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Abstract: Sanitary landfill is a common solution for the final solid waste disposal in developing countries. The appropriate landfill location is a very complicated task, as the site selection process involves several factors and guidelines. In this study, suitable candidate landfill sites with minimum risks to public health and environment for the Multan District of Pakistan were identified by integrating the fuzzy set theory and analytical hierarchy process (AHP) within GIS. The socio-economic (i.e., distance to main roads, railway lines, airport, settlements and slope), ecological (i.e., distance to the protected area, distance to the source of surface water, groundwater level, soil type, and land cover type), and infrastructure (distance to tube wells and electric power lines) criteria were taken into consideration. In the fuzzy set, criteria standardisation was done by using different membership functions, whereas the weighting was performed using AHP method to determine the relative importance of the sub-criteria. The results showed that almost 8.5% of the total study area was the most suitable for landfills. After ground-truthing, the three best suitable landfill sites were selected across the district in terms of significant criteria.

Keywords: multi-attribute decision making; multi-attribute decision-making; MADM; solid waste; site selection; suitability map; ground validation.

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1 Introduction

Landfilling is an essential component in solid waste management plans, and in most urban areas of developing countries, the landfill is a cost-effective choice (Gorsevski et al., 2012; Soroudi et al., 2018). Finding the best disposal site is the crucial step to control pollution and minimising environmental risks in solid waste management (Liu et al., 2014). The selection of suitable sites for landfill with optimal capacities is complicated because of several factors, such as population growth, increase in waste quantities, public health and environmental risk factors, and scarcity of land for waste disposal. The main challenge is to make an economically viable and environment-friendly site selection (Kharat et al., 2016). Landfill leachate generally consists of significant amounts of contaminants like chloride, nitrate, ammonia, and heavy metals. These contaminants can get into the waterways, degrade water resources, and become dangerous to human health (Nas et al., 2010).

Landfill sites are considered obnoxious facilities and generally opposed by the public (Aragones-Beltran et al., 2010). Landfills must be located at a sufficient distance for economic viability; in contrast, they should be far enough from the waste source to avoid social conflicts and also play an essential role in reducing environmental pollution. Also, the location should be such that technological changes can be made in the design, operation and support the monitoring of post-closure maintenance. Site selection involves a wide range of intensive points, verifying a given set of restrictions and considering several criteria to eventually provide an ideal solution. The failure in the selection of suitable landfills has caused adverse effects and great controversies. Public awareness regarding environmental impacts, and distrust in systematic studies to identify appropriate sites have certainly left little room for error to waste managers.

The selection of landfills involves many potential criteria; thus, the problem of landfill location can be regarded as a multi-attribute decision-making (MADM) problem. For this purpose, GIS-based methods have been extensively used because these methods can process a large amount of spatial data and integrate several environments (Khorram et al., 2015; Barakat et al., 2017; Rahmat et al., 2017; Islam et al., 2018). GIS-based methods are time-efficient and cost-effective to provide a digital dataset that can be used for long-term landfill monitoring (Sumathi et al., 2008). Analytical hierarchy process (AHP) is one of the most widely used methods for multi-criteria decision-making (Zamorano et al., 2008; Moeinaddini et al., 2010; Ismail, 2016). It is a method for structured and systematic analysis of complex decisions. In this method, decision hierarchy is constructed, and complex decision problems are decomposed into a simpler form; each of which is independent for further analysis. The pairwise comparison matrix is used to evaluate different factors by comparison. The two-criterias comparison defines the essential criterion and its level of importance with each other. Comparison between 1 and 9 is made in which 1 specifies that it is equally important, while 9 represents that it is the most important.

Furthermore, for comparison, the criteria are standardised on a common scale where a sum of weights is equal to 1, while for final suitability estimates, the aggregate output makes a single evaluation score for each pixel. These weights assigned to each criterion define the level of compensation, while the important criteria weights can compensate the score of less important criteria. In aggregation, weights are applied to which important criteria have a more significant impact on the result. It is important to note that if the value of $CR < 0.1$, then the inconsistency is acceptable (Saaty, 1980). If CR does not reach the threshold value, the comparison matrix is reviewed. Calculated weights are used as an input with each standardised criterion map in the weighted sum method to produce the final landfill site suitability map. In this paper, AHP method was also used, which allowed users to select the landfill location by considering the relative importance of each involved criterion.

However, in the decision process, it is easier to explain a value for an alternative through linguistic terms due to the uncertainty, availability of information, imprecision in human feelings and recognition (Donevska et al., 2012; Torabi-Kaveh et al., 2016). Fuzzy set theory can play an essential role in such type of decision situation (Zadeh, 1965). It is the common approach used for the standardisation of criteria. Different shapes of fuzzy membership functions, e.g., sigmoidal, complex non-monotonic, j-shaped, and linear are used for standardisation of the raster-based criteria. The nature of fuzzy logic and the ability of fuzzy systems to handle environmental parameters that have no clear limits and a well-defined effect on the landfill settlement process can help improve the selection of the landfill site (Anitha and Acharjya, 2017).

In this study, an integrated Fuzzy AHP approach generated more sophisticated results since fuzzy set theories applied advanced algorithms to deal with the vagueness, incompleteness, and uncertainties, and increased the robustness associated with the suitability criteria. All probable criteria were selected according to the expert experience and local conditions of the study area. The objective was to identify suitable landfill sites for Multan district, Pakistan, which fulfil the environmental and scientific criteria. This study is the first of its kind that integrates socioeconomic, ecological and infrastructure parameters in the GIS-based fuzzy AHP model for optimum landfill site selection particularly in Pakistan. This study also finds that distance to settlements, distance to surface water and distance to wells are the most influential factors for landfill site selection in the study area which can provide a guideline for decision- makers to choose the suitable landfill sites in the future.

2 Study area

The district of Multan is in the southern part of the province of Punjab, Pakistan. Geographically, the Multan district lies between the latitudes 30° 26' 38" N and 29° 25' 22" N and the longitudes 71° 30' 49" E and 71° 9' 29" E and covers an area of 3682 square km (Figure 1). It is famously known as the 'City of Sufis' due to the many Sufi saints and shrines. Multan city is closely related to tehsil Saddar, tehsil Shuja Abad, and tehsil Jabalpur Pirwala. The current population of the Multan district is 4.74 million, and almost 1,800 tonnes/day of waste are generated throughout the district (Table 1). Previously, the district had one sanitary landfill site at Habiba Sial. The Multan Waste Management Company (MWMC) is currently dumping wastes at the BOAPUR open dumping site because there is no other replacement. The climate of the Multan district is arid subtropical continental with large seasonal fluctuation in both temperatures and rainfall. It has two well-defined seasons, namely a long, hot summer with late monsoon rains and a relatively mild and short winter. The average annual rainfall is 215 mm; more than half of which falls from July to September in the form of high-intensity rains, and the rest is received in winter-spring as low-intensity showers of long duration brought in by western disturbances (Soil Survey of Pakistan, 2008). The hottest month is June with the maximum average temperature of 42.2ºC and the maximum of 49.80ºC. January is the coldest month with an average minimum temperature of 5.10ºC and the lowest minimum of –2.0ºC (Urban Unit, 2016).

Figure 1 Study area location (see online version for colours)

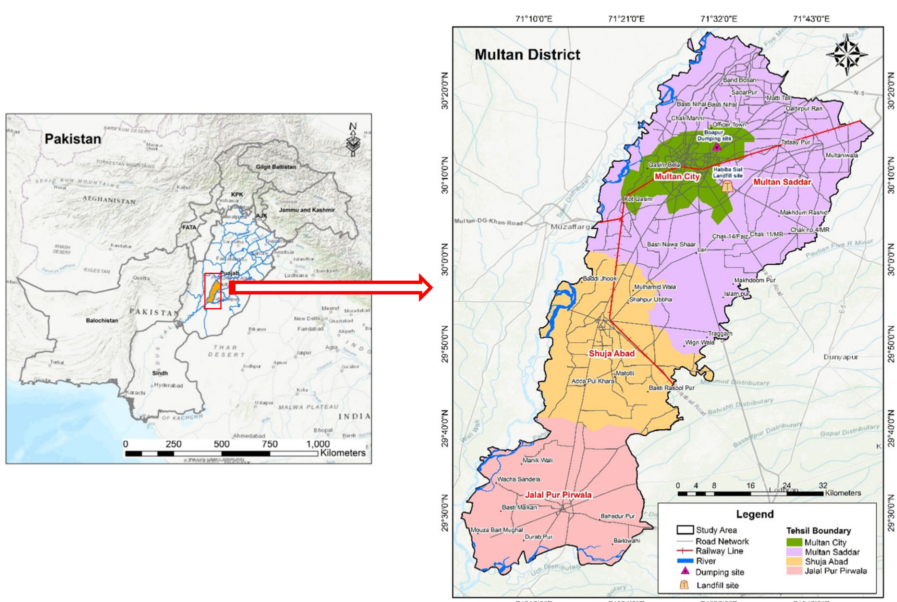


Table 1 Waste generation of urban and rural areas of the Multan District

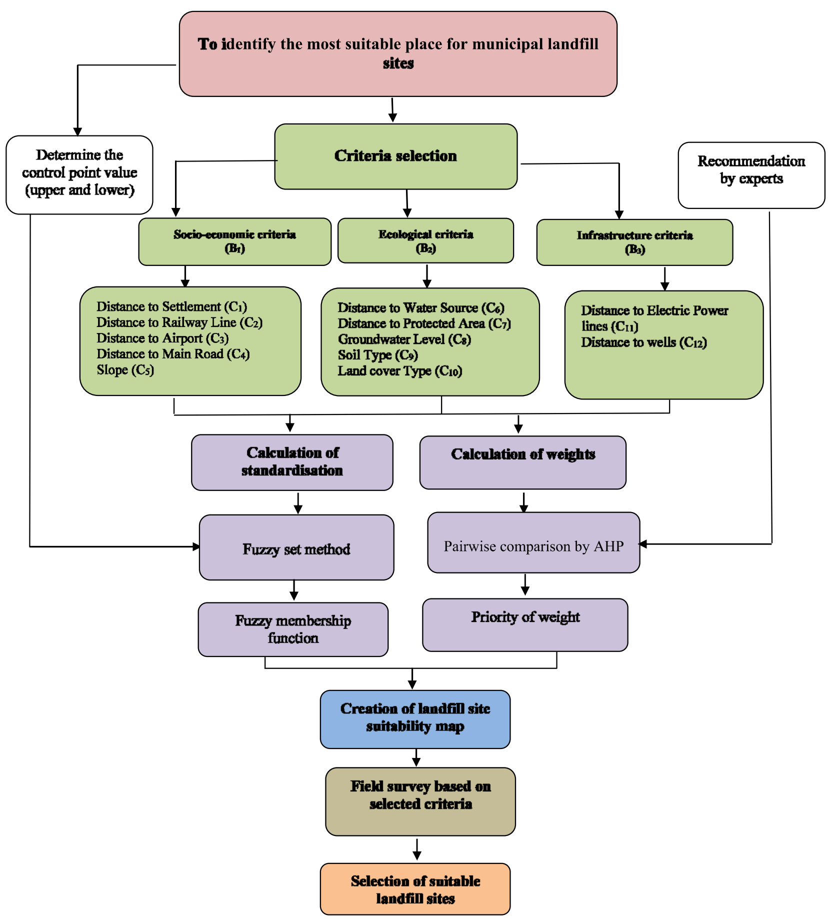
Tehsil	*Waste generation (tonne/day)*		
	Urban	*Rural*	*Total*
Multan City	865	145	1,010
Multan Saddar	20	385	405
Jalalpur Pirwala	25	155	180
Shuja Abad	40	170	210
Total	950	855	1800

Source: Urban Unit (2016)

3 Methodology

The different stages and processes are presented in Figure 2, which are involved in the landfill site suitability assessment.

Figure 2 Framework for landfill site suitability assessment (see online version for colours)



3.1 Identification of influencing landfill site suitability criteria

Defining criteria for landfill site selection is the main step in the site selection process. For the current study, the three main criteria, namely: socio-economic, ecological and infrastructure and 12 sub-criteria (distance to main road, railway line, airport, settlement, protected area, source of surface water, tube wells, electric power lines, slope, groundwater level, soil type, and land cover type) that can affect the landfill site selection process were selected. The significance of each selected criterion is presented in Table 2. Guidelines on solid waste disposal (Environment Protection Department), relevant literature (Ekmekcioglu et al., 2010; Moeinaddini et al., 2010; Islam et al., 2018), expert knowledge, and data availability were used to recognise the influential criteria of landfill site selection.

Table 2 Importance of criteria for landfill site selection

Main criteria	*Sub criteria*	*Importance*
Socio-economic	Distance to settlement	To protect the public from possible environmental hazards
		Site visibility issues/aesthetically obnoxious
		To avoid adversely affecting the value of the land
		(Source: Donevska et al., 2012; Demesouka et al., 2013)
	Distance to main road	To reduce the cost of developing connection routes
		To minimise environmental pollution by vehicular emission
		To provide a useful route for the transport of waste to minimise fuel cost and the inconvenience of traffic
		(Source: Kara and Doratli, 2012; Khoshand et al., 2018)
	Distance to airport	To avoid attracting birds that can obstruct air traffic
		(Source: Moeinaddini et al., 2010; Gbanie et al., 2013)
	Distance to railway line	To minimise the visual imposition caused by landfill and to avoid accidents that could occur due to heavy objects that deviate when strong wind phenomena occur
		(Source: Demesouka et al., 2013; Alanbari et al., 2014)
Ecological	Slope	To protect landscape processes, such as erosion capacity of soil water composition, surface, and subsurface flow rate and runoff
		Economic considerations
		(Source: Gorsevski et al., 2012; Barakat et al., 2017)
	Groundwater level	To prevent contamination of groundwater by infiltration of leachates
		(Source: Barakat et al., 2017; Khoshand et al., 2018)
	Land cover type	To conserve nature
		(Source: Nas et al., 2010; Islam et al., 2018)
Infrastructure	Distance to surface water source	To avoid contamination of water bodies by solid waste
		(Source: Isalou et al., 2013; Güler and Yomralıoğlu, 2017)

Table 2 Importance of criteria for landfill site selection (continued)

Main criteria	*Sub criteria*	*Importance*
	Soil type	To avoid leachate To reduce permeability; enough to delay the channel of leachate from the site considerably (Source: Moeinaddini et al., 2010; Rathore et al., 2016)
	Distance to protected area	To avoid deterioration of the sensitive ecosystem (Source: Sener et al., 2010)
	Distance to electric powerlines	To avoid a high level of voltage power Power supply for a landfill infrastructure (Source: Effat and Hegazy, 2012; Chabuk et al., 2016)
	Distance to wells	To avoid drinking water contamination that immediately affects human health (Source: Eskandari et al., 2012; Isalou et al., 2013)

3.2 Sub-criteria standardisation using fuzzy membership function

Standardisation is carried out to make each sub-criterion value equal as each one has a different range value (Suh and Brownson, 2016). A total of 12 input layers were applied to assess suitable waste disposal sites in the district of Multan (Table 3). The fuzzy method has ability to change the numerical data in the membership function value that could be used as a representative for the suitability categories (Anitha and Acharjya, 2017). In the fuzzy method, users can assign the values, which are typically between 0 and 1 to the element with no limitation (Zadeh, 1965). It describes numerically to what extent an object belongs to a group. Equation (1) shows the mathematical definition of the fuzzy set. The most suitable areas for the location of landfills are those having values close to 1 (Figure 6).

$$A = \{x, \mu_A(x)\} \quad \textit{for each} \quad x \varepsilon X \tag{1}$$

where μ_A is the MF (membership of x in fuzzy set A) so that;

If x completely belongs to A, then $\mu_A = 1$

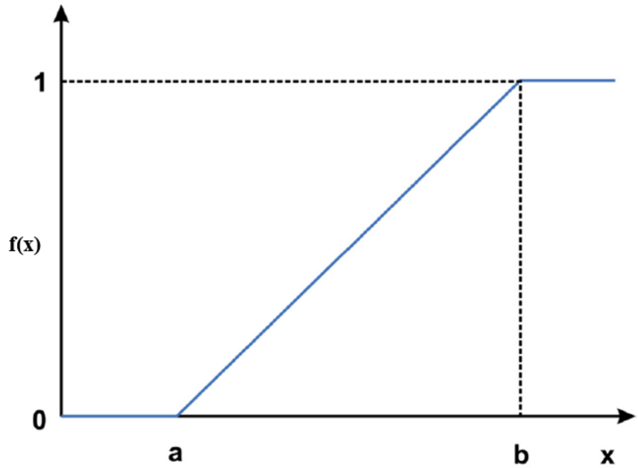
If x does not belong to A, then $\mu_A = 0$

If x belongs to a certain degree to A, then $0 < \mu_A(x) < 1$.

For this research, the Linear-sigmoid curve model of fuzzy membership was used. This model was divided into linear S-up and S-down curve models (Subiyanto et al., 2018). The linear S-up curve model was used when the suitability increased with the increase in sub-criteria value [equation (2), Figure 3, and Table 3].

$$\mu_A(x) = f(x) = \begin{cases} 0 & x \le a \\ \dfrac{x-a}{b-a} & a < x < b \\ 1 & a \ge b \end{cases} \tag{2}$$

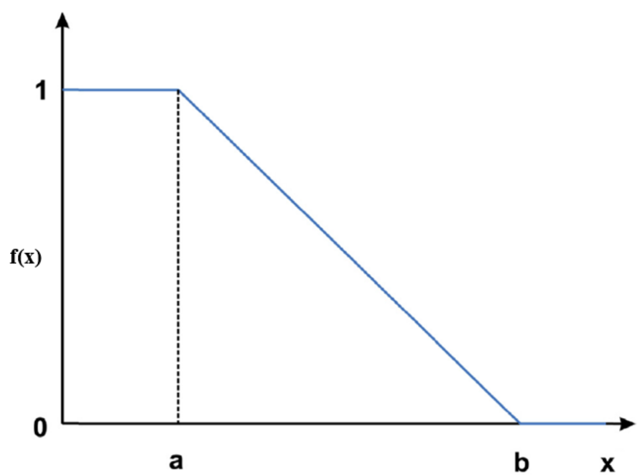
Figure 3 Linear S-up curve model (see online version for colours)



Meanwhile, when the suitability decreased as the sub-criteria value increased, the linear S-down curve model [equation (3) and Figure 4] was used (Table 3).

$$\mu_A(x) = f(x) = \begin{cases} 1 & x \leq a \\ \dfrac{b-x}{b-a} & a < x < b \\ 0 & a \geq b \end{cases} \tag{3}$$

Figure 4 Linear S-down curve model (see online version for colours)



Qualitative data (i.e., soil texture and land cover) cannot be directly used into fuzzy membership function calculation, but user-defined fuzzy membership function can be used for such data (Bianchini et al., 2019) (Figure 5).

Figure 5 User-defined functions in fuzzy set

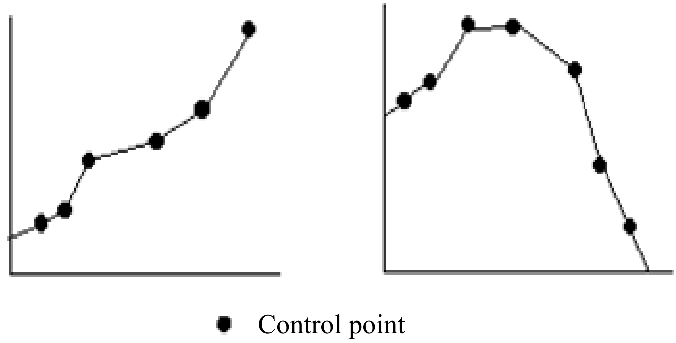
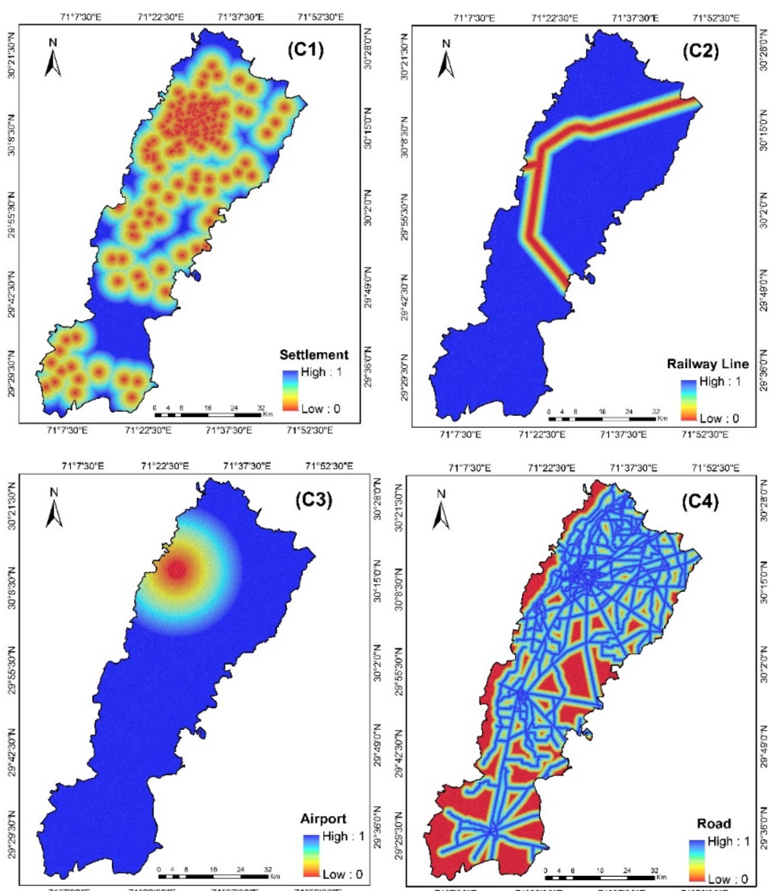


Figure 6 Membership value trend assigned to sub-criteria: (C1) distance to settlement (C2) distance to railway line (C3) distance to airport (C4) distance to main road (C5) slope (C6) distance to surface water source (C7) distance to protected area (C8) groundwater level (C9) soil texture (C10) land cover type (C11) distance to power lines (C12) distance to wells (see online version for colours)



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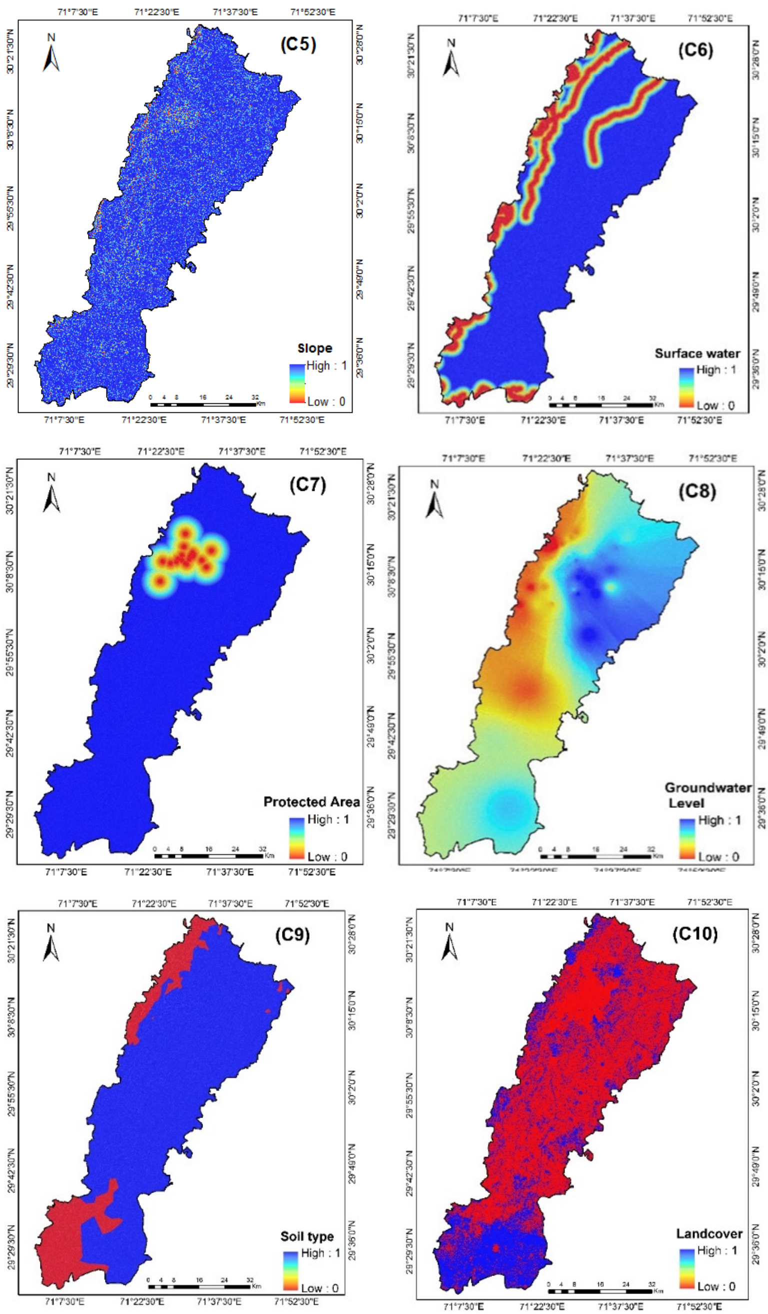

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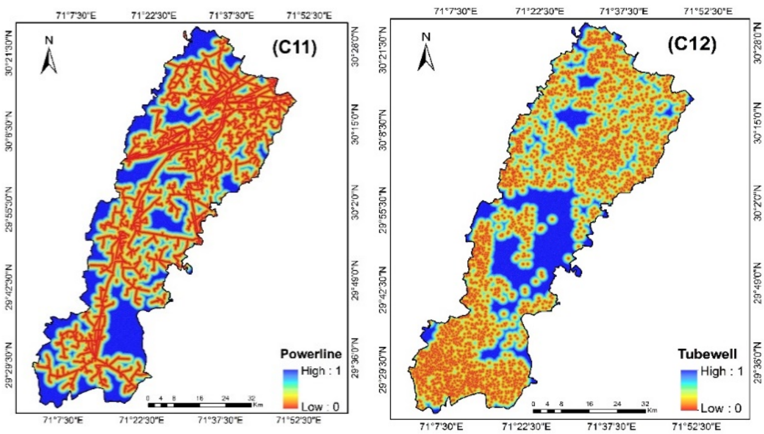

Table 3 Suitability assessment sub-criteria, threshold values, and fuzzy membership function model

Main criteria	*Sub-criteria*	*Value points/control point*	*Fuzzy membership function model*
Socio-economic	Distance to settlement	a = 1,000 m	S-up
		b = >2,500 m	
	Distance to railway line	a = 500 m	S-up
		b = >1,000	
	Distance to airport	a = 3,000 m	S-up
		b = >9,000m	
	Distance to main road	a = 750 m	Reducing – J-Shape
		b= 1,000m	
		c= 20,000	
	Slope	a = > 15%	S-down
		b = 5%	
Ecological	Distance to surface water source	a = 500 m	S-up
		b = 15,000m	
	Distance to protected area	a = 500 m	S-up
		b = >2,000m	
	Groundwater level	a = 5 m	S-up
		b = >15m	
	Soil type	a = Fine sandy loams	User-defined
		b = Silty clay loams	
	Land cover type	a = Built-up area	User-defined
		b = Barren land	

Table 3 Suitability assessment sub-criteria, threshold values, and fuzzy membership function model (continued)

Main criteria	*Sub-criteria*	*Value points/control point*	*Fuzzy membership function model*
Infrastructure	Distance to electric power lines	a = 0–100 m b = >500 m	S-up
	Distance to wells	a = 500 m b = >1,000 m	S-up

3.3 Determination of weights by AHP

AHP is one of the most common multi-criteria methods used in landfill site suitability analysis (Rathore et al., 2016; Barakat et al., 2017; Khoshand et al., 2018). Weighting in the landfill suitability analysis is helpful to recognise the level of importance of the sub-criteria (Subiyanto et al., 2018). AHP is one of the best methods to address the different factors in a hierarchical structure (Zhang et al., 2015). AHP method in this study was used to develop a pairwise comparison matrix to determine the relative weights of the criteria (Tables 4, 5, 6, and 7). In AHP, assigning weights through pairwise comparison is more appropriate as compared to direct weight allocation due to its advantages in verifying the weight consistency by calculating the consistency ratio (Subiyanto et al., 2018). It is obtained by dividing the value of the consistency index (CI) with a random index value (RI). The values of RI vary with the number of criteria that are compared. For this study, the CR values for the socio-economic sub-criteria and ecological and infrastructure criteria were 0.08, 0.03, and 0, respectively, which indicated that the weighting performed was acceptable and can be used for the next process of landfill site suitability analysis.

Table 4 Pairwise comparisons of matrix A-B_1, B_2, B_3

A	*B_1*	*B_2*	*B_3*	*Weight*	*CR*
B_1	1	1/2	3	0.32	0.02
B_2	2	1	4	0.56	
B_3	1/3	1/4	1	0.12	

Notes: A, Landfill suitability; B_1, Socio-economic criteria; B_2, Ecological criteria; B_3, Infrastructure criteria.

Table 5 Pairwise comparisons matrix B_1-C_1–C_5

B_1	*C_1*	*C_2*	*C_3*	*C_4*	*C_5*	*Weight*	*CR*
C_1	1	1	6	7	2	0.34	0.08
C_2	1/7	1	1/4	1	1/8	0.03	
C_3	1/6	1/5	1	4	1/7	0.07	
C_4	1	1	5	1	1	0.29	
C_5	1/2	1	7	8	1	0.27	

Notes: B_1, Socio-economic criteria; C_1, settlements; C_2, railways; C_3, airport; C_4, main roads; C5, slope.

Table 6 Pairwise comparisons matrix B_2-C_6–C_{10}

B_2	*C_6*	*C_7*	*C_8*	*C_9*	*C_{10}*	*Weight*	*CR*
C_6	1	3	2	1	2	0.30	0.03
C_7	1/2	1	1/2	1/2	1	0.11	
C_8	1/3	2	1	2	2	0.25	
C_9	1	2	1/2	1	2	0.22	
C_{10}	1/2	1	1/2	1/2	1	0.12	

Notes: B_2, Ecological criteria; C_6, surface water; C_7, protected areas; C_8, groundwater level; C_9, soil type; C_{10}, land cover type

Table 7 Pairwise comparisons of matrix B_3-C_{11}–C_{12}

B_3	*C_{11}*	*C_{12}*	*Weight*	*CR*
C_{11}	1	1/3	0.24	0
C_{12}	3	1	0.76	

Notes: B_3, infrastructure criteria; C_{11}, power lines; C_{12}, wells

3.4 Weighted sum analysis

The fuzzy map of each criterion was overlaid together with their computed weights to create the final landfill site suitability map using the following equation (4) (Ayoade, 2017; Kahsay et al., 2018).

$$SI = \sum\nolimits_1^n (W_i * X_i) \tag{4}$$

where *SI* is the suitability index, W_i = weight derived from AHP pairwise comparison and X_i = criterion maps (e.g., standard raster maps).

3.5 Ground validation

In this stage, the accuracy and suitability of computed landfills were tested to verify the precision of the process (Moeinaddini et al., 2010; Islam et al., 2018). For this purpose, field visits as well as screening on satellite images were made to compare the real field situations with the result of the GIS modelling. Accessibility, distance to settlements and surface water sources, environmentally sensitive areas, and vegetation were observed and noted through the field visits, while slope, soil type, and groundwater level were checked through their respective maps.

4 Results and discussion

4.1 Landfill site suitability analysis

4.1.1 Selection of suitable landfill sites through fuzzy AHP

Unfortunately, there is no sanitary landfill site in the whole Multan district. There is a dire need of sanitary landfills for the safe disposal of waste. Currently, collected waste is being disposed at the 'Boya Pur' dumpsite. This site is situated 8 km from the Multan city on Link road 2 at the northern bypass. A secondary single access road (10 ft wide) leading to the site is approximately 3 km. The site is situated inside a private housing society. The other side of the site is linked to a heavily populated area. This site has been in use for the last 2-3 years, but the district is still deprived of a sanitary landfill after the closure of the Habiba Sial Landfill site in 2015. Disposed waste remains uncovered at the Boya Pur site and leachate (percolated contaminated water from solid waste) generated from this waste seeps through the soil and contaminates the groundwater as Multan city depends on groundwater. The geology of the study area is quite complex. The sediments are composed of fluvial facies of three meandering river systems namely river Ravi, river Chenab, river Sutlej as well as the abandoned river channel of beas. Most of the city of Multan is a bar upland (interfluve). According to population and waste projection, the area required for the landfill site is 50 hectares for the next 18–20 years (Urban Unit, 2016). The present study described the sanitary landfill site selection process by considering important criteria. For this purpose, 12 criteria were selected according to data availability and EPD rules. Fuzzy membership functions were used to standardise the criteria (Table 3). The standardised maps for each sub-criterion were created (Figure 6).

Weights were assigned with the help of the pairwise comparison matrix, and the criteria were ranked with the help of experts' experiences and characteristics of the district (Tables 4, 5, 6, and 7). As shown in Table 4, the weight of ecological criteria (0.56) indicates a significant role as compared to socio-economic and infrastructure criteria (0.32 and 0.12). That might be due to the environmental problems where their role in ecological pollution has directly or indirectly affected human health, which makes it a more challenging problem compared to other studied problems (Khoshand et al., 2018). Residential areas from the set of socio-economic criteria were assigned to the highest weight because social acceptability is a subject of great concern; mainly when it arises with the establishment of obnoxious facilities (Mahmood et al., 2015). The phenomena of 'not in my backyard' (NIMBY), 'not in anyone's backyard' (NIABY), and 'not on planet Earth' are becoming popular in GIS-based landfill planning, which create extraordinary pressure on those responsible for making decisions (Chang et al., 2008). Similar investigation was found in the study reported by Islam et al. (2018). In addition, the distance from the main road was followed by a settlement area having a weight of 0.29. This may be due to the fact that the main road was used to transport waste from the collection points to the landfill, and thus, distance to the main road can significantly affect the cost of waste transport.

In the ecological criteria, surface water was given the highest weight due to its proximity to rivers; the area is flooded every year, especially along the Chenab River (Figure 1). Furthermore, surface water resources contaminated with pollution as a result of waste disposal generally have a low level of dissolved oxygen. They can attract disease-carrying organisms, and subsequently, decrease the ecological health of water bodies (Townsend et al., 2015; Soroudi et al., 2018). Furthermore, in another study, Kharat et al. (2016) also proved that contamination of surface water bodies caused by landfill leachate poses a danger to the environment and human health. The wells were given the highest weight in the infrastructure criteria. Wells are a vital source of water for different purposes including drinking water and are influenced by many factors, including agricultural and various reactions that take place in landfills (Atafar et al., 2008). In the last stage, the weighted sum method (the most common MCDA method (Malczewski and

Rinner, 2015) was used to create a landfill site suitability map with five suitability classes (Figure 7). Among the five suitability classes, a very highly suitable class with an area of 316.26 square kilometres was ranked 5, while 667.49 square kilometres areas were ranked 1 (unsuitable) for landfill site construction. Low suitable class having an area of 652.14 square kilometres was ranked 2, with the moderate class having an area of 1,089.86 square kilometres ranked as 3, and 954.49 square kilometres of a highly suitable class ranked as 4. The study discovered that almost 8.5% of the total area was the most suitable for landfill location.

Figure 7 Final landfill site suitability map by the fuzzy AHP method (see online version for colours)

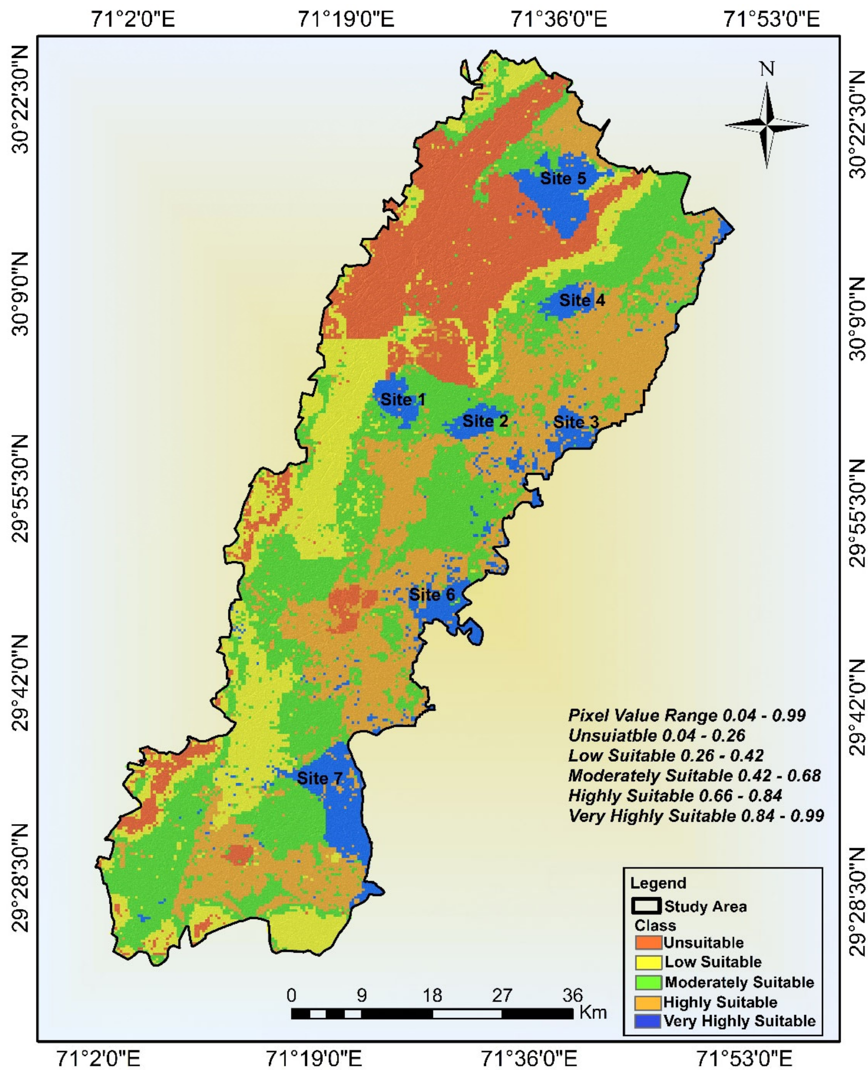

Figure 8 Location of landfill sites after ground validation (see online version for colours)

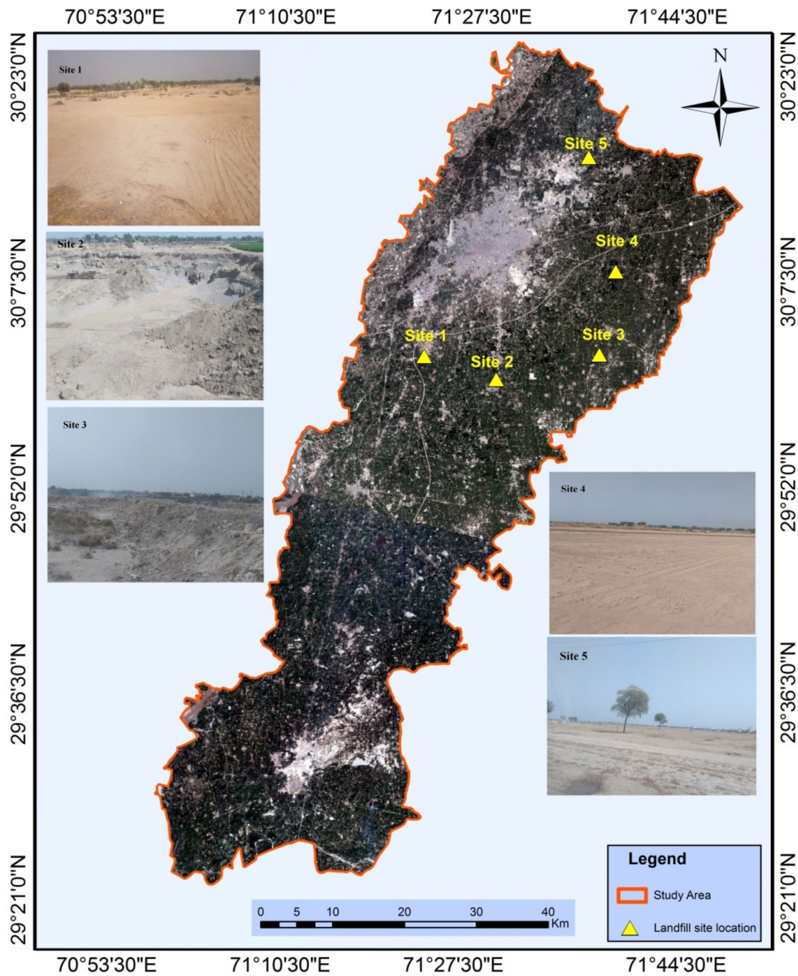

Table 8 Pairwise comparison matrix for candidate landfill sites

Criteria		*C1*	*C4*	*C6*	*C8*	*C12*	*Weight*	*CR*
[C1]	Distance to settlements	1	3	4	4	4	0.445	0.07
[C4]	Distance to main roads	1/3	1	4	3	3	0.257	
[C6]	Distance to surface water source	1/4	1/3	3	1	1	0.123	
[C8]	Groundwater level	1/4	1/4	1	1/2	1/3	0.066	
[C12]	Distance to wells	1/4	1/3	2	1	1	0.109	

4.1.2 Selection of suitable landfill sites through ground validation

Fuzzy AHP suitability map has been categorised into five suitability classes (Figure 7). At the last stage, an accuracy assessment was done to confirm the accuracy of the process (Yousefi et al., 2018). For this purpose, the area with 316.26 square kilometres of a very highly suitable class from the landfill site suitability map was selected for ground validation (Islam et al., 2018.). Field validation of seven potential landfill areas resulted in five of the most suitable sites for landfill construction. A distance of more than 30–35 km from the city centre will increase the cost of transporting waste as reported by Effat and Hegazy, (2012). Candidate site 6 with coordinates 29° 48' 7.36" N and 71° 25' 36.22" E and candidate site 7 with coordinates 29° 33' 12.90" N and 71° 20' 9.21" E were 50 and 70 km away from the city centre, so these sites were not considered for further analysis. While selecting the appropriate sites, complete land cover was also analysed. The landcover was calculated using Landsat satellite imagery of 30-metre resolution. In the current research, discussed traits of selected sites were confirmed using high resolution satellite imagery (Quickbird image of 0.6 metre resolution) to check and assess the proximity of main features like roads, water bodies, railway lines and landcover types (built-up, agricultural and barren land). Further, field verification was also conducted for suitable site selection. The five identified suitable landfill sites were candidate site 1 with coordinates 30° 2' 56.19" N and 71° 23' 21.02" E, candidate site 2 with coordinates 30° 1' 12.53" N and 71° 29' 26.21" E, candidate site 3 with coordinates 30° 1' 53.97" N and 71° 37' 24.34" E, candidate site 4 with coordinates 30° 5' 14.39" N and 71° 40' 23.68" E, and candidate site 5 with 30° 16' 44.40" N and 71° 36' 16.32" E (Figure 8).

The five potential landfill sites were further compared with respect to the most significant criteria (i.e., distance to the surface water source, distance to wells, distance to the main road, distance to settlements, and groundwater level) to make the final selection more accurate (Khoshand et al., 2018; Yousefi et al., 2018). The AHP method was used again to determine each criterion's weight (Table 8). The suggested candidate sites after conducting ground validation complied with the main socio-economic and environmental characteristics required for the site selection process and none of these imposed restrictions on the selection of the site.

All five selected landfill sites were ranked based on the distance to the surface water source, distance to wells, distance to the main road, distance to settlements, and groundwater level (Table 9). Based on the derived weights and linear combination of ranking, candidate landfill sites 3 and 4 were the least suitable landfill sites in terms of the criteria mentioned in Table 8. Finally, candidate landfill sites 1, 2, and 5 were identified as the most suitable sites in the study area.

Table 9 Candidate landfill sites ranking

Candidate site number	*Ranking Criteria*					*Overall ranking*	*Area (hectare)*
	Distance to settlements	*Distance to main roads*	*Distance to water bodies*	*Distance to wells*	*Groundwater level*		
Site 1	1	2	3	1	4	1	70
Site 2	2	1	3	4	2	2	75
Site 3	4	3	2	5	4	5	55
Site 4	5	2	3	3	2	4	73
Site 5	3	1	2	5	2	3	60

5 Conclusions

The provision of a landfill facility is a critical infrastructure element that the city provides to its people and is vital for the safe management of waste according to integrated solid waste management practices. The current research was an effort to minimise open dumping impacts on the environment and surrounding people by suggesting the most suitable locations for landfill facilities. An integrated fuzzy logic and AHP methodology in a GIS environment were used for the sanitary landfill site selection. Multan district was selected as a case study area because it does not have a sanitary landfill site after the closure of Habiba Sial sanitary landfill site, and solid waste is being dumped in open places. Different fuzzy membership functions were used for the standardisation of criteria. AHP method was used to calculate the weights of selected criteria and establish the relative importance of each criterion. The final landfill site suitability map was produced by using a weighted sum method. The obtained results showed that almost 8.5% of the study area was the most suitable for landfill sites. The distance to the surface water source, distance to wells, distance to the main road, distance to settlements, and groundwater level criteria were considered for selection of the final candidate landfill sites (site 1, site 2, and site 5).

It can be concluded that in the study area, this research provides scientific authentication on the landfill site selection process and demonstrates that socioeconomic, ecological, and infrastructure factors should be taken into consideration and public health should be given a preference. For future environmental control and to predict the effects of these landfills on the environment, a detailed hydrogeological study of the selected landfill sites must be carried out. A GIS with the integration of fuzzy and AHP methodology can also be used for landfill site suitability analysis in other populated cities of developing countries like Pakistan since it is a time-efficient and cost-effective method.

References

Alanbari, M.A., Al-ansari, N. and Jasim, H.K. (2014) 'GIS and multicriteria decision analysis for landfill site selection in Al-Hashimyah Qadaa', *Natural Science*, Vol. 6, No. 5, pp.282–304.

Anitha, A. and Acharjya, D.P. (2017) 'Crop suitability prediction in Vellore District using rough set on fuzzy approximation space and neural network', *Neural Computing and Applications*, doi:10.1007/s00521-017-2948-1.

Aragones-Beltran, P., Pastor-Ferrando, J.P., García-García, F. and Pascual-Agulló, A. (2010) 'An analytic network process approach for siting a municipal solid waste plant in the metropolitan area of Valencia (Spain)', *Journal of Environmental Management*, Vol. 91, No. 5, pp.1071–1086.

Atafar, Z., Mesdaghinia, A., Nouri, J., Homaee, M., Yunesian, M., Ahmadimoghaddam, M. and Mahvi, A.H. (2008) 'Effect of fertilizer application on soil heavy metal concentration', *Environmental Monitoring and Assessment*, Vol. 160, Nos. 1–4, pp.83–89, doi:10.1007/s10661-008-0659-x.

Ayoade, M.A. (2017) 'Suitability assessment and mapping of Oyo State, Nigeria, for rice cultivation using GIS', *Theoretical and Applied Climatology*, Vol. 129, Nos. 3–4, p.1341, doi:10.1007/s00704-016-1852-4.

Barakat, A., Hilali, A., Baghdadi, M.E. and Touhami, F. (2017) 'Landfill site selection with GIS-based multi-criteria evaluation technique. A case study in Béni Mellal-Khouribga Region, Morocco', *Environmental Earth Sciences*, Vol. 76, No. 12, pp.1–13, https://doi.org/10.1007/s12665-017-6757-8.

Bianchini, S., Soldato, R., Montalti, C. and Casagli (2019) 'Ground subsidence susceptibility (GSS) mapping in Grosseto plain (Tuscany, Italy) based on satellite InSAR data using frequency ratio and fuzzy logic', *Remote Sensing*, Vol. 11, No. 17, p.2015, doi:10.3390/rs11172015.

Chabuk, A.J., Al-Ansari, N., Hussain, H.M., Knutsson, S. and Pusch, R. (2016) 'Landfill Siting using GIS and AHP (analytical hierarchy process): a case study Al-Qasim Qadhaa, Babylon, Iraq', *Journal of Civil Engineering and Architecture*, Vol. 10, pp.530–543, https://doi.org/10.17265/1934-7359/2016.05.002.

Chang, N., Parvathinathan, G. and Breeden, J.B. (2008) 'Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region', *Journal of Environmental Management*, Vol. 87, No. 1, pp.139–153, https://doi.org/10.1016/j.jenvman.2007.01.011.

Demesouka, O.E., Vavatsikos, A.P. and Anagnostopoulos, K.P. (2013) 'Suitability analysis for siting MSW landfills and its multicriteria spatial decision support system: method, implementation and case study', *Waste Management*, Vol. 33, No. 5, pp.1190–1206, https://doi.org/10.1016/j.wasman.2013.01.030.

Donevska, K.R., Gorsevski, P.V. and Jovanovski, M. (2012) 'Regional nonhazardous landfill site selection by integrating fuzzy logic, AHP and geographic information systems', *Environmental Earth Sciences*, Vol. 67, No. 1, pp.121–131.

Effat, H.A. and Hegazy, M.N. (2012) 'Mapping potential landfill sites for North Sinai cities using spatial multicriteria evaluation', *Egyptian Journal of Remote Sensing and Space Science*, Vol. 15, No. 2, pp.125–133, https://doi.org/10.1016/j.ejrs.2012.09.002.

Ekmekcioglu, M., Kaya, T. and Kahraman, C. (2010) 'Fuzzy multicriteria disposal method and site selection for municipal solid waste', *Waste Management*, Vol. 30, Nos. 8–9, pp.1729–1736.

Eskandari, M., Homaee, M. and Mahmodi, S. (2012) 'An integrated multi criteria approach for landfill siting in a conflicting environmental, economical and socio-cultural area', *Waste Management*, Vol. 32, No. 8, pp.1528–1538, https://doi.org/10.1016/j.wasman.2012.03.014.

Gbanie, S.P., Tengbe, P.B., Momoh, J.S., Medo, J. and Kabba, V.T.S. (2013) 'Modelling landfill location using geographic information systems (GIS) and multi-criteria decision analysis (MCDA): case study Bo. Southern Sierra Leone', *Applied Geography*, Vol. 36, No. 1, pp.3–12.

Gorsevski, P.V, Donevska, K.R., Mitrovski, C.D. and Frizado, J.P. (2012) 'Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection : a case study using ordered weighted average', *Waste Management*, Vol. 32, No. 2, pp.287–296, https://doi.org/10.1016/j.wasman.2011.09.023.

Güler, D. and Yomralıoğlu, T. (2017) 'Alternative suitable landfill site selection using analytic hierarchy process and geographic information systems: a case study in Istanbul', *Environmental Earth Sciences*, Vol. 76, No. 20, p.678, https://doi.org/10.1007/s12665-017-7039-1.

Isalou, A.A., Zamani, V., Shahmoradi, B. and Alizadeh, H. (2013) 'Landfill site selection using integrated fuzzy logic and analytic network process (F-ANP)', *Environmental Earth Sciences*, Vol. 68, No. 6, pp.1745–1755, https://doi.org/10.1007/s12665-012-1865-y.

Islam, A., Ali, S.M., Afzaal, M., Iqbal, S. and Zaidi, S.N.F. (2018) 'Landfill sites selection through analytical hierarchy process for twin cities of Islamabad and Rawalpindi, Pakistan', *Environmental Earth Sciences*, Vol. 77, No. 3, p.72, https://doi.org/10.1007/s12665-018-7239-3.

Ismail, S.N.S. (2016) 'Landfill site selection model using an integrated approach of GIS and multi criteria decision analysis (MCDA): example of Selangor, Malaysia', *Asian Journal of Earth Sciences*, Vol. 10, No. 1, pp.1–8, https://doi.org/10.3923/ajes.2017.1.8.

Kahsay, A., Haile, M., Gebresamuel G. and Mohammed, M. (2018) 'Land suitability analysis for sorghum crop production in northern semi-arid Ethiopia: application of GIS-based fuzzy AHP approach', *Cogent Food & Agriculture*, Vol. 4, No. 1, pp.1–24, doi:10.1080 /23311932.2018.1507184.

Kara, C. and Doratli, N. (2012) 'Application of GIS/AHP in siting sanitary landfill: a case study in Northern Cyprus', *Waste Management and Research*, Vol. 30, No. 9, pp.966–980, https://doi.org/10.1177/0734242X12453975.

Kharat, M.G., Kamble, S.J., Raut, R.D. and Kamble, S.S. (2016) 'Identification and evaluation of landfill site selection criteria using a hybrid fuzzy Delphi, fuzzy AHP and DEMATEL based approach', *Modeling Earth Systems and Environment*, Vol. 2, No. 5, p.98, https://doi.org/ 10.1007/s40808-016-0171-1.

Khorram, A., Yousefi, M., Alavi, S.A. and Farsi, J. (2015) 'Convenient landfill site selection by using fuzzy logic and geographic information systems: a case study in Bardaskan, East of Iran', *Health Scope*, Vol. 4, No. 1, pp.19383, doi: 10.17795/jhealthscope-19383.

Khoshand, A., Bafrani, A.H., Zahedipour, M., Mirbagheri, S.A. and Ehtehsami, M. (2018) 'Prevention of landfill pollution by multicriteria spatial decision support systems (MC-SDSS): development, implementation, and case study', *Environmental Science and Pollution Research*, Vol. 25, No. 9, pp.8415–8431, https://doi.org/10.1007/s11356-017-1099-3.

Liu, H-C., You, J-X., Chen, Y-Z. and Fan, X-J. (2014) 'Site selection in municipal solid waste management with extended VIKOR method under fuzzy environment', *Environmental Earth Sciences*, Vol. 72, No. 10, pp.4179–4189, doi:10.1007/s12665-014-3314-6.

Mahmood, K.H., Batool, S.A., Chaudhry, M.N. and Daud, A. (2015) 'Evaluating municipal solid waste dumps using geographic information system', *Polish Journal of Environmental Studies*, Vol. 24, No. 2, p.879.

Malczewski, J. and Rinner, C. (2015) *Multicriteria Decision Analysis in Geographic Information Science*, p.331, Springer Science, New York, NY, USA.

Moeinaddini, M., Khorasani, N. and Danehkar, A. (2010) 'Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study : Karaj)', *Waste Management*, Vol. 30, No. 5, pp.912–920, https://doi.org/10.1016 /j.wasman.2010.01.015.

Nas, B., Cay, T., Iscan, F. and Berktay, A. (2010) 'Selection of MSW landfill site for Konya, Turkey using GIS and multi-criteria evaluation', *Environmental Monitoring and Assessment*, Vol. 160, Nos.1–4, pp.491–500, https://doi.org/10.1007/s10661-008-0713-8.

Rahmat, Z.G., Niri, M.V., Alavi, N., Goudarzi, G., Babaei, A.A., Baboli, Z. and Hosseinzadeh, M. (2017) 'Landfill site selection using GIS and AHP: a case study: Behbahan, Iran', *KSCE Journal of Civil Engineering*, Vol. 21, No. 1, p.111, https://doi.org/10.1007/s12205-016-0296-9.

Rathore, S., Ahmad, S.R. and Shirazi, S.A. (2016) 'Use of the suitability model to identify landfill sites in Lahore- Pakistan', *Journal of Basic and Applied Sciences*, Vol. 12, No. 1, pp.103–108.

Report Soil Survey of Pakistan (2008) *Land Resource Inventory and Agricultural Land Use Plan of Multan*, Soil Survey of Pakistan, Lahore.

Saaty, T.L. (1980) *The Analytic Hierarchy Process*, McGraw Hill, New York, NY, USA.

Sener, S., Sener, E., Nas, B. and Karaguzel, R. (2010) 'Combining AHP with GIS for landfill site selection: a case study in the Lake Beysehir catchment area (Konya, Turkey)', *Waste Management*, Vol. 30, No. 11, pp.2037–2046.

Soroudi, M., Omrani, G., Moataar, F. and Jozi, S. (2018) 'Modelling an integrated fuzzy logic and multi-criteria approach for land capability assessment for optimized municipal solid waste landfill siting yeast', *Polish Journal of Environmental Studies*, Vol. 27, No. 1, p.313, https://doi.org/10.15244/pjoes/69576.

Subiyanto, H., Arief, U.M. and Nafi, A.Y. (2018) 'An accurate assessment tool based on intelligent technique for suitability of soybean cropland: case study in Kebumen Regency, Indonesia', *Heliyon*, Vol. 4, No. 7, p.e00684, doi: 10.1016/j.heliyon.2018. e00684.

Suh, J. and Brownson, J. (2016) 'Solar farm suitability using geographic information system fuzzy sets and analytic hierarchy processes: case study of Ulleung Island, Korea', *Energies*, Vol. 9, No. 8, p.648, doi:10.3390/en9080648.

Sumathi, V.R., Natesan, U. and Sarkar, C. (2008) 'GIS-based approach for optimized siting of municipal solid waste landfill', *Waste Management*, Vol. 28, No. 11, pp.2146–2160, doi:10.1016/j.wasman.2007.09.032.

The Urban Unit Report (2016) *Situation Analysis of Solid Waste Management Services in Multan, Pakistan*, Lahore.

Torabi-Kaveh, M., Babazadeh, R., Mohammadi, S.D. and Zaresefat, M. (2016) 'Landfill site selection using combination of GIS and fuzzy AHP, a case study: Iranshahr, Iran', *Waste Management and Research*, Vol. 34, No. 5, pp.438–448, https://doi.org/10.1177/0734242X16633777.

Townsend, T.G., Powell, J., Jain, P., Xu, Q., Tolaymat, T. and Reinhart, D. (2015) *Sustainable Practices for Landfill Design and Operation*, doi:10.1007/978-1-4939-2662-6.

Yousefi, H., Javadzadeh, Z., Noorollahi, Y. and Yousefi-Sahzabi, A. (2018) 'Landfill site selection using a multi-criteria decision-making method: a case study of the salafcheghan special economic zone, Iran', *Sustainability*, Switzerland, Vol. 10, No. 4, pp.1–16, https://doi.org/10.3390/su10041107.

Zadeh, L.A. (1965) 'Fuzzy sets', *Inf. Control*, Vol. 8, No. 3, pp.8338–353.

Zamorano, M., Molero, E., Hurtado, Á., Grindlay, A. and Ramos, Á. (2008) 'Evaluation of a municipal landfill site in Southern Spain with GIS-aided methodology', *Journal of Hazardous Materials*, Vol. 160, Nos. 2–3, pp.473–481, https://doi.org/10.1016/j.jhazmat.2008.03.023.

Zhang, J., Su, Y., Wu, J. and Liang, H. (2015) 'GIS based land suitability assessment for tobacco production using AHP and fuzzy set in Shandong province of China', *Computers and Electronics in Agriculture*, Vol. 114, pp.202–211, doi:10.1016/j.compag.2015.04.004.