SJC, Mendes TSG (2022) Multicriteria analysis and logistical grouping method for selecting areas to consortium landfills in Paraiba do Sul river basin, Brazil. Environ Earth Sci 81(8):1–16

Sisay G, Gebre SL, Getahun K (2021) GIS-based potential landfill site selection using MCDM-AHP modeling of Gondar Town, Ethiopia. African Geograph Rev 40(2):105–124

Tercan E, Dereli MA, Tapkın S (2020) A GIS-based multi-criteria evaluation for MSW landfill site selection in Antalya, Burdur, Isparta planning zone in Turkey. Environ Earth Sci 79(10):1–17

Tulun Ş, Gürbüz E, Arsu T (2021) Developing a GIS-based landfill site suitability map for the Aksaray province, Turkey. Environ Earth Sci 80(8):1–15

Uyan M (2014) MSW landfill site selection by combining AHP with GIS for Konya, Turkey. Environ Earth Sci 71(4):1629–1639

Wang G, Qin L, Li G, Chen L (2009) Landfill site selection using spatial information technologies and AHP: a case study in Beijing, China. J Environ Manag 90(8):2414–2421

Yang N, Damgaard A, Lü F, Shao LM, Brogaard LKS, He PJ (2014) Environmental impact assessment on the construction and operation of municipal solid waste sanitary landfills in developing countries: China case study. Waste Manage 34(5):929–937