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Landfill site selection using multi-criteria evaluation in the GIS interface: a case study from the Gaza Strip, Palestine

Moustafa El Baba · Prabin Kayastha · Florimond De Smedt

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Abstract Selection of landfill sites for solid waste disposal is one of the biggest problems in urban areas because of impacts on public health. Based on the nature of the study area, appropriate landfill sites should be selected using multi-criteria evaluation techniques. There are three main landfill sites in the Gaza Strip, one in the Rafah Governorate, one in the Middle Governorate, and one in the Gaza Governorate. The Gaza Strip is one of the most densely populated areas in the world having a population density of 4660 persons per square kilometer and, hence, faces enormous difficulties with respect to waste disposal. At present, the available waste disposal sites are insufficient. This study focuses on the selection of new suitable landfill sites in the Gaza Strip using multi-criteria decision analysis (MCDA) with the help of the analytical hierarchy process (AHP) method. To achieve this aim, different thematic layers such as land use, soil type, depth to groundwater, distance from roads, rainfall, and elevation are considered. The results show that only 5.5 % of the total area of the Gaza Strip is highly suitable for landfill sites. The high suitable zone for landfill sites is predominantly located in the southeast of the Khan-Younis and Rafah Governorates. These suitable areas consist of cultivated area or natural resources, with sandy loess soil over loess, clay loam, or loessal sandy soil. The depth to ground water varies from 70 to 100 m from soil surface, the rainfall varies from 200 to 350 mm/year, and the altitudes are between 60 and 80 m above mean sea level. Moreover, these suitable sites are also located within 500 m from the road network. This information can be used by concerned authorities and stakeholders for establishing new solid waste disposal sites in the Gaza Strip.

Keywords Landfill site selection · Analytical hierarchy process · Multi-criteria evaluation · Geographical information system · Gaza Strip

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Introduction

Pollution caused by waste disposal is among the most challengeable environmental issues in the present world (Deng and Englehardt 2006; Eggen et al. 2010; Koshy et al. 2007). Contamination of groundwater by landfill leachate has been reported by several researchers (Nixon et al. 1997; Scultz and Kjeldsen 1986; Sawney and Kozoloski 1984). Hence, it is important to find suitable landfill locations to prevent environmental pollution and harmful impact on inhabitants. However, most people do not like landfill sites near residential areas, and "not in my back yard (NIMBY)" is a common problem everywhere. Hence, establishing new landfill sites is a difficult challenge for the concerned authorities (Jankowski and Nyerges 2001; Khamehchiyan et al. 2011).

Different factors such as hydrological, geological, topographical, environmental, and economical conditions should be taken into account for selection of a suitable landfill site. Bolton and Curtis (1990) suggested the following objectives to minimize the environmental impact related with the landfill site selection: (1) landfill site should be selected in such a way that it is acceptable for the public and should be located in such places which help to minimize contamination and pollution associated with noise, dust, smoke, traffic, and odor; (2) the site should comply with planning and development in the area; (3) the site should be acceptable for development of a waste disposal in terms of accessibility, land vacancy, flood potential, and the life of the site; and (4) the ecology of the site should not be significantly altered. Special consideration must be given to the biodiversity and uniqueness of the area; (5) public health and safety are also important factors which should be taken into account. The groundwater pollution hazard must be minimized to protect portable water supplies, and (6) the site must be suitable for operation and maintenance in terms of the availability of cover material and ease of machinery operation.

Delgado et al. (2008) reported that landfill site selection needs not only to comply with existing environmental regulations but also to account for operational and economic issues, which are considered as the key requirement that affects the financial sustainability of landfills. Hence, the design and planning of a landfill site involves the selection of treatment and disposal facilities, allocation of solid wastes and waste residues from the generator to the treatment and disposal sites, and the selection of transportation routes (Yesilnacar and Cetin 2005). Moreover, other criteria, such as distance from roads, distance from restricted areas, depth of ground water table, land use, soil type, availability of solid wastes, land slope, investment costs, and availability of land, should be considered for the selection of a suitable landfill site (Wang et al. 2009).

Different researchers have studied landfill site selection in different parts of the world in the last two decades. Some of the studies have attempted to develop computational models for landfill site selection. For instance, Alidi (1992) developed an integer goal programming model for the selection of hazardous waste disposal sites; Kao and Lin (1996) developed a raster-based programming in C-language based on branch-and-bound algorithms for landfill site selection with optimal compactness; Daneshvar et al. (2003) developed a user-

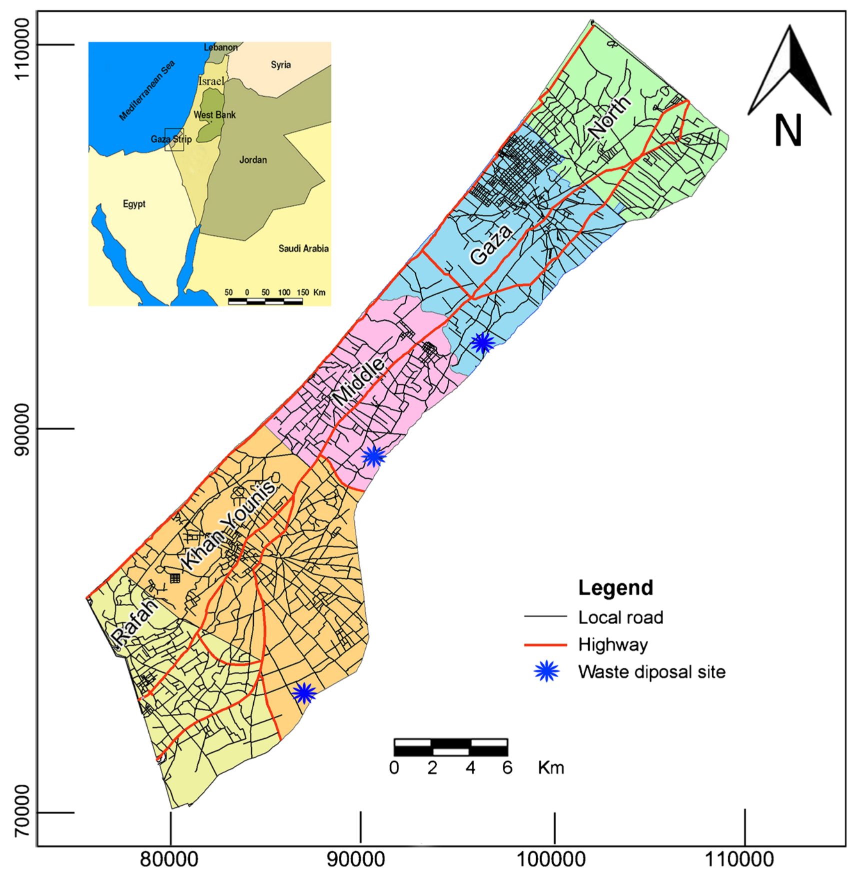


Fig. 1 Location map of the Gaza Strip, Palestine with Governorates, road networks, and landfill sites

friendly landfill site selection GIS tool in Arcmap; Zamoranoa et al. (2008) used the EVIAVE-based method developed at the University of Granada, Spain to select a suitable solid waste landfill site in Granada, Spain; Nazari et al. (2012) developed landfill site selection tools based on fuzzy multi-attribute decision making methods; and Cao et al. (2006) used gray situation decision making theory for waste sanitary landfill site selection in Xuzhou city, China. Besides these programming models, various researchers have incorporated different methodologies for landfill site selection in a GIS interface. Other studies used GIS to implement federal guidelines for landfill location such as Marín et al. (2012) in Morelos State, Mexico.

Many researchers applied expert-based judgment methods for landfill site selection using rating methods for the different parameters required for the landfill site selection and integrated those ratings with GIS tools to find suitable landfill sites. For instance, Bolton and Curtis (1990) used the heuristic method to find a solid waste disposal site in Saskatchewan, Canada; Frantzis (1993) used index values for different parameters for a municipal landfill site selection in Athens, Greece; Adeli and Khorshiddoust (2011) used the rating value method to find suitable sites for a landfill in Boban city, Iran; Khamehchiyan et al. (2011) used an expert-based method for selection of a hazardous waste landfill site in Zanjan Province, Iran; Moghaddas and Namaghi (2011) used a ranking method to find suitable hazardous waste landfill sites in Khorasan Razavi Province, Iran; Şener et al. (2011a) used an expert-based method for landfill site selection in Konya, Turkey; and Pandey et al. (2012) used an expert-based ranking method for selection of a municipal solid waste landfill site in Bhagalpur, India. Arkoc (2014) used a combination of point count index and constraint overlaying method for selection of a municipal solid waste landfill site in Çorlu District, Turkey.

Other studies used multi-criteria evaluation or multi-criteria decision analysis such as the analytical hierarchy process (AHP), analytical network process (ANP), factor importance coefficient (FIC), Delphi, fuzzy logic, Dempster Shafer Theory (DST), or combinations of these methods for landfill site selection. For instance,

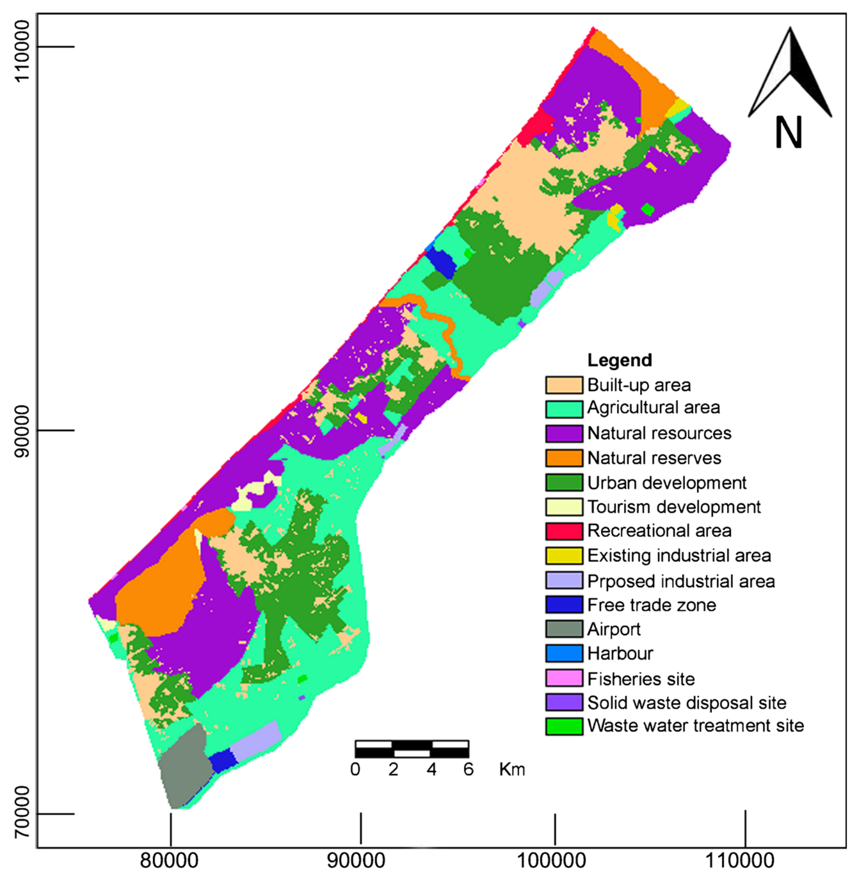


Fig. 2 Land use map of the Gaza Strip, Palestine

Nateshan and Suresh (2002) used AHP, FIC, ANN, and Delphi methods in Chennai, India; Al-Jarrah and Abu-Qdais (2006) used fuzzy logic techniques in Amman, Jordan; Şener et al. (2006) used simple additive and AHP methods in Ankara, Turkey; Banar et al. (2007) used ANP method in Eskisehir city, Turkey; Chang et al. (2008) used fuzzy logic techniques in Harlingen, Texas, USA; de Lima et al. (2008) used fuzzy logic in Rio de Janeiro, Brazil; Sumathi et al. (2008) used AHP in Pondicherry, India; Sharifi et al. (2009) used AHP in Kurdistan Province, Iran; Wang et al. (2009) used AHP in Beijing, China; Aragonés-Beltrán et al. (2010) used ANP method in Valencia, Spain; Gemitzi et al. (2010) used AHP and fuzzy logic techniques in Evros, Greece; Mahamid and Thawaba (2010) used multi-criteria evaluation to select a suitable landfill site in the Ramallah Governorate, Palestine; Moeinaddini et al. (2010) used AHP in Karaj, Iran; Şener et al. (2010) used the AHP method for landfill site selection in the Beyşehir Lake Catchment area; Ferretti (2011) used ANP for selection on Province of Torino, Italy; Mahiny and Gholamalifard (2011) used AHP and fuzzy logic techniques in Gorgan city, Iran; Şener et al. (2011b) used AHP in the Senirkent–Uluborlu (Isparta) Basin, Turkey; Donevska et al. (2012) used both fuzzy logic and AHP methods in Polog region, Macedonia; Eskandari et al. (2012) used AHP and rank order methods in Marvdasht city, Iran; Gorsevski et al. (2012) used fuzzy logic and AHP methods for landfill site selection in the Polog region, Macedonia; Kumar and Hassan (2013) used AHP in Delhi, India; and Vasiljević et al. (2012) used the AHP method in the Srem region, Serbia.

The Gaza Strip is one of the most densely populated areas in the world and, hence, faces enormous difficulties with respect to waste disposal. At present, the available waste disposal sites are insufficient. Even though different researchers used different types of multi-criteria decision analysis methods to identify the suitable site for landfill, the present study focuses on the selection of new suitable landfill sites in the Gaza Strip using the analytical hierarchy process (AHP) method. The advantages of using AHP method as

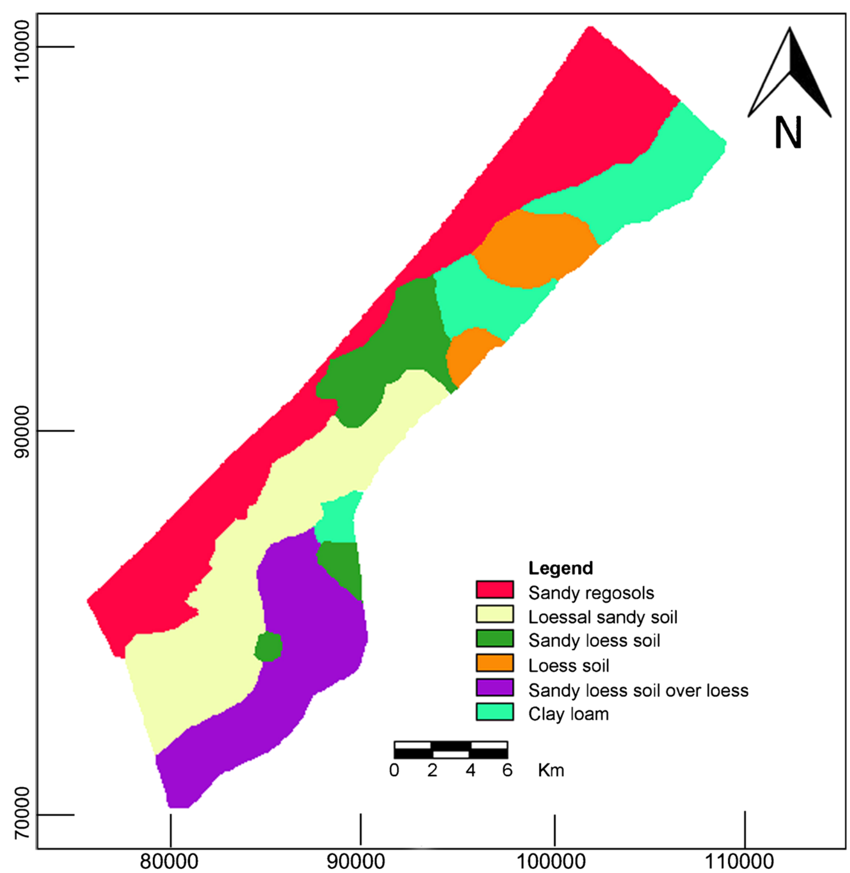


Fig. 3 Soil map of the Gaza Strip, Palestine

expert-based method for multi-criteria evaluation are as follows (Long and De Smedt 2012): (1) all types of information related to problems can be included in the discussion process; (2) judgment is structured in such a way that all information is considered; (3) the rules of discussions are based on knowledge, skill, and experience of the expert; (4) the weights for each relevant factor are obtained automatically by normalized principal eigenvector calculation of the decision matrix; and (5) inconsistencies in the decision process can be detected and, hence, can be updated and corrected. The main disadvantage of this method is that the expert ranking is personal and varies from one expert to another.

Study area

The Gaza Strip (Fig. 1) is about 45 km long and 6 to 12 km wide, with a total land area of 365 km^2. Situated in a coastal zone, transitional between the temperate Mediterranean climate and arid climate of the Negev and Sinai Deserts, the Gaza Strip has a semi-arid climate with two well-defined seasons: a wet season from October to April and a dry season from May to September. The average daily mean temperature ranges from 27 °C in summer to 13 °C in winter and the average annual rainfall is about 335 mm/year (MEnA 2001). There were about 1.5 million people living in the Gaza Strip in the year 2008 (PCBS 2009). The current population is estimated to be in excess of 1.7 million, resulting in a population density of 4,660 persons per square kilometer.

There are three main landfill sites in the Gaza Strip, one in the Rafah Governorate, one in the Middle Governorate, and one in the Gaza Governorate (Fig. 1). Solid waste in the Gaza Strip consists mainly of household waste, building debris, agricultural waste, industrial waste, medical wastes, and car workshop waste. The solid waste generation rate varies between 0.65 and 1.0 kg/capita/day. This leads to about 860 t/day in the cities and villages and about 290 t/day in the refugee camps. Regarding agricultural, industrial, and medical

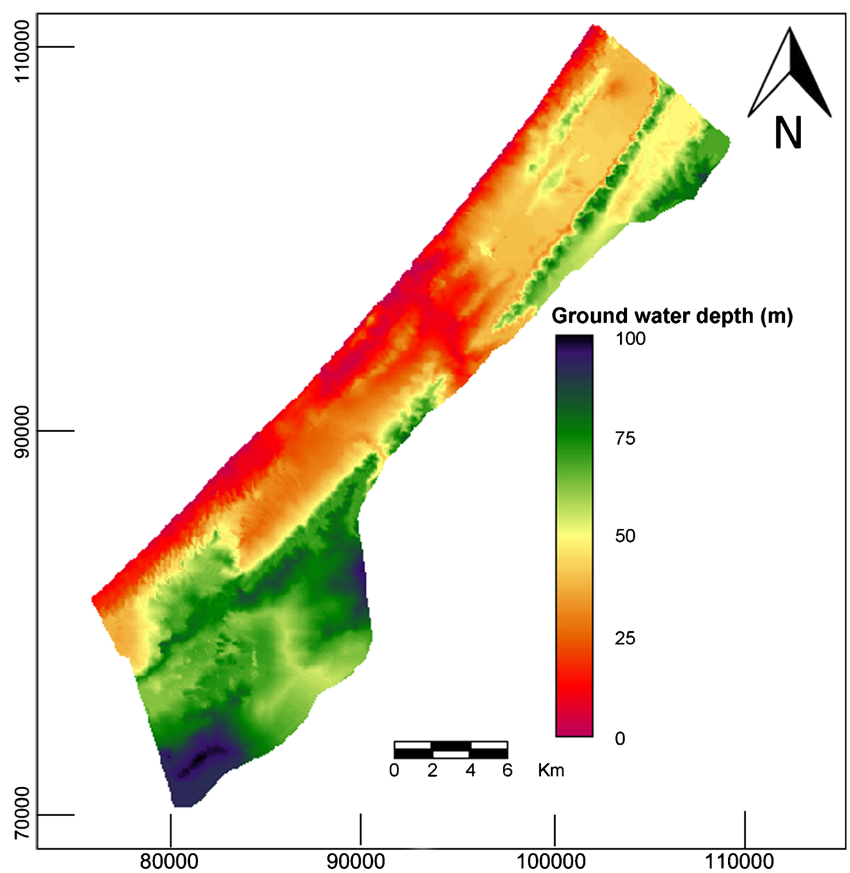


Fig. 4 Map showing the depth of ground water from the soil surface in the Gaza Strip, Palestine

wastes, only some tentative estimates are available (JICA and EQA 2007). More solid waste sites are needed in the near future, but due to the dense population, new sites are difficult to find.

Relevant data

Thematic data maps were collected from different sources such as the Palestine Water Authority (PWA), Palestinian Meteorological Office (PMO), Ministry of Agriculture, and Ministry of Planning and International Cooperation. These data sources were used to generate thematic digital maps using GIS software. All maps are raster based with a cell size of 10× 10 m. The preparation procedures for each data layer are summarized below.

Land use

Land use is one of most important factors for landfill site selection. Based on a land use map of the Gaza Strip, 15 land use classes are considered, as shown in Fig. 2, i.e., (1) built-up area, (2) cultivated land, (3) natural resources, (4) natural reserves, (5) urban development, (6) tourism development, (7) recreational area, (8) existing industrial area, (9) proposed industrial area, (10) free trade zone, (11) airport, (12) harbor, (13) fisheries site, (14) solid waste disposal site, and (15) waste water treatment site. Land uses such as built-up area, natural reserves, urban development, tourism development, existing industrial area, free trade zone, airport, harbor, fisheries site, and waste water treatment site are restricted for new landfill sites. These restricted zones cover 45.2 % of the Gaza Strip, while the present solid waste disposal sites are the highest preferred areas for new landfill sites followed by cultivated area and natural resources.

Soil type

Soil properties such as thickness, texture, structure, hydraulic conductivity, and porosity determine the transportation of

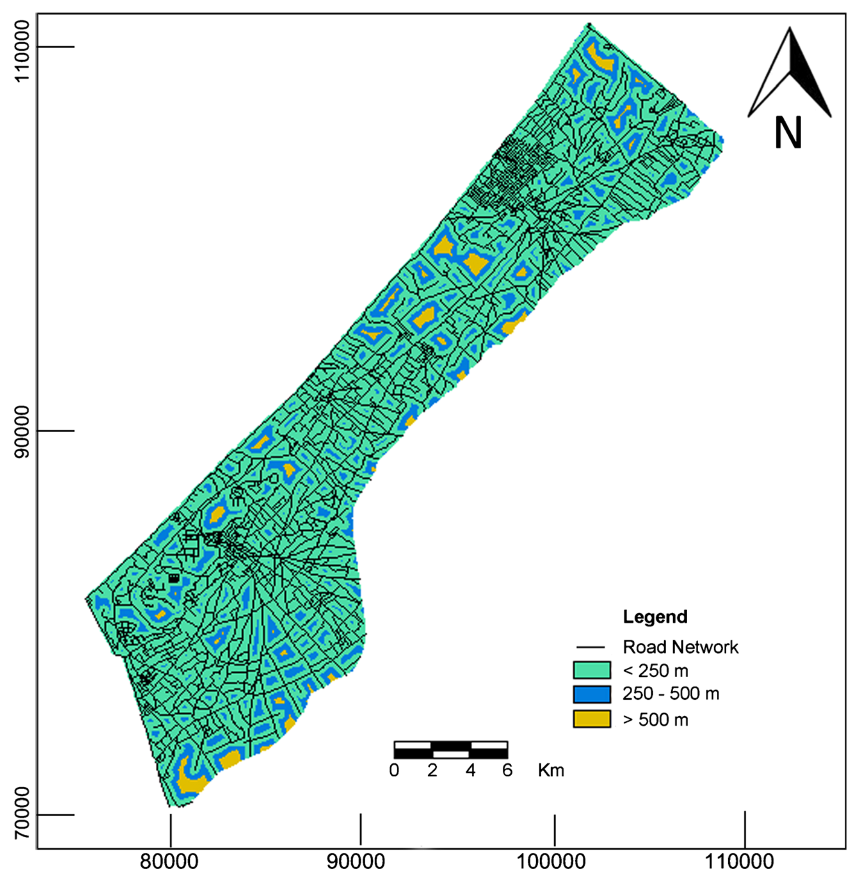


Fig. 5 Map showing the road buffer with road networks in the Gaza Strip, Palestine

contaminants to the groundwater (Todd 1980). Hence, soil type is an important factor that should be considered in the landfill site selection. For the Gaza Strip, soil types are classified into six different classes as shown in Fig. 3: (1) sandy Regosols, (2) loessal sandy soil, (3) sandy loess soil, (4) loess soil, (5) sandy loess soil over loess, and (6) clay loam. Clay loam is considered to be the best soil type for the landfill site selection followed by loess (loam) and sandy loess (sandy loam).

Depth of groundwater

The depth of groundwater is taken into consideration as an influential factor for the landfill site selection because a landfill site has a direct influence on the contamination of the underlying ground water (Almasri 2008). Ground water depth data were obtained from the Palestine Water Authority (PWA). A digital map (Fig. 4) was prepared using the Inverse Distance Weighted (IDW) interpolation method. The ground water depth from soil surface varies from 0 to 100 m, which is then classified into ten classes with intervals of 10 m. Areas with deep water table depths are considered as the best for the landfill site selection whereas areas with shallow water tables are worst due to the higher probability of ground water contamination (Şener et al. 2011a; Kumar and Hassan 2013).

Distance from road

Access to landfill sites is one of the most important criteria for landfill site selection. A suitable landfill site should be accessible for all Governorates. As the width of the Gaza Strip varies from 6 to 12 km and the length is only about 45 km, there is a good transportation network as shown in Fig. 1. Hence, it is only required that a new landfill site should be located close to the road network. A thematic access to roads map is derived by classifying the study area into three buffer zones (Fig. 5): (1) <250, (2) 250–500, and (3) >500 m from the road network. Close accessibility is

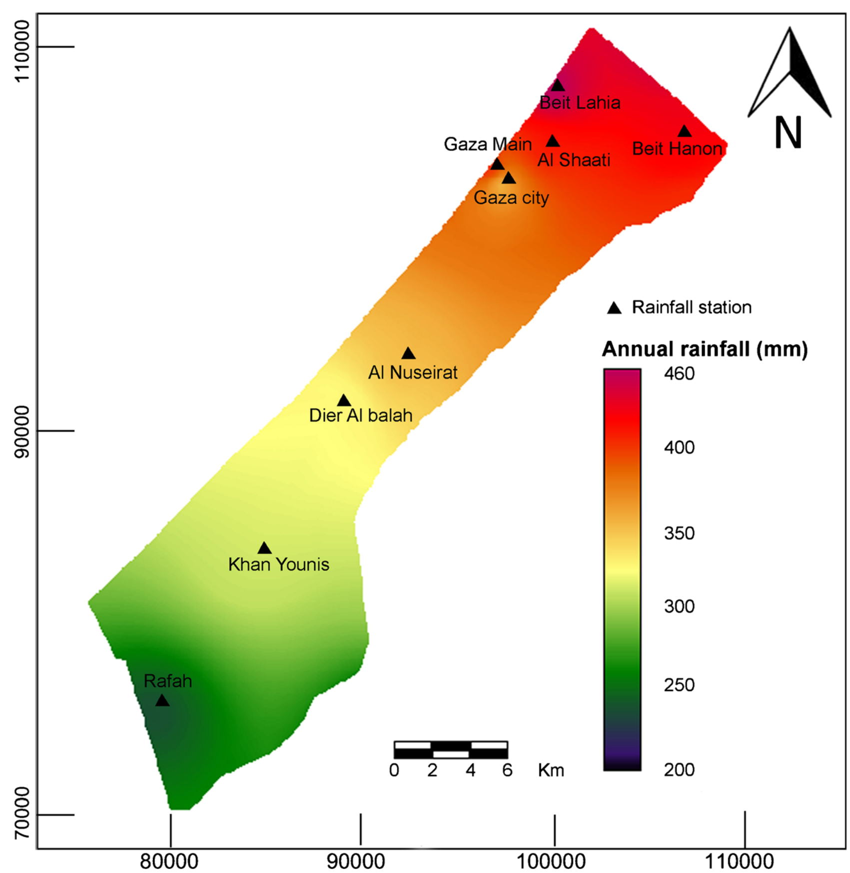
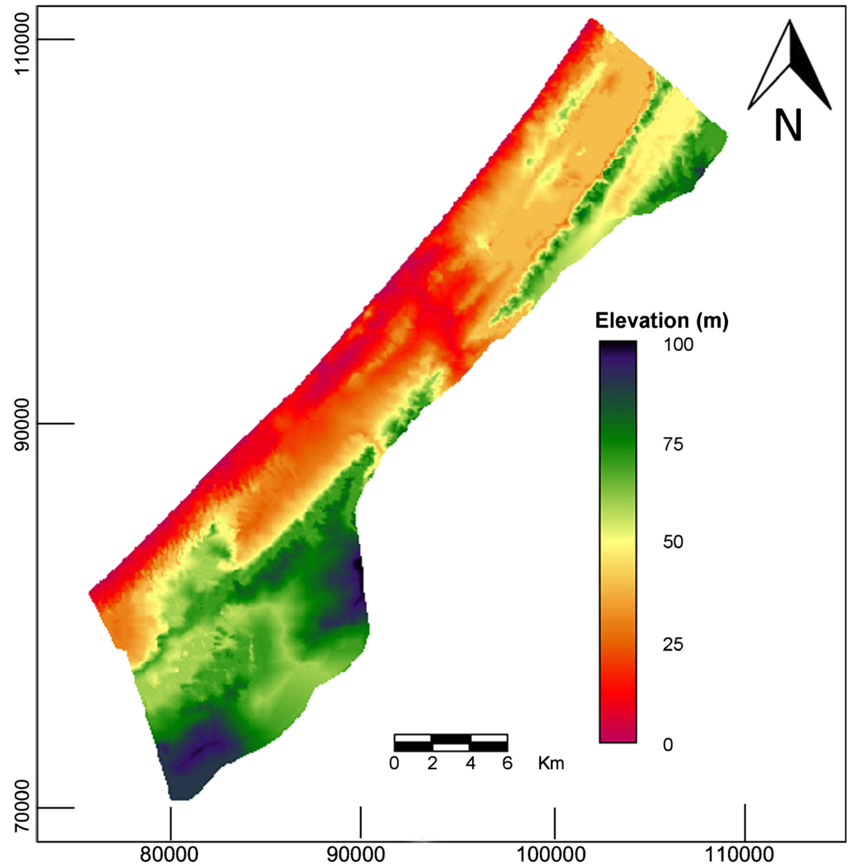


Fig. 6 Annual average rainfall map and rainfall stations in the Gaza Strip, Palestine

Fig. 7 Digital elevation model (DEM) of the Gaza Strip, Palestine



taken as the best preference for landfill site selection (Şener et al. 2010).

Rainfall

Annual total rainfall from 1973 to 2005, observed in 12 hydrometeorological stations (Fig. 6) situated in the study area, was used to prepare a rainfall map (Fig. 6), which was classified into six classes: (1) 200–250, (2) 250–300, (3) 300–350, (4) 350–400, (5) 400–450, and (6) >450 mm/year. Areas having less rainfall are considered as optimal for the landfill site selection.

Elevation

A digital elevation model (DEM) of the study area (Fig. 7) was prepared on the basis of digital elevation contours with intervals of 10 m. Altitude varies from 0 to 100 m. From this DEM, the study area is classified into ten elevation classes with intervals of 10 m. In the present study, higher elevation is

Table 1 Scale of preference between two parameters in AHP (Saaty 1977)

Preference factor	Degree of preference	Explanation
1	Equally	Two factors contribute equally to the objective
3	Moderately	Experience and judgment slightly to moderately favor one factor over another
5	Strongly	Experience and judgment strongly or essentially favor one factor over another
7	Very strongly	A factor is strongly favored over another and its dominance is showed in practice
9	Extremely	The evidence of favoring one factor over another is of the highest degree possible of an affirmation
2, 4, 6, 8	Intermediate	Used to represent compromises between the preferences in weights 1, 3, 5, 7, and 9
Reciprocals	Opposites	Used for inverse comparison

Table 2 Pair-wise comparison matrix and normalized principal eigenvector for landfill site suitability factors and for the classes within each factor, as required for applying the AHP method

Suitability factors and classes within each factors	Pair-wise comparison matrix															Normalized principal eigenvector
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	
All factors																
[1] Land use	1															0.2305
[2] Soil type	1	1														0.2305
[3] Depth of ground water table	2/3	2/3	1													0.1536
[4] Distance from roads	1/2	1/2	3/4	1												0.1279
[5] Average annual rainfall	1/2	1/2	3/4	1	1											0.1279
[6] Elevation	2/3	2/3	1	3/4	3/4	1										0.1296
Land use																
[1] Built-up area	1															0.0242
[2] Cultivated area	7	1														0.1877
[3] Natural resources	6	1	1													0.1819
[4] Natural reserve	1	1/9	1/9	1												0.0232
[5] Urban development	1	1/9	1/9	1	1											0.0232
[6] Tourism development	1	1/9	1/9	1	1	1										0.0232
[7] Recreational area	2	1/3	1/3	2	2	2	1									0.0919
[8] Existing industrial area	1	1/9	1/9	1	1	1	1/2	1								0.0232
[9] Proposed industrial area	2	1/4	1/3	2	2	2	1	2	1							0.0910
[10] Free trade zone	1	1/9	1/9	1	1	1	1/9	1	1/9	1						0.0217
[11] Airport	1	1/9	1/9	1	1	1	1/9	1	1/9	1	1					0.0201
[12] Harbor	1	1/9	1/9	1	1	1	1/9	1	1/9	1	1	1				0.0190
[13] Fisheries site	1	1/9	1/9	1	1	1	1/9	1	1/9	1	1	1	1			0.0190
[14] Solid waste dumping site	9	2	2	9	9	9	5	9	5	5	9	9	9	1		0.2307
[15] Waste water treatment site	1	1/9	1/9	1	1	1	1/9	1	1/9	1	1	1	1	1/9	1	0.0201
Soil type																
[1] Sandy Regosols	1															0.0322
[2] Loessal sandy soil	3	1														0.0963
[3] Sandy loess soil	5	7/4	1													0.1630
[4] Loess soil	7	9/4	3/2	1												0.2221
[5] Sandy loess soil over loess	6	2	1	1	1											0.1929
[6] Dark brown clay loam	9	3	2	5/4	3/2	1										0.2934
Depth of ground water																
[1] 0–10 m	1															0.0183
[2] 10–20 m	2	1														0.0360
[3] 20–30 m	3	3/2	1													0.0530
[4] 30–40 m	4	2	4/3	1												0.0707
[5] 40–50 m	5	5/2	5/3	5/4	1											0.0880
[6] 50–60 m	6	3	2	3/2	6/5	1										0.1061
[7] 60–70 m	7	7/2	7/3	7/4	7/5	7/6	1									0.1235
[8] 70–80 m	8	4	8/3	2	8/5	4/3	8/7	1								0.1414
[9] 80–90 m	9	9/2	3	9/4	9/5	3/2	9/7	9/8	1							0.1601
[10] 90–100 m	9	5	4	3	5/2	2	7/4	3/2	5/4	1						0.2029
Distance from roads																
[1] Close (<250 m)	1															0.5813
[2] Nearby (250–500 m)	1/2	1														0.3092
[3] Distant (>500 m)	1/5	1/3	1													0.1096
Average annual rainfall																

Table 2 (continued)

Suitability factors and classes within each factors	Pair-wise comparison matrix															Normalized principal eigenvector
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	
[1] 200–250 mm/year	1															0.4625
[2] 250–300 mm/year	1/2	1														0.2354
[3] 300–350 mm/year	1/4	1/2	1													0.1135
[4] 350–400 mm/year	1/6	1/3	2/3	1												0.0813
[5] 400–450 mm/year	1/8	1/4	1/2	3/4	1											0.0568
[6] >450 mm/year	1/9	1/5	1/2	3/4	1	1										0.0505
Elevation																
[1] 0–10 m	1															0.0191
[2] 10–20 m	2	1														0.0377
[3] 20–30 m	3	3/2	1													0.0570
[4] 30–40 m	4	2	7/5	1												0.0731
[5] 40–50 m	5	5/2	5/3	5/4	1											0.0925
[6] 50–60 m	6	3	2	3/2	7/6	1										0.1136
[7] 60–70 m	7	7/2	7/3	2	3/2	7/6	1									0.1348
[8] 70–80 m	7	7/2	7/3	2	3/2	7/6	1	1								0.1348
[9] 80–90 m	8	4	8/3	9/4	7/4	7/5	7/6	7/6	1							0.1566
[10] 90–100 m	9	5	3	5/2	2	3/2	7/5	7/5	7/6	1						0.1809

preferred for landfill site selection as suggested by Şener et al. (2006, 2010).

Methodology for landfill selection using analytical hierarchy process (AHP)

The analytical hierarchy process (AHP) was developed in the late 1970s (Saaty 1977, 1980). AHP is a decision-making tool to deal with multi-criteria evaluation and can be used with integrated GIS spatial analysis for landslide susceptibility assessment (Long and De Smedt 2012; Pourghasemi et al. 2012; Kayastha et al. 2013), identification of potential ground water recharge zone (Kaliraj et al. 2014), ground water potential mapping (Rahmati et al. 2014), soil erosion hazard mapping (Kachouri et al. 2014), urban development suitability (Youssef et al. 2011), and site selection of suitable land (Yasser et al. 2013). AHP allows to make a structured decision-making approach using expert judgment, which includes several steps (Saaty 1980): (1) problem definition; (2) hierarchy construction and development of the problem into component factors related to the objectives and outcomes of the problem; (3) specification of numerical values using pair-wise comparison scales; (4) calculation of normalized principal eigenvectors, maximum eigenvalue, consistency index, and consistency ratio for each criteria; (5) if inconsistencies in the decision process exist, revise the process till a consensus is reached; and (6) integration of weight values to reach an optimum decision.

In AHP, comparison of factors can be made using a scale from 1 to 9 if the factors have a direct relationship and a scale from 1/2 to 1/9 if the factors have an inverse relationship as shown in Table 1 (Saaty 1977).

Table 3 Random consistency index (RI) (Saaty 1980, 2000)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56	1.57	1.59

Table 4 Order of matrix (N), largest eigenvalue (λ_{max}), consistency index (CI), random consistency index (RI), and consistency ratio (CR) for the landfill site suitability factors and classes within each factor

Suitability factors	N	λ_{max}	CI	RI	CR
All	6	6.0576	0.0115	1.24	0.0093
Land use	15	16.0353	0.0739	1.59	0.0465
Soil type	6	6.0128	0.0026	1.24	0.0021
Depth of ground water	10	10.0102	0.0011	1.49	0.0008
Distance from road	3	3.0049	0.0025	0.58	0.0042
Average annual rainfall	6	6.0179	0.0036	1.24	0.0029
Elevation	10	10.0063	0.0007	1.49	0.0005

This pair-wise comparison can be used not only to rank the thematic factor maps but also to rank the classes within a factor map. As a result, comparison matrices are obtained as shown in Table 2. The normalized principal eigenvector of each comparison matrix gives the preference weight for each factor or class within a factor related to the landfill site selection. The consistency of the rating can be tested by the calculation of a consistency index (CI), defined as (Saaty 2000):

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

where λ_{max} is the largest eigenvalue and N is the order of each comparison matrix.

Saaty (1980, 2000) developed an average random consistency index (RI) for different matrix orders from 1 to 15 as shown in Table 3, and defined the consistency ratio (CR) as the ratio of the consistency index (CI) and the random consistency index (RI). If the CR coefficient is less than 0.1, the rating of the factors or classes is consistent. If CR is greater than 0.1, the comparison matrix is inconsistent and should be revised. For the present study, all CR values are less than 0.10 (Table 4), which shows that the rating values used to produce the comparison matrices are

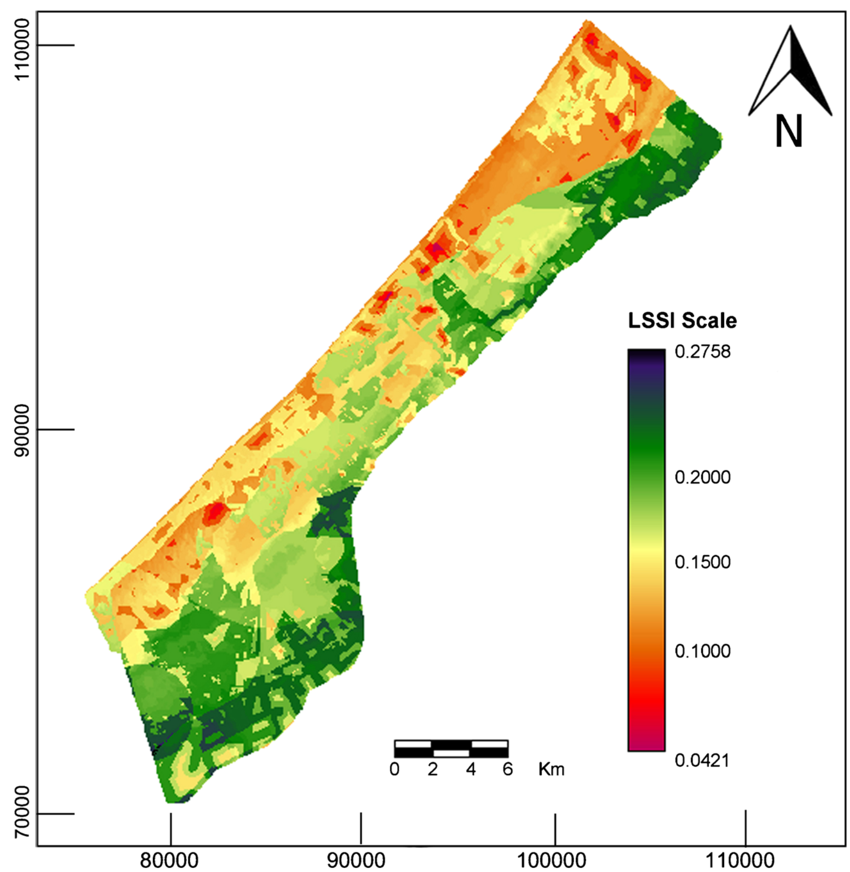


Fig. 8 Landfill site suitability index (LSSI) map of the Gaza Strip, Palestine

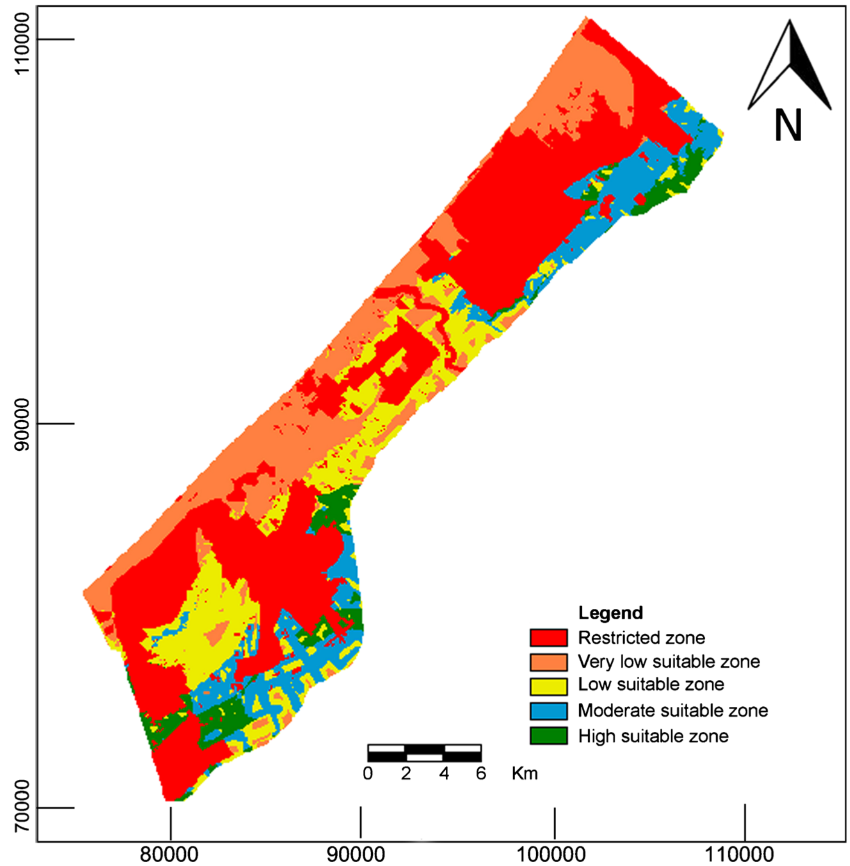


Fig. 9 Landfill site suitability map of the Gaza Strip, Palestine

consistent. The normalized principal eigenvectors of each matrix are given in the last column of Table 2. These weight values show that land use and soil type are the most important factors for the selection of a landfill site in the study area, followed by depth of the ground water, elevation, distance from road, and rainfall.

Finally, the integration of the various factors and classes of each factor in a single landfill site suitability index (LSSI) is obtained by a procedure based on the weighted linear sum

$$\mathrm{LSSI} = \sum_{j=1}^{n} W_j w_{ij} \qquad (2)$$

where W_j is the weight value of factor j, w_{ij} is the weight value of class i in factor j, and n is the number of parameters. The resulting LSSI map is shown in Fig. 8 in which the LSSI values vary from 0.0421 to 0.2758. Some land uses are restricted for landfill sites, as explained before, which cover 45.23 % of the total area of the Gaza Strip. The remaining part of the Gaza Strip, i.e., 54.77 % of area, is classified into four zones, i.e., very low, low, moderate, and high suitable zones, in such a way that 40 % of the remaining part of the Gaza Strip have the lowest LSSI values, 30 % have low LSSI values, 20 % have moderate LSSI values, and 10 % have the highest LSSI values. These different zones are shown in Fig. 9. The high suitable zone covers 5.47 % of the total study area, whereas the moderate, low, and very low zones cover 10.95, 16.43, and 21.91 %, respectively, as shown in Table 5.

Table 5 Area covered by the different suitability zones of the landfill site suitability map

Suitability zones	Area	
	(km^2)	(%)
Restricted	165.11	45.23
Very low	79.96	21.91
Low	59.97	16.43
Moderate	39.98	10.95
High	19.99	5.48
Total	365.00	100.00

Evidently, the high suitable zone should be preferred for installing new waste disposal sites. The high suitable zone for landfill sites is predominantly located in the southeast of the Khan-Younis and Rafah Governorates.

Discussions and conclusions

The analytical hierarchy process was applied for the selection of new landfill sites in the Gaza Strip. Using GIS techniques, different thematic maps such as land use, soil, depth to groundwater, distance from roads, rainfall, and elevation were considered as factors to derive a landfill site suitability map. From the analysis, it was found that land use and soil type are the most important factors for the selection of a landfill site, while elevation, rainfall, distance from roads, and depth to ground water have a less, almost similar, influence on the selection criteria.

From the study, it is concluded that in the Gaza Strip only 5.48 % of the total area is suitable for new landfill sites. Most of these sites are located in the southeastern part of the Khan-Younis and Rafah Governorates. These highly suitable zones consist of cultivated area or natural resources, with sandy loess soil over loess, clay loam, or loessal sandy soil. The depth to ground water in these suitable zones varies from 70 to 100 m from soil surface, the rainfall varies from 200 to 350 mm/year, and the altitudes are between 60 and 80 m above mean sea level. The suitable sites are also located within 500 m from the road network.

The landfill site selection map presented in this study can be a good source for concerned authorities and provides valuable information for development works related to solid waste management. Very likely, the landfill site suitability analysis would be even more accurate if economic factors such as price of land had also been considered as a thematic layer. But unfortunately, such information was not available for the present study.

The limitation of the AHP method is that weights are assigned based on expert's judgment. Hence, selection factors may vary from one place to another, such that the rating scheme developed in this study may not be suitable for other parts of the world. However, the methodology can be adapted, while the pair-wise relative comparisons of the parameters can always be verified for inconsistencies as demonstrated in the present study.

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