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Research article

Sustainable landfill sites selection using geospatial information and AHP-GDM approach: A case study of Abha-Khamis in Saudi Arabia

Muhammad Arshad [a,*], Mohd Abul Hasan [b], Mohammed K. Al Mesfer [a], Basem Abdullah Al Alwan [a], Mohamed Noor Qureshi [c], Moutaz Eldirderi [a]

[a] *Department of Chemical Engineering, King Khalid University, Abha, Postal code: 61421, Kingdom of Saudi Arabia*
[b] *Department of Civil Engineering, King Khalid University, Abha, Postal code: 61421, Kingdom of Saudi Arabia*
[c] *Department of Industrial Engineering, King Khalid University, Abha, Zip code: 61421, Kingdom of Saudi Arabia*

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ABSTRACT

Social, environmental, and technical factors must be combined to solve the complex problem of ever-growing municipal solid waste (MSW) and minimize its negative impact on the environment. Saudi Arabia has launched a US$13 billion tourism strategy to transform the Asir region into a year-round tourist destination and has pledged to welcome 10 million local and foreign visitors by 2030. The estimated share of Abha-Khamis will increase to 7.18 million tons of household waste per year. With a gross domestic product (GDP) of USD 820.00 billion by the end of 2022, Saudi Arabia can no longer afford to neglect the issue of waste production and its safe disposal. In this study, to account for all factors and evaluation criteria, a combination of remote sensing, geographic information systems and an analytical hierarchy process (AHP) was used to determine the best locations for municipal solid waste (MSW) disposal in Abha-Khamis. The analysis revealed that 60% of the study area consists of faults (14.28%), drainage networks (12.80%), urban (11.43%), land use (11.41%) and roads (8.35%), while 40% of the suitable area for landfill. Of these, a total of 20 sites ranging in size from 100 to 595 ha are distributed at reasonable distances from the cities of Abha-Khamis, which meet all the critical criteria for suitable landfill sites mentioned in the literature. Current research shows that the use of integrated remote sensing, GIS and the AHP-GDM approach significantly improves the identification of land suitability for MSW management.

1. Introduction

One of the key goals of Solid Waste Management (SWM) is the proper disposal of the ever-growing Municipal Solid Waste (MSW) and mitigating its negative impact on the ecosystem. In addition to industrialized countries, where the disposal of MSW has increased at an alarming rate [[1–4]]]], in developing countries, poor solid waste disposal practices [[2,3]], population growth, migration to cities [5] and expansion of the tourism industry [6] have led to serious environmental problems. According to Ref. [7], globally 33% of all solid waste collected is disposed of and/or incinerated in open landfills, and he predicted that annual solid waste generation will

* Corresponding author.
E-mail address: moakhan@kku.edu.sa (M. Arshad).

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reach 3.40 billion tons in 2050, a 70% increase since 2016.

Many researchers [[8–18]] advocated a ban on solid waste disposal in open areas due to the inherent risk of air and groundwater pollution, serious health, aesthetic and environmental problems, property depreciation, fire and explosion due to spontaneous combustion and slope instabilities in some hilly areas.

In developed countries, landfilling is the most popular form of final disposal of municipal waste [19]. At the global level (Table 1), North America (column 6) leads in solid waste generation (kg/capita/day) by region, while Bermuda leads by country with the highest generation rate (last column).

Currently, Saudi Arabia produces almost 10–14 million tons of household waste per year with an average of (1.4–1.8) kg/capita/day [[20,21]] and lags behind many developed countries in the proper disposal of household waste. Every day solid waste is collected by the municipality and disposed of in open landfills without covering the solid waste and often set on fire [[22,23]]. In coastal areas, especially in the densely populated urban cities with adjacent industrial clusters, the environmental problems of uncontrolled disposal of household waste led to surface and groundwater contamination [24]. Open dumpsites must be closed and new landfill sites identified and operated based on comprehensive scientific analysis in consultation with local stakeholders.

In view of the 2030 vision, Saudi Arabia plans to spend billions of dollars on scenic and historical sites in the country to attract local and international tourists. Asir province, with an estimated population of 2.3 million, has launched a US$13 billion tourism strategy to transform the Asir region into a year-round tourist destination and has committed to welcoming 10 million local and foreign visitors by 2030 (SPA, 2021). The estimated share of Asir Province, with a population of 2.3 million, is 1.34 million tons of municipal solid waste per year, which will increase to 7.18 million tons per year after Asir Province's population increases by 10 million tourists.

It is also relevant that all new landfill projects must meet the priorities of local communities on the one hand and the protection of public health and the environment on the other [[25,26]].

1.1. Literature review

To integrate waste management strategies into urban planning for healthy and sustainable societies, researchers [[27–34]] have demonstrated the use of remote sensing (RS) and geographic information systems (GIS) methods for planning, landfill management; and landfill site selection to replace expensive and time-consuming ground surveys for solid waste landfill selection and management. Other studies [[35–37]] have combined the analytical hierarchy process (AHP) with RS and GIS for assessment of complex decision problems in the selection of landfills. AHP is a Multi-Criterion Decision-Making technique (MCDM) proposed by Ref. [38], in which the problem is organised into a hierarchy with priorities at the top.

[19] used both GIS and MCDA to determine the number of landfills to build and then used AHP to optimize the waste transportation network, while [4,39] suggested that a systematic scientific methodology should be used to rely not solely on economic criteria to select a solid waste landfill. The landfills should be located at least 5 km from the outskirts of the city [40]. indicated that a larger number of roads should be available to facilitate waste transportation and reduce road wear, while [41] emphasized that transportation to landfills must be cost-effective, with minimal health and environmental impacts on the surrounding community [42]. emphasized that another essential aspect of landfills is that they should be located at sites with a gradient of more than 1% and less than 20%. Neglecting the gradient has shown negative effects not only on groundwater [[41,43,44]], but also on surface water; and rivers [45]. Areas with high rainfall are not preferred, so dry locations should receive more points [5]. Another important criterion is the geology of the landfills. Outcrop areas of marl and shale clay and thick soil cover are favored over the formation of limestone outcrops [5]. indicated that areas with exposed sand or gravel and fractured rocks should be avoided. According to [[46,47]], only an in-depth analysis of the physical, ecological, social, infrastructural, and financial requirements will suffice suitable landfills for solid waste. Some of the particularly important criteria selected for landfill are listed in Table 2.

In the current research, the study area exhibits overly complex lithology and intense faulting and intrusion of exposed outcrop. Few

Table 1
Information is extracted from Ref. [7], "What a waste 2.0: A global snapshot of SWM to 2050."

By Region	Population	Solid Waste Generated (Million tons)	Urban	Rural	Regional Average (Kg/capita/day)	The country with the highest generation Rate (Kgs)
North America	322 (Millions)	289	99.7%	–	2.21	Bermuda (4.54); USA (2.24)
South Asia	2.54 (Billions)	334	77%	40%	0.52	Maldives (1.44)
Middle East and North Africa	437 (Millions)	129	90%	74%	0.81	Bahrain (1.83); Saudi Arabia (1.40)
Europe and Central Asia	912 (Millions)	392	96%	55%	1.18	Iceland (4.45)
Sub-Saharan Africa	1.03 (Billions)	174	43%	09%	0.46	Seychelles (1.57)
Latin America and Caribbean	638 (Millions)	231	85%	30%	0.99	US Virgin Islands (4.46)
East Asia and Pacific	2.27 (Billions)	468	77%	45%	0.56	Singapore (3.72)

Table 2
Major criteria and buffer zones as suggested by researchers in Literature.

No.	Criterion	[48]	[49]	[50]	[47]	[51]	[52]	[53]	[54]	[55]	[56]	[57]	[58]	[59]	[60]	[61]	[34]	[62]	[46]
1.	**Groundwater depth (m)**	**1.5**		**6**	**-**	**>2**	**10**			**-**	**-**	**-**	**-**	**-**	**30**	**-**			
2.	**Water bodies (Km)**	**0.2**		**-**	>**1**	**-**		**0.5**	**1**	**-**	**-**	**-**	**1**	**1**	**0.5**	**-**	**0.8**	**0.9**	>**1**
3.	**Roads (Km)**	**-**		**0.5**	**-**	>**0.1**				**0.5**		**1**	**-**	**-**	**-**	**-**	**-**	**1**	>**1**
4.	**Slope (Degrees)**	**1–30**		**0–5**	**-**	**-**				**0–5**	**0–5**	**-**	**-**	**-**	**-**	**-**	**-**		**8–10**
5.	**Landuse**	**-**		**-**	**-**	**-**				**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**		>**5**
6.	**Geology & Lithology**	**-**		**-**	**-**	**-**				**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**		
7.	**Faults (m)**	**-**		**-**	**-**	**-**				**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**300**	**1000**
8.	**Airports (Km)**	**3**		**-**	**-**	>**1.5**				**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**		
9.	**Urban Centers (Km)**	**1**	**2**	**5**	**3**	**-**				**5**	**-**	**-**	**-**	**-**	**-**	**5**	**-**	>**2**	>**5**
10.	**Villages (Km)**									**1**			**1**				**0.4**		>**1**
11.	**Cultural sites (Km)**					>**0.5**		**0.5**	**0.5**		**1**		**1**					>**2**	>**1**
12.	**Power lines (m)**							**50**		**30**				**30**	**40**				
13.	**Parks (Km)**					>**0.5**													>**0.5**
14.	**Rivers (Km)**					>**0.5**													
15.	**Elevation (Km)**																		**1.5–1.25**

studies have included the fault criterion in their investigation into landfill site selection. Furthermore, in countries like Saudi Arabia, where water resources are limited, hydrological and geological parameters need to be given more weight. The aim of this work is to present a novel method by combining RS, AHP-GDM, and GIS data to investigate and find suitable sanitary landfills large enough to dispose of massive amounts of domestic waste, which will accrue in the coming years with the influx of tourists to the Asir region, particularly Abha and Khamis.

To the best of the authors' knowledge, few studies have been conducted to identify potential landfill sites where intense faulting and intrusion by exposed crops are commonplace, using the AHP-GDM approach in the GIS environment in areas.

2. Material and methods

2.1. Study area

Asir Province has an estimated population of 2.3 million covering an area of around 80,000 km^2 [63]. Abha is the capital of Asir and serves as the administrative center for the governorate. The average annual precipitation is around 190 mm with temperature fluctuations between 8 and 31 °C [64]. Fig. 1 shows the digital elevation map (DEM) in the watershed where landfill sites for the towns of Abha and Khamis-Mushait are being sought.

The Abha Region is located in the southwest corner of the Arabian Shield and overlies Pre-cambrian igneous and metamorphic rocks [[65,66], & [67]]. The lithology of the study area (Abha-Khamis) is overly complex and intense faulting and intrusions of exposed outcrop can be observed throughout [67,68].

According to Ref. [69], the geological classes in the area are dioritic and gabbroic rocks. In the water uptake tests, these rocks were observed to have a permeability of the order of 10^{-6} to 10^{-5} m/s [70]. Every day solid waste is collected by the municipality and dumped in open landfills without covering the solid waste and often put on fire. Open dumpsites must be closed and new landfill sites identified and operated based on comprehensive scientific analysis in consultation with local stakeholders.

2.2. Methodology

The first critical step was to identify the required set of standard criteria based on an in-depth literature review. The second crucial step required the establishment of various maps including road networks, slopes, vegetation, soil type, and lithology, villages, urban areas, land use, drainage patterns, watersheds in digital GIS format and then redirecting them into a common projection. Geological

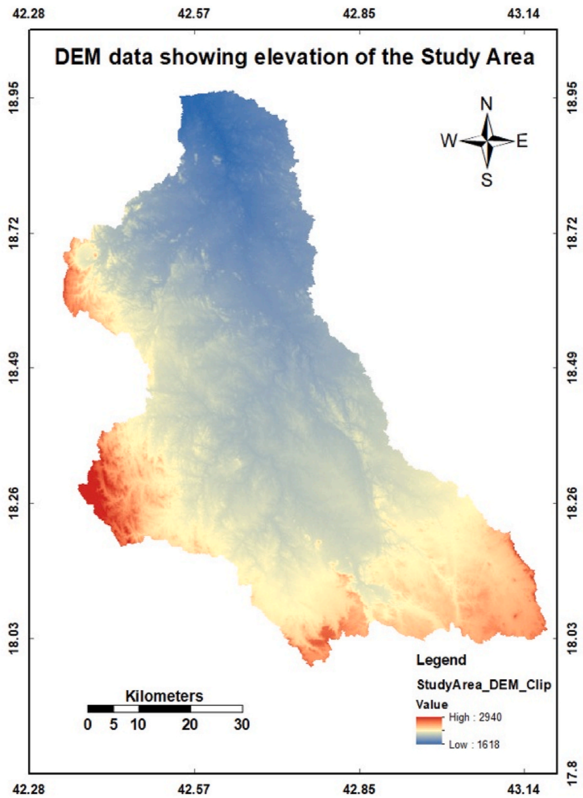

Fig. 1. Map of the watersheds in the study area for the selection of suitable landfill sites.

maps of the study area were obtained from the Saudi Geological Survey (SGS), scanned, and geocorrected using GIS software. The digital elevation model (DEM) was obtained from King Abdul Aziz City of Science and Technology (KACST) at a spatial resolution of 30 × 30 m. Landsat 08 OLI satellite images were downloaded from the United States Geological Survey (USGS) website (https://earthexplorer.usgs.gov/) to retrieve vegetation using ENVI 5.5 software. Geomatica software was utilized to delineate fault areas from Landsat 08 OLI imagery. Urban areas, road networks, land cover, and villages were downloaded from online OpenStreetMap (OSM) data and processed by using ArcGIS Editor for OSM 10.7, a free add-in for ArcMap to produce the desired maps. All created maps were finally converted to a raster format. Essential areas such as airports, villages, urban areas, agricultural lands, and industrial zones were masked out for landfill site selection by buffering them at safe distances from the periphery or edges as suggested in the literature review (see Table-2), while roads, streams, and faults were buffered on both sides using ArcGIS 8.8 software. In addition to complying with national and local regulations, establishing buffer zones is essential to protect human health and water resources from pollution. The buffer zones indicate that they should not be considered (avoided) when selecting landfill sites. The positive prospect in our research is that the groundwater table is very deep, which minimizes the negative effects of groundwater pollution by leachate infiltration and thus a map of the groundwater is not necessary. The last crucial step was the use of GIS and AHP-GDM for the selection of suitable landfill sites. Fig. 2 shows the hierarchy of a structure in the AHP-GDM model with three levels of decision options.

2.3. *The combined approach of GIS and AHP-GDM*

GIS also finds use in the location of landfill for the disposal of solid waste. The AHP along with GDM is an established MCDM method that is commonly used in many engineering applications and can therefore be augmented with GIS in the landfill site selection. Many researchers have successfully applied the combined method of GIS and AHP-GDM to identify potential landfill sites. The AHP-GDM methodology is simple, accurate, and science based. GIS provides useful information using spatial and non-spatial data.

Nineteen (19) key criteria were retrieved from the literature review for the selection of landfill sites. The DMs involved in this study have strong expertise in their background disciplines including ArcGIS software, civil and environmental engineering, and waste management. Several sessions were arranged to train the DMs in the AHP-GDM approach before they could perform the evaluation of the pairwise comparison between the important criteria. During the brainstorming sessions, the DMs observed and agreed that fifteen (15) criteria strongly influences the selection of solid waste landfills for Abha and Khamis, such as Drainage Network (m), Surface Water Bodies (m), Elevation (AMSL), Slope (Degrees), Lineaments (m), Land use (Military, m), Vegetation (Percent), Urban (Periphery, m), Villages (m), Schools (m), Hospitals (m), tourist Sites (m), roads (m), airport (Km), and Industry (m).

In the AHP-GDM methodology, the criteria weight plays a crucial role in finding a solution to a given problem. Pairwise comparison was utilized to extract weight for each of the fifteen parameters based on their relative importance. As shown in Fig. 2, the research

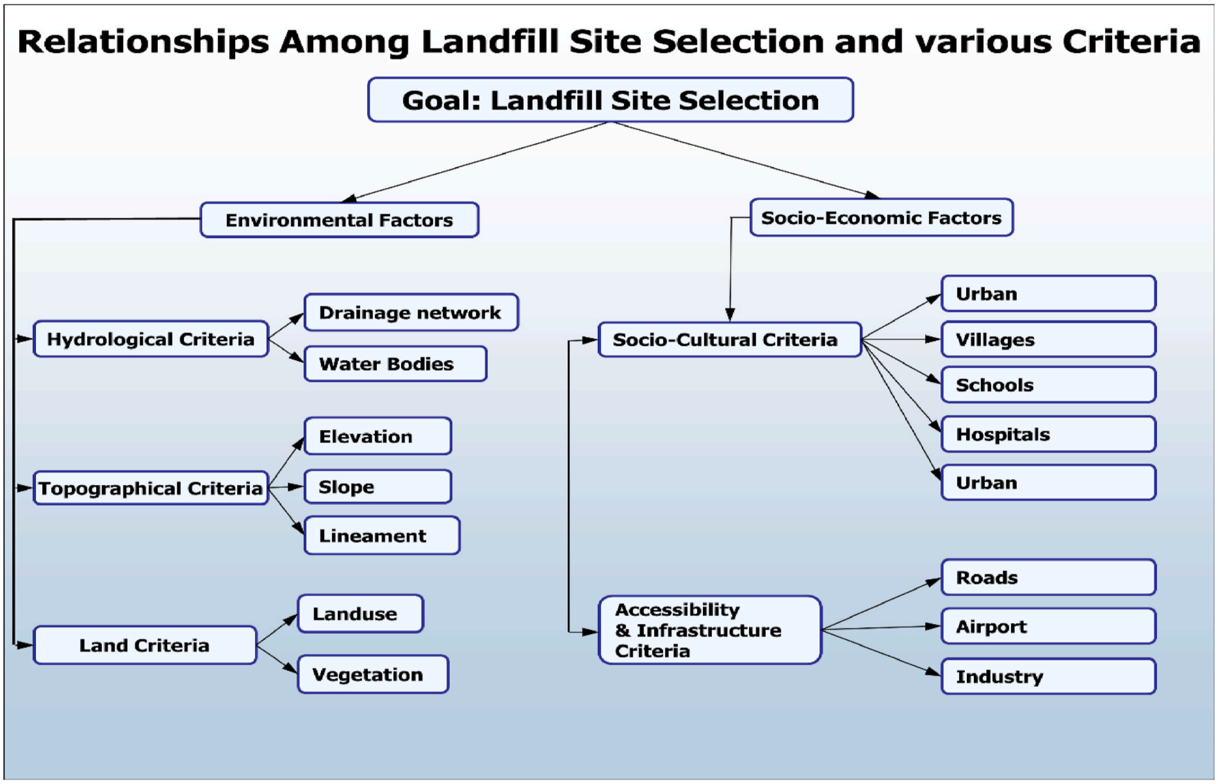

Fig. 2. Relationship among landfill site selection and various criteria.

problem was divided into main criteria, criteria, and sub-criteria, and then structured into three levels to achieve the goal of landfill selection. The AHP-GDM approach is as follows: pairwise comparisons of parameters, consistency check with the consistency ratio, and then synthesizing the findings of the pairwise comparison to derive the criteria weights. The pairwise comparison uses Saatys nine-point scale as shown in Table S1 in the supplementary files. The comparison matrix D, also known as the decision matrix, was developed using landfill site criteria. As a result, each element in the D matrix was compared to a related entry at its corresponding level of significance.

This means that the element (d_{mn}) of the D matrix compares the m^{th} element with that of the n^{th} in terms of its significance level. Equation (1) was used to compare the main criteria, criteria, and sub-criteria for landfill siting. The calculated weight and final normalized weight for landfill site criteria were measured, as shown in Table 3.

$$D = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ d_{m1} & d_{m2} & \dots & d_{mn} \end{bmatrix} \quad (1)$$

The synthesized pairwise AHP-GDM pairwise comparisons of all three DMs are explained in Table S2 in the supplementary files. Whether such a decision is reasonable rests on the consistency of DM. A consistency ratio (CR) of less than 10% pairwise comparison is essential for decision-making; otherwise, the process must be repeated. Consequently, the consistency of each pairwise table must be verified using equation (2). A random index (RI) for an (n x n) matrix is shown in Table S3 in the supplementary Files. For a pairwise comparison, the Consistency Index (CI) can be calculated using equation (3), where λ_{max} is the principal eigenvalue and n is the matrix size in (n x n).

$$CR = \frac{CI}{RI} \quad (2)$$

$$C.I. = \frac{\lambda_{max} - n}{n - 1} \quad (3)$$

The CR for pairwise comparison of sub criteria under sociocultural criteria by DM1, DM2, and DM3 is presented in Table S2 in the Supplementary files. Similarly, for other criteria, a pairwise comparison was performed, confirming that the acceptance in the current decision-making process is less than 10%. The geometric mean approach was utilized to synthesize all the pairwise comparisons. Additionally, in ArcGIS 10.8.0, the weighted linear combination (WLC) technique was utilized to delineate all map layers (Fig. 3).

The suitability analysis was carried out using a 5-point scale. The scale has five indicators: 1 is unsuitable, 2 is moderately suitable, 3 is very suitable, and 4 is strongly suitable, while 5 is the most suitable. Table S4 in Supplementary Files shows the Landfill Suitability Index (LSI). A final map was created with a tool overlay in GIS that highlighted all suitable landfill sites in white patches within the study region (Fig. 4). Using the AHP-GDM method, all scores (R) were multiplied by the weight of each criterion (W) (See Table S4). Equation (4) is used to calculate the final weight in the last column, which is the sum of various criteria.

$$\boldsymbol{LSI} = \sum \boldsymbol{W_i R_i} \quad (4)$$

where LSI denotes the area's Land suitability index, $\boldsymbol{W_i}$ each criterion weight, $\boldsymbol{R_i}$ signifies the suitability criterion ranking.

3. Results

A total of nineteen (19) criteria were selected for the search for suitable landfills based on a thorough literature review, including

Table 3
Weights and Final normalized weights of Main Criteria, Criteria, and Sub-Criteria.

Main Criteria	W1	Criteria	W2	Sub-Criteria	W3	Final Weight	Rank
Environmental Factor	0.6135	Hydrological	0.3129	Drainage Network	0.6667	**0.1280**	**2**
				Water bodies	0.3333	0.0640	7
		Topological	0.4303	Elevation	0.1724	0.0455	10
				Slope	0.2869	0.0757	6
				Faults	0.5407	**0.1428**	**1**
		Land	0.2568	Land Use	0.7238	**0.1141**	**4**
				Vegetation	0.2762	0.0435	11
Socio-Economic Factor	0.3865	Sociocultural	0.6705	Urban	0.4411	**0.1143**	**3**
				Village	0.2183	0.0566	8
				School	0.0704	0.0182	14
				Hospital	0.0660	0.0171	15
				Tourism	0.2043	0.0529	9
		Accessibility-Infrastructure	0.3295	Road	0.6560	0.0835	**5**
				Airport	0.1512	0.0193	13
				Industry	0.1928	0.0245	12

Legend: W1: the weight of layer 1, W2: the weight of layer 2, W3: the weight of layer 3, Final weight = W1*W2*W3, CR: consistency ratio ≤0.1.

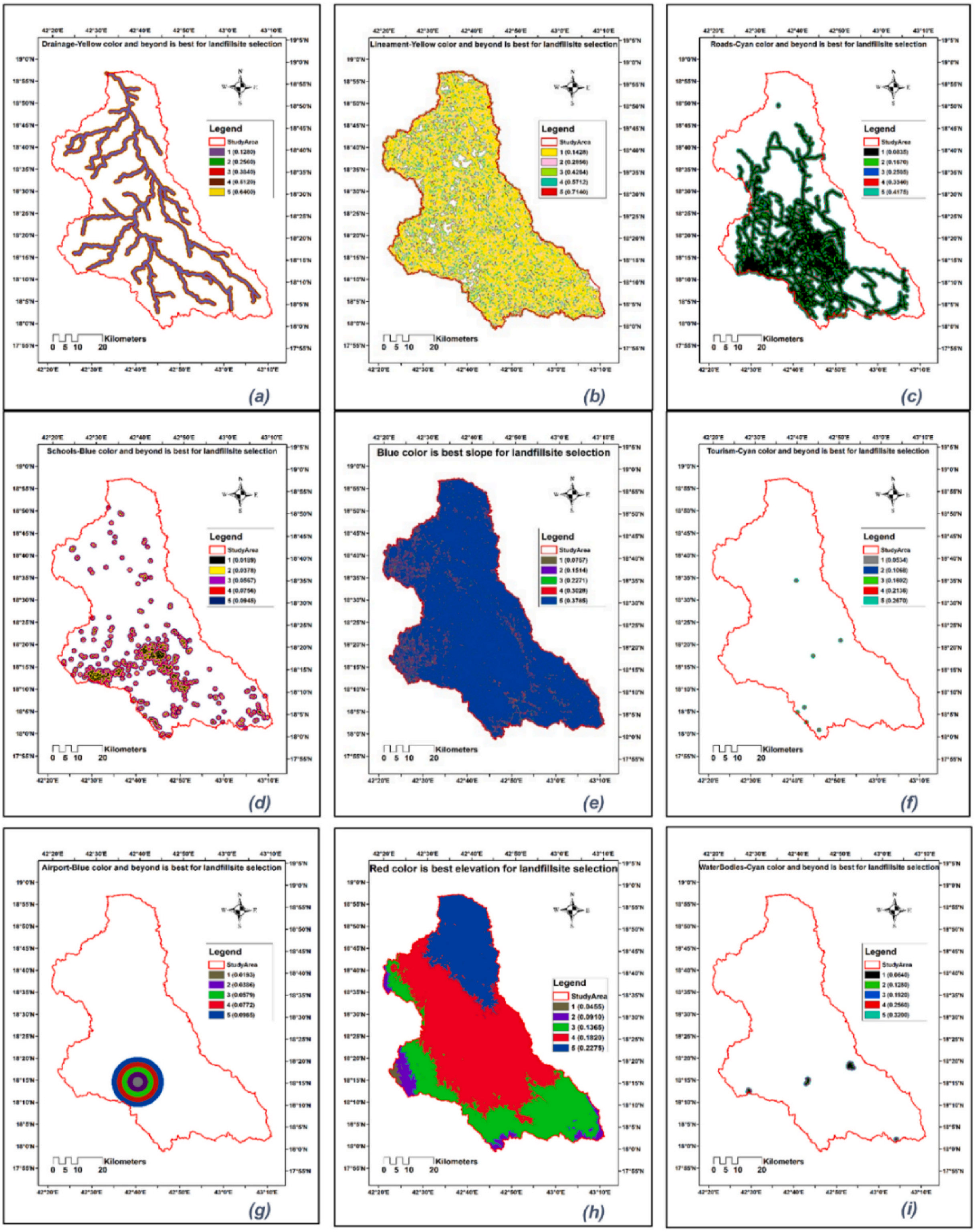

Fig. 3. (a) Drainage, (b) Lineament, (c) Roads, (d) Schools, (e) Slope, (f) Tourism, (g) Airport, (h) Elevation, (i) Waterbodies, (j) Villages, (k) Vegetation, (l) Landuse, (m) Urban areas, (n) Hospitals, and (o) Industrial areas.

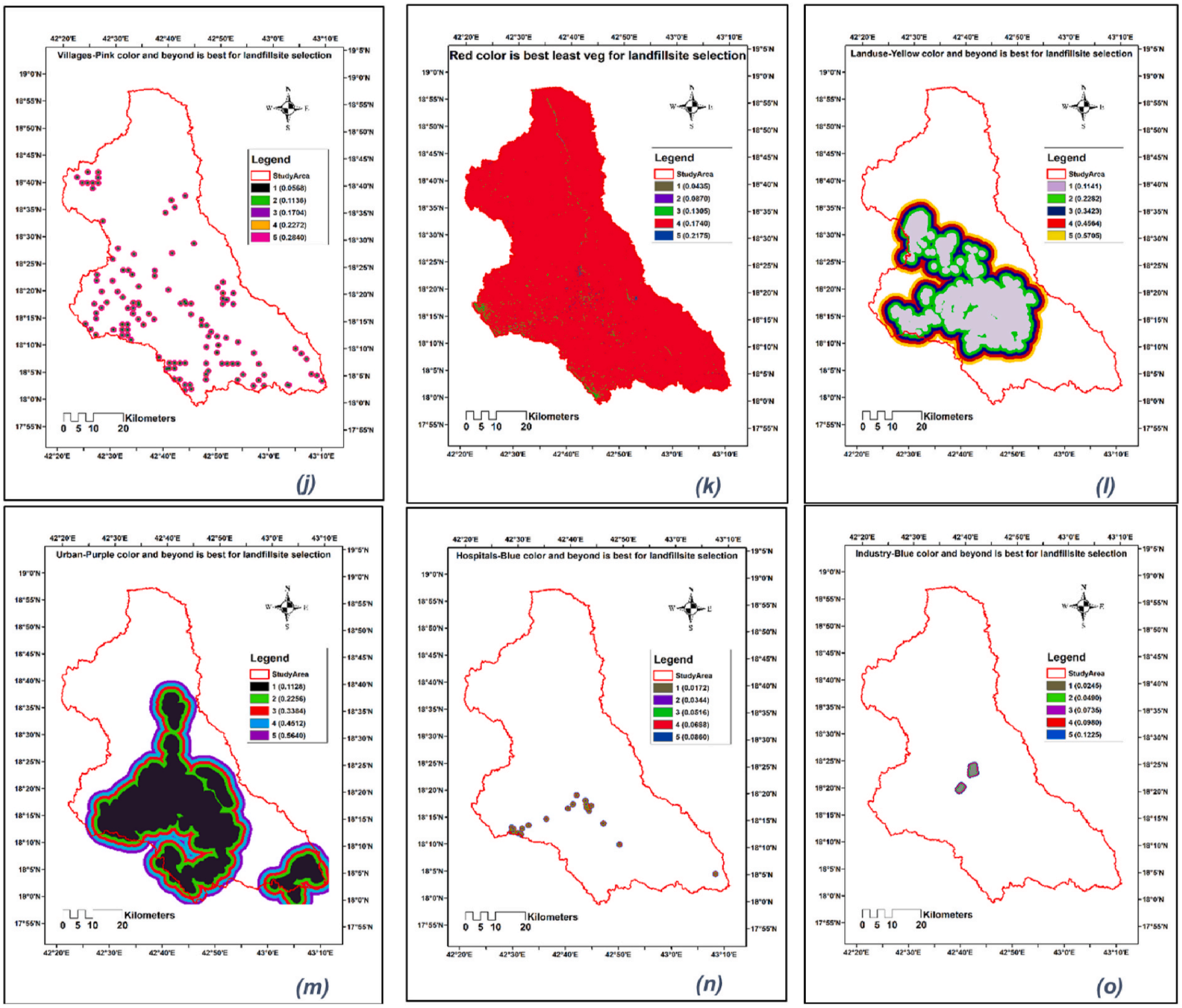

Fig. 3. (*continued*).

environmental, economic, and social perspectives, as well as input from experts with extensive knowledge of the study area. Fifteen (15) critical criteria were selected for the identification of suitable landfill sites in consultation with the DMs (Fig. 2). The weights of each criterion were calculated using the AHP-GDM algorithm (Table S4). ArcGIS software was utilized to create maps for each criterion (Fig. 3). The GIS overlay tool was then applied to create the final map for identifying suitable landfill sites in the study area by overlaying maps of each criterion with different weights (Fig. 4). Table (3) above shows the order in which the various sub-criteria are ranked in terms of their significance. Several faults discovered in the study area are shown in (Fig. 3b). In its list of priorities, it ranked first (14.28%). The faults were thus buffered for at least 500 m. The drainage network is shown in Fig. 3 (a). It was rated the second most important criterion by experts (12.80%). Fig. 3 (k and m) shows city and land use maps rated as the third and fourth most important criteria with weights of 11.43% and 11.41%, respectively. Roads were ranked as the fifth most important criterion in the accessibility and infrastructure category (Table 3). Fig. 3 (c) shows the road network in the study area with a total weighting of (8.35%). The state of vegetation in the study area is shown in Fig. 3k. Fig. 3[(d), (e), (f), (g), (h), (i), and (j)] and Fig. 3[(l), (n), and (o)] show that less weightage has no impact on landfill site selection. (Figure (4) shows the spread of useable landfills that meet all specifications around the cities of Abha and Khamis, ranging in size from 50 to 1000 ha (Table 4).

4. Discussion

Many researchers [[8–18]] advocated prohibiting the disposal of solid waste in open areas owing to the inherent threat of air and groundwater pollution, serious health, aesthetic and environmental problems, property depreciation, fire, and explosion owing to spontaneous combustion and slope instabilities in some hilly areas. Researchers [[27–34]] have highly recommended the application of geospatial techniques for integrating waste management strategies (WMS) into urban planning to replace expensive and

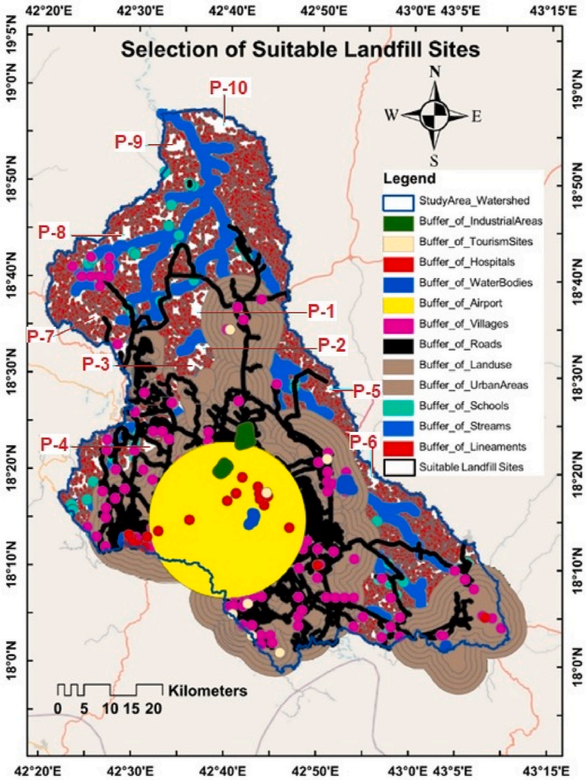

Fig. 4. Suitable sites for solid waste disposal in the study area.

Table 4
Suitability of landfill sites along with the location in the study area.

S. No.	Potential (LFS)	Area (Ha)	Lat, Lon	Remarks
1.	P-1	**595**	18.61417, 42.608872	Most suitable for **Khamis**
2.	P-2	**100**	18.547624, 42.614029	Most suitable for **Abha & Khamis**
3.	P-3	**200**	18.59414, 42.419968	Most suitable for **Abha & Khamis**
4.	P-4	**120**	18.477212, 42.853486	Most suitable for **Abha & Khamis**
5.	P-5	**200**	18.631068, 42.394849	Most suitable for **Khamis**
6.	P-6	**175**	18.690953, 42.487706	Most Suitable for **Khamis**
7.	P-7	**150**	18.737218, 42.627227	Moderately Suitable for **Khamis**
8.	P-8	**545**	18.896529, 42.565741	Less Suitable for **Khamis**
9.	P-9	**1000**	18.934279, 42.640779	Less Suitable for **Khamis**
10.	P-10	**100**	18.901353, 42.692232	Less Suitable for **Khamis**

time-consuming ground measurements for solid waste landfill selection and management [4,19,39]. successfully ~~used~~ applied the advanced tools of GIS, MCDA and AHP to locate sustainable landfills and optimize the waste transportation network rather than solely relying on economic criteria when selecting a solid waste landfill.

While investigating the effect of various criteria on landfill site selection, it was found that fault criteria were overlooked in some previous landfill site selection projects possibly resulting in serious environmental problems that required further investigation. As can be found in (Fig. 3b), fault criterion came first (14.28%) on the priority list and was buffered for at least 500 m. Studies like [[41,43,44, 71]] suggest that faults are known to serve as conduits for underground water. To reduce groundwater pollution, landfills should not be selected near fault zones [[44,60]]. Through these fractures, landfills cause damage to groundwater, surface water and rivers [45]. According to Ref. [72], an ideal landfill must lie over rock with limited permeability. Expansion of landfills in drier areas can help mitigate negative impacts on water resources [[5,43,44]].

The drainage network is shown in Fig. 3 (a). It was rated the second most important criterion by experts (12.80%). Many studies including [[11,12,16,73]] emphasized the significance of studying drainage networks in locating sustainable landfills owing to the significant ~~risk~~ danger of infiltration of underground and surface leachate leading to pollution of groundwater and surface water. Within the city, roads are seen as a positive feature as higher road density can reduce wear and tear. Collection and transport account for about 46% of waste management costs; thus, increased road density could reduce solid waste transportation costs [[29,40]]. Since landfills can have negative environmental, economic and biodiversity impacts, finding landfills in less populated areas is highly desirable [41]. A normalized difference vegetation index is a common technique for assessing the status (NDVI) of vegetation in the study area. Higher NDVI values indicate healthier vegetation, while lower NDVI values indicate sparse or fewer plants. According to Ref. [31], fugitive emissions can cause NDVI reductions near landfills; Therefore, expanding landfills in regions with lower NDVI can minimize their effect on healthy vegetation. The weight assigned to vegetation is (4.35%). This is justified by the fact that the preferred landfill sites are in the least vegetated areas. According to experts who are familiar with the area, the ecological and socio-economic perspectives were assessed as the dominant criteria in the study area with a total weight of 61.35% and 38.65% respectively. As shown in Fig. 4, this study identified more than twenty possible landfill sites; However, 10 of these locations were randomly listed in Table 4 as the most suitable, moderately suitable, and less suitable areas.

Zoning is a common land use planning and regulation tool to ensure orderly neighborhood growth and development by separating incompatible land uses [74]. It is highly desirable to include zoning regulations, windrose diagram and landfill costs as critical criteria once landfills for disposal of solid waste owing to NIMBY (not in my backyard) syndrome are completed [36].

5. Conclusion

Population growth, rural-urban migration and the predictable flow of tourists, have exacerbated the difficulty of solid waste generation, collection and disposal for planning authorities. Proper landfill selection for solid waste disposal is critical to reducing air, soil, and groundwater pollution, as well as mitigating serious health, aesthetic, and environmental issues. This research addressed the ~~use~~ application of GIS and AHP-GDM methods in combination with expert judgment from decision makers to find suitable landfill sites for the twin cities of Abha-Khamis based on fifteen criteria based on environmental, economic, and social factors. In the priority list, faults came first with 14.28%, followed by drainage network as the second most important criterion with 12.80% and urban and land use as the third and fourth most important criteria with 11.43% and 11.41% respectively. Roads were ranked as the fifth most important criterion with 8.35% in the accessibility and infrastructure category. When selecting landfill sites for solid waste disposal ~~due~~ owing to NIMBY (not in my backyard) syndrome, zoning regulations must be included as a key criterion in future research. In examining the effect of various criteria on landfill selection, it was found that fault criteria, which have a weight of 14.28%, have been overlooked in several previous landfill selection projects. Additional research is ~~needed~~ necessary to evaluate environmental effects of fault criterion on infrastructure and pollution of ground and surface water. It is suggested that in future research when investigating landfills selection for solid waste disposal, additional criteria such as land use regulations, windrose diagrams for proper understanding of meteorological effects and sensitivity analysis to help identify those with the most significant impact on the final decision, ~~cost of~~ landfills cost, fault criteria, and community willingness must be included as ~~a~~ key criteria.

Ethics approval and consent to participate

(NA)

Consent for publication

(NA)

Availability of data and materials

All data generated or analyzed during this study are included in this published article [and its supplementary information files].

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors contributions

Conceived and designed the experiments, M.A., M.A.M., B.A.; Performed the experiments, M.A., M.N.Q., M.A.H. and B.A.; Analyzed and interpreted the data, M.A., M.A., M.M., M.N.Q; Contributed analysis tools or data M.A., M.A. M.A.M. M.N.Q., M.A.H. and B.A; Wrote the paper M.A., M.A.H, M.N.Q.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e16432.

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