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Basak Sener
M. Lütfi Süzen
Vedat Doyuran

Landfill site selection by using geographic information systems

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B. Sener (✉)
Department of Geological Engineering,
Mugla University, 48100 Mugla, Turkey
E-mail: bsener@mu.edu.tr
Fax: +90-312-2101263

M. L. Süzen · V. Doyuran
Department of Geological Engineering,
Middle East Technical University,
06531 Ankara, Turkey

Abstract One of the serious and growing potential problems in most large urban areas is the shortage of land for waste disposal. Although there are some efforts to reduce and recover the waste, disposal in landfills is still the most common method for waste destination. An inappropriate landfill site may have negative environmental, economic and ecological impacts. Therefore, it should be selected carefully by considering both regulations and constraints on other sources. In this study, candidate sites for an appropriate landfill area in the vicinity of Ankara are determined by using the integration of geographic information systems and multicriteria decision analysis (MCDA). For this purpose, 16 input map layers including topography, settlements (urban centers and villages), roads (Highway E90 and village roads), railways, airport, wetlands, infrastructures (pipelines and power lines), slope, geology, land use, floodplains, aquifers and surface water are prepared and two different MCDA methods (simple additive weighting and analytic hierarchy process) are implemented to a geographical information system. Comparison of the maps produced by these two different methods shows that both methods yield conformable results. Field checks also confirm that the candidate sites agree well with the selected criteria.

Keywords Landfill · Site selection · GIS · Multicriteria decision analysis · Ankara

Introduction

Source reduction, recycling and waste transformation are methods widely used to manage solid waste, however, in all these methods there is always a residual matter even after the recovery process to disposal. The necessity of getting rid of these waste yields in an economic approach which is called as landfilling (Tchobanoglous and Kreith 2002).

Landfill siting is an extremely difficult task to accomplish because the site selection process depends on different factors and regulations. It is becoming increasingly difficult due to growing environmental awareness, decreased amount of governmental and municipal funding with extreme political and social opposition. The increasing population densities, public health concerns, and less land available for landfill construction are also the difficulties to overcome (Kao and Lin 1996). Environmental factors are very important because the landfill may affect the biophysical environment and the ecology of the surrounding area (Siddiqui et al. 1996; Erkut and Moran 1991; Lober 1995). Economic factors must be considered in the siting of landfills, which include the costs associated with acquisition, development, and operation of the site (Erkut and Moran 1991). Social and political opposition to landfill siting have been indicated as the greatest obstacle for successfully locating waste disposal facilities (Lober 1995). The NIMBY (not in my back yard) phenomenon (Kao and Lin 1996; Lober 1995; Erkut and Moran 1991), is both an important consideration and restraint to landfill siting. The external cost and undesirable characteristics of landfills often cause people to perceive the hazards and risks which outweigh the long-term benefits (Baxter et al. 1999). It is evident that many factors must be incorporated into landfill siting decisions, and geographic information systems (GIS) is ideal for this kind of preliminary studies due to its ability to manage large volumes of spatial data from a variety of sources. It efficiently stores, retrieves, analyzes and displays information according to user-defined specifications (Siddiqui et al. 1996).

Multicriteria decision analysis (MCDA) is used to deal with the difficulties that decision-makers encounter in handling large amounts of complex information. The principle of the method is to divide the decision problems into more smaller understandable parts, analyze each part separately and then integrate the parts in a logical manner (Malczewski 1997).

The integration of GIS and MCDA is a powerful tool to solve the landfill site selection problem, because GIS provides efficient manipulation and presentation of the data and MCDA supplies consistent ranking of the potential landfill areas based on a variety of criteria.

The main objective of this study is to develop a methodology involving both GIS and MCDA and to apply this methodology to an area of roughly 22×28 km^2 located at the west of Ankara (Fig. 1).

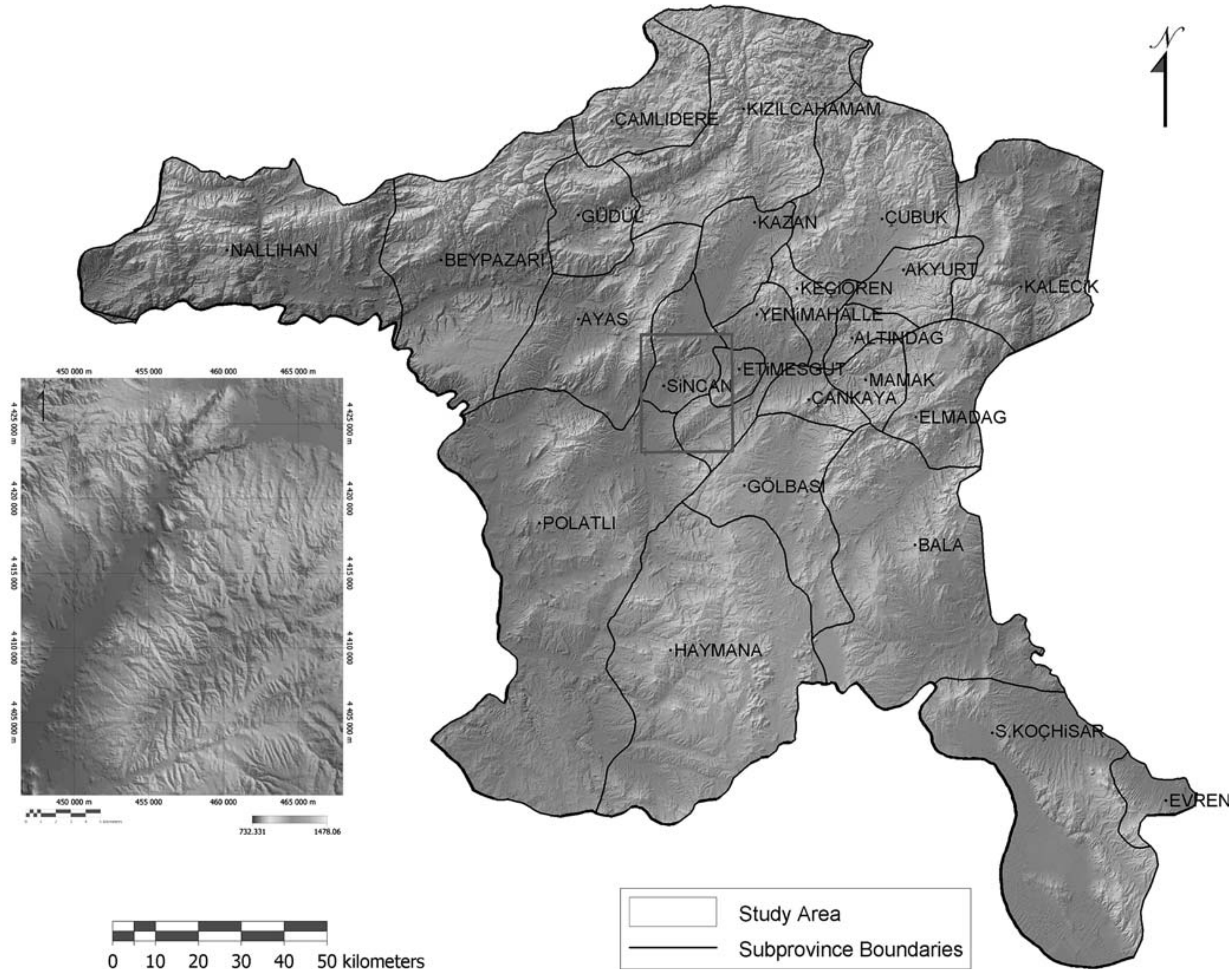


Fig. 1 The location map of the study area

Table 1 The summary of the input layers used in the analysis

Layer name	Source map	Buffer zone	Ranking	Area (%)
Elevation	1/25,000 scale topographical maps	750–1,000 m	0	32.61
		< 750 m, > 1,000 m	1	67.39
Settlement areas				
Urban centers	1/25,000 scale topographical maps	0–1,000 m, > 30,000 m	0	23.20
		5,000–10,000 m	10	22.12
		10,000–15,000 m	8	27.71
		15,000–10,000 m	6	21.61
		20,000–15,000 m	4	5.35
		25,000–30,000 m	2	0.01
Villages		0–1,000 m	0	41.85
		> 1,000 m	1	58.15
Roads				
Intercity highway	1/25,000 scale topographical maps	0–500 m	0	3.49
		0–500 m	3	3.56
		1,000–2,000 m	2	6.83
		> 2,000 m	1	86.12
Small roads		0–100 m	0	8.37
		100–500 m	3	29.17
		500–1,000 m	2	26.32
		> 1,000 m	1	36.14
Railways	1/25,000 scale topographical maps	0–500 m	0	6.91
		> 500 m	1	93.09
Airports	1/25,000 scale topographical maps	Not suitable	0	1.66
		Suitable	1	98.34
Wetlands	1/25,000 scale topographical maps	Not suitable	0	1.84
		Suitable	1	98.16
Infrastructures				
Pipelines	1/25,000 scale topographical maps	Not suitable	0	2.12
		Suitable	1	97.88
Powerlines		Not suitable	0	2.04
		Suitable	1	97.96
Slope	Digital elevation model derived from 1/25,000 scale topographical maps	0–5	5	52.85
		6–10	4	28.82
		11–15	3	12.70
		> 15	0	5.63
Geology	Available reports and maps from MTA (Akyürek et al. 1997)	Qa	0	19.75
		Ja, Km, Pkb	1	3.32
		Khv, Kkk, Tb	2	9.35
		Jg, Kh	3	0.56
		Trael	4	0.39
		Tma, Tt	5	14.20
		Tg	9	28.32
		Th	10	24.10
Land use	1/50,000 scale land use map	AOIA, WWTP	0	48.82
		P	5	1.00
		PA	8	38.76
		AG 6,7; AG 4; B; RT	10	11.42
Floodplain	Derived from 1/25,000 geological map	Floodplain	0	18.80
		Non-floodplain	1	81.20
Aquifer	1/25,000 scale geological maps	Major aquifer	0	19.13
		Minor aquifer	5	48.69
		Non-aquifer	10	32.19
Surface water	1/25,000 scale topographical maps	High density	0	20.95
		Medium density	5	65.37
		Low density	10	13.68

Qa sand, gravel; *Ja* white, cream limestone with silicified bands and nodules; *Jg* volcanics, agglomerate, volcanogenic sandstone and limestones; *Kh* alternation of conglomerate, sandstone, shale; *Khv* basalt; *Kkk* alternation of sandstone, conglomerate, mudstone, calciturbidite interbeds; *Km* reefal limestone, sandstone; *Pkb* limestone blocks; *Tb* basalt; *Tg* conglomerate, sandstone, mudstone; *Th* sandsone, siltstone, marl, clayey limestone, tuff, gypsum, bituminous shale; *Tma* agglomerate, tuff, andesite; *Trael* metaconglomerate, metasandstone, sandy limestone, sandstone, limestone; *Tt* andesite, trachyandesite, tuff, agglomerate; *AOIA* alternative organized industrial area; *WWTP* waste water treatment plant; *AG 1,2,3* agricultural lands of grade 1,2,3; *UC* urban centers; *V* villages; *OIA* organized industrial area; *IL* irrigable lands; *P* plantations; *PA* pasture areas; *RT* rocky terrain; *B* bushlands; *AG 4* agricultural land of grade 4; *AG 6,7* agricultural lands of grade 6,7

Input data

In this study, 16 input map layers including topography, settlements (urban centers and villages), roads (Highway E90 and village roads), railways, airport, wetlands, infrastructures (pipelines and power lines), slope, geology, land use, floodplains, aquifers and surface water are evaluated and prepared to be used in the analysis in GIS environment. All the data layers are derived and prepared from related maps by scanning, geocoding and digitizing the relevant information. The information compiled from literature about the safe distances to a landfill site is used to determine the buffer zones for each layer. An extended collection of these safe distances from various case studies can be found at Sener (2004). After creating the classes for each layer by using buffer zones, each layer is converted into individual raster maps. The layers, used buffer zones and rankings are summarized in Table 1.

Analysis

After the preparation of all input data layers, two methods named as "simple additive weighting method" and "analytical hierarchy method" are selected among the decision rules to analyze the data for landfill site selection by using GIS. The output maps produced by both methods include the multiplication of data layers, weights and constraints as represented in Fig. 2.

Before the application of both methods, the areas restricted by rules and physical constraints are excluded from the study area which are assigned 0 during the data preparation stage. The exclusion of certainly unsuitable areas is done by mask operation. To prepare a mask of unsuitable areas, all data layers are multiplied by each other so that if any pixel has a value of 0 coming from any layer, then the value of that pixel will become 0 which means that the pixel is completely unsuitable as a landfill site. The white areas in the mask (Fig. 3) are the excluded areas. All data layers converted to raster are multiplied by mask to make them ready for ranking.

Implementation of simple additive weighting method

Simple additive weighting method is the simplest and most often used as a multiattribute decision technique (Malczewski 1997; Janssen 1992; Eastman 1993). The

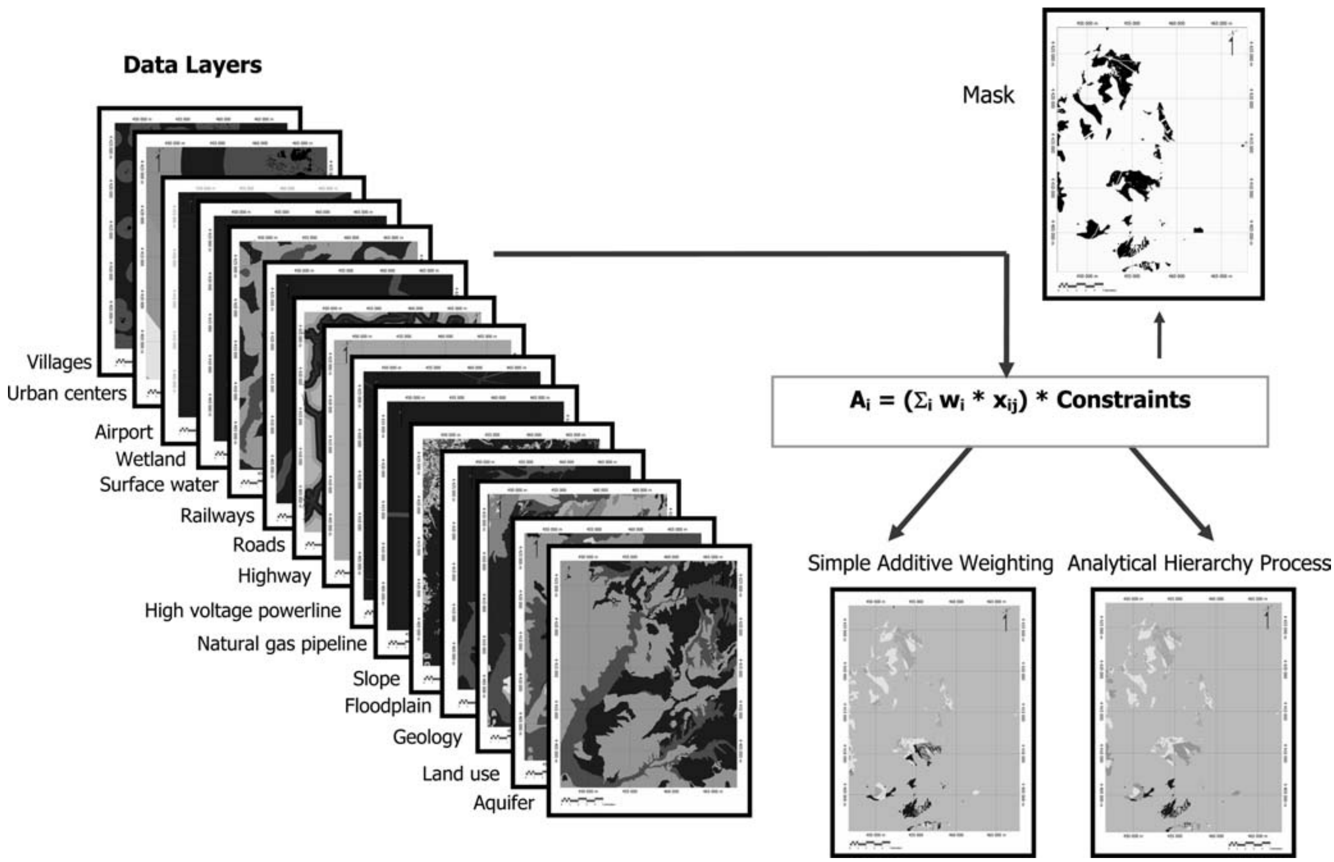


Fig. 2 The procedure for both multicriteria decision analysis (MCDA) methods

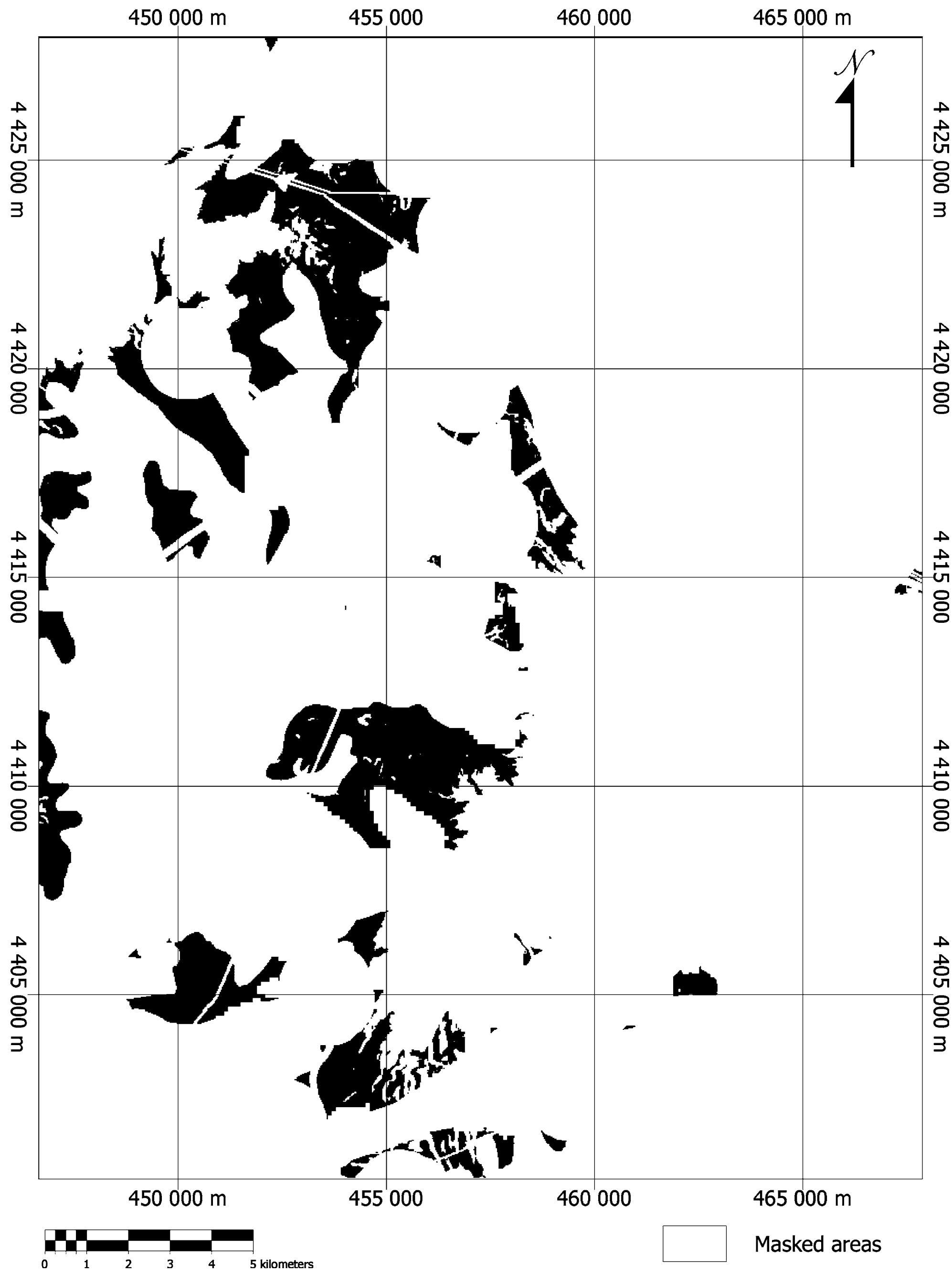


Fig. 3 Mask prepared to exclude the restricted areas (*white areas* are the masked areas that are unsuitable for landfilling at least for one variable)

method is based on the weighted average. An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by decision maker followed by summing of the products for all criteria. The first step of GIS-based SAW method is defining the set of evaluation criteria (Malczewski 1999). The 16 map layers, each of which defines a criterion necessary to be considered in landfill site selection are prepared. The set of feasible alternatives which are the pixels of the map suitable for landfill siting are obtained by exclusion of the areas restricted by rules and physical constraints. Because the scores of the criteria are given on different scales, they must be standardized to a common dimensionless unit. For this process, the score range procedure is selected and applied. In the score range procedure, the standardized scores are calculated by dividing the difference between the maximum raw score and a given raw score by the score range.

Table 2 The criterion weights defined for simple additive weighting (SAW) method

Data layer	Weight	Normalized weights
Urban centers	10	0.1136
Villages	9	0.1023
Surface Water	8	0.0909
Flood	8	0.0909
Swamp	8	0.0909
Geology	7	0.0795
Aquifer	7	0.0795
Land use	6	0.0682
Slope	5	0.0568
Pipeline	5	0.0568
Electricity	3	0.0341
Elevation	3	0.0341
Highway E90	3	0.0341
Airport	3	0.0341
Village Road	2	0.0227
Railway	1	0.0114

$$X'_{ij} = \frac{X_j - X_{ij}}{X_j^{\max} - X_j^{\min}}$$

Where X'_{ij} is the standardized score for the ith alternative and jth attribute, X_{ij} is the raw score, and $X_j^{\max}$ and $X_j^{\min}$ is the maximum and minimum score for the jth attribute, respectively. This procedure is applied to each input raster in GIS environment (Malczewski 1999).

After the standardization of scores in each map layer, the criterion weights are defined as shown in the Table 2. The criterion weights are normalized to generate the overall score for each alternative. These weights are then converted into map forms by means of generating geo-formulas in TNTMIPS environment. The score value histogram of this resultant map is evaluated (Fig. 4) and the output values are divided into six classes, one of which is the masked areas with a value of 0 and defined as restricted areas for landfill siting. The other classes in terms of increasing suitability are "suitable but avoid", "least suitable", "suitable", "moderately suitable" and "most suitable" classes. The output map produced by the method of SAW is given in Fig. 5. As it can be seen from Fig. 5, the area belonging to "suitable but avoid" class covers 0.073%, "least suitable" class 38.186%, "suitable" class 36.141%, "moderately suitable" class 12.769% and "most suitable" class 12.830% of the unmasked area.

Implementation of analytic hierarchy process

In the analytic hierarchy process (AHP) developed by Saaty (1980), a complex decision problem is decomposed into simpler decision problems to form a decision hierarchy (Fig. 6). When developing a hierarchy, the top level is the ultimate goal which in this case is landfill site selection.

After the decomposition stage is completed, cardinal rankings for criteria are determined, which is done by pairwise comparisons. Two alternatives and the importance in relation between them are considered at a time which provides easier ranking. The comparison matrix developed for 16 criteria is shown in Fig. 7. After the comparison matrix is developed, the composite weights are produced by means of a sequence of multiplication.

First, the decision matrix is squared; the row sums are calculated and then normalized. This procedure is con-

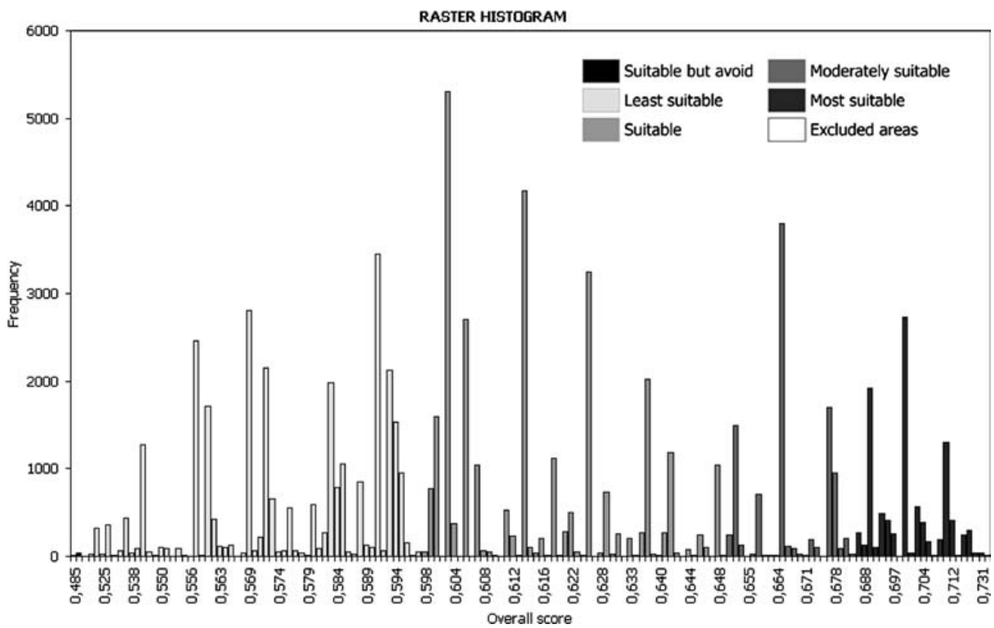


Fig. 4 The histogram of resultant map prepared by simple additive weighting (SAW) method

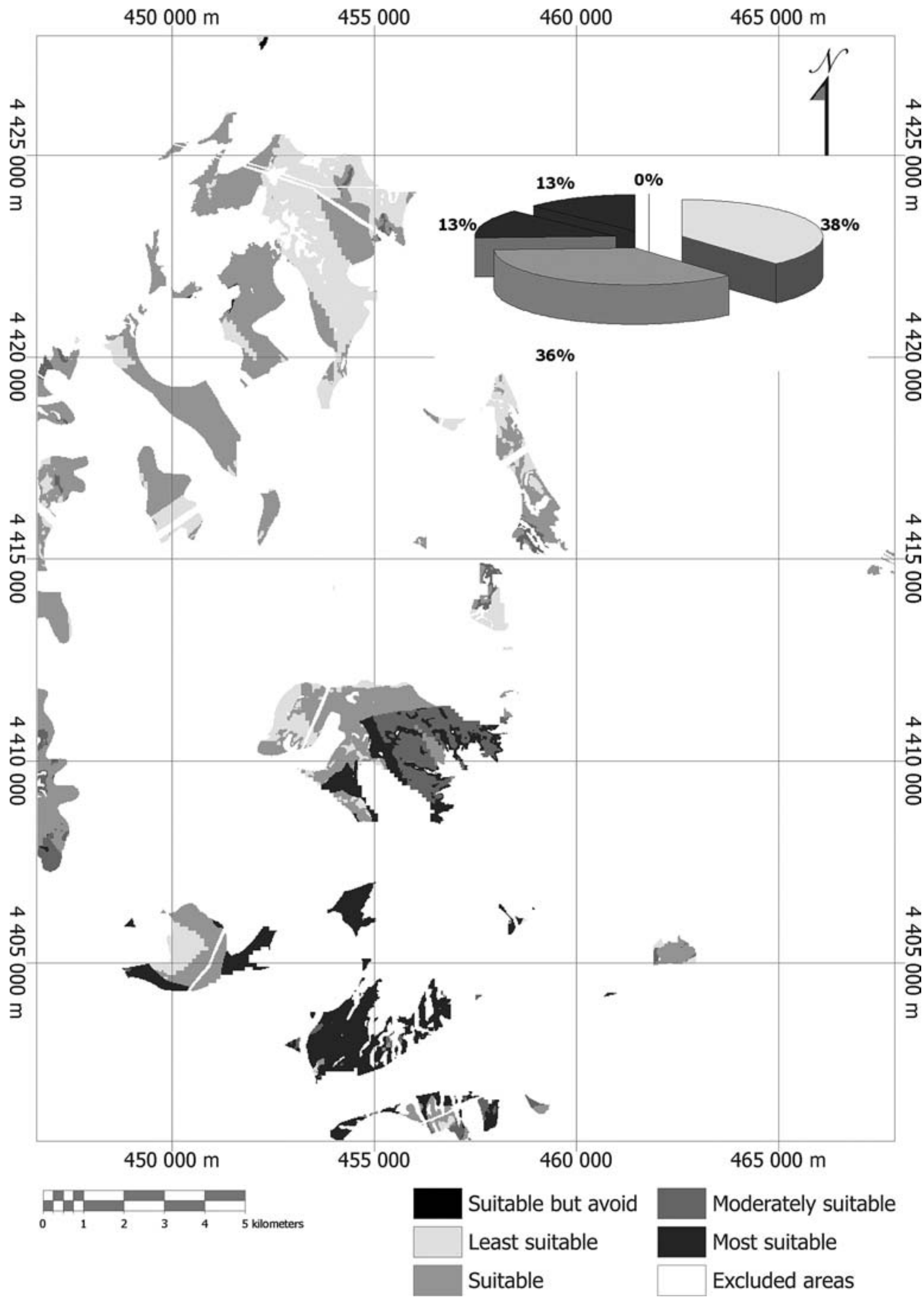


Fig. 5 The resultant map prepared by SAW method

tinued till the differences between normalized weights of the iterations are reached to a very small value. After the weights for each criterion is obtained, the geoformula is used to generate the overall score of the alternatives in the GIS environment. Following this, to maintain the harmony relative to the SAW result map and to let further comparisons, the same 6 U classification scheme is again applied to the resultant map after the evaluation of the histogram of AHP score map (Fig. 8).

Figure 9 shows the distribution of the classes. The areas belong to the suitable but avoid class covers 18.419%, least suitable class 41.740%, suitable class 11,013%, moderately suitable class 19.279% and most suitable class 9.549% of the unmasked area.

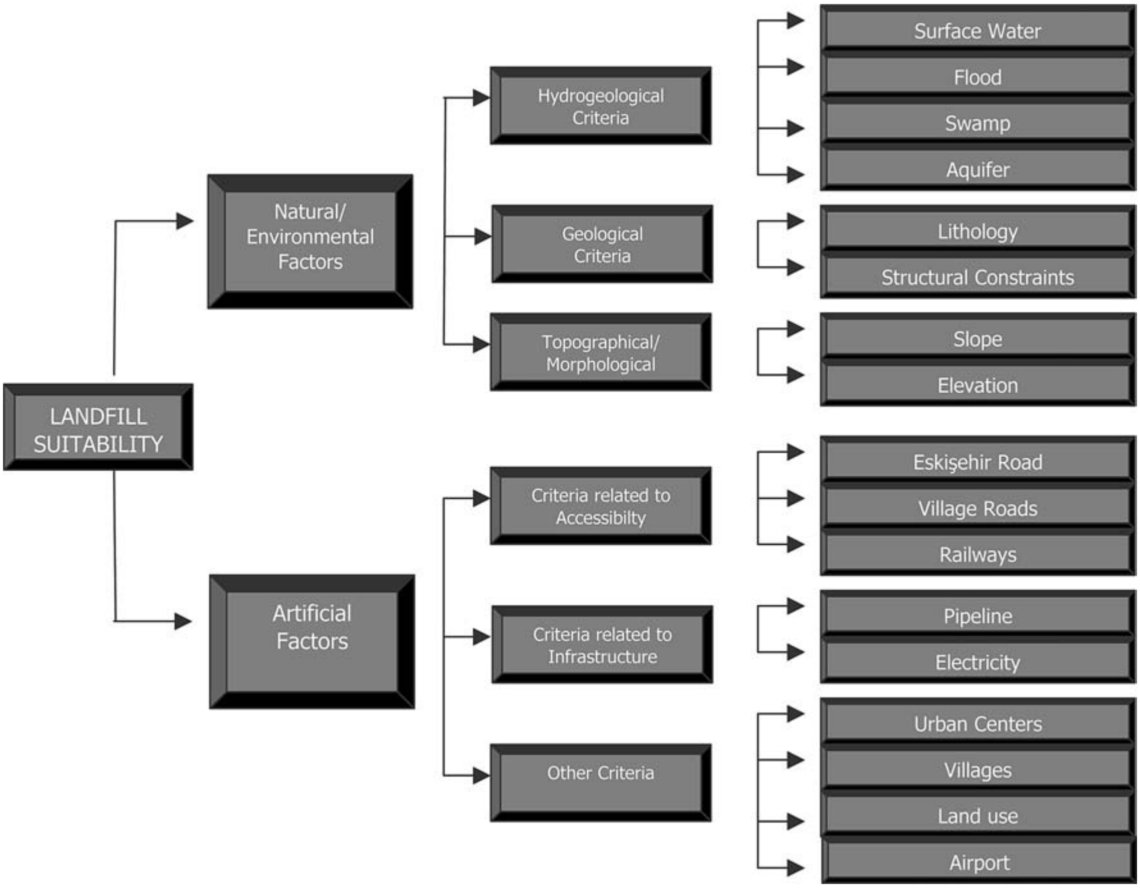


Fig. 6 The decision tree developed for the landfill site selection problem

Comparison of two maps

In order to compare the output maps of the two methods, a comparison matrix (Süzen and Doyuran 2004) is constructed and a geoformula is written for both the methods separately to classify the unmasked sites ranging from suitable but avoid areas to most suitable areas. For SAW method, each class is given a number changing from 0 to 5 and for AHP ranging from 0 to 50. After the preparation of the maps of six classes, they are added so that the matrix shown in Table 3 is established. In this matrix, 11, 22, 33, 44 and 55 refer to the pixels of correct classes in both methods. 14, 15, 25, 41, 51 and 52 are the mismatched classes, and the others are acceptable classes.

The dark gray areas shown in the matrix and histogram are the correct pixels in the output map with a percentage of 51.18. The light gray areas are acceptable pixels with a percentage of 48.82. If the acceptable and correct pixel percentages are summed, it can be said that two methods are conformable with a percentage of 100% (Fig. 10).

Assessment of suitability of candidate sites

After the comparison of two output maps developed through SAW and AHP methods, a number of candidate sites with the highest scores have been selected. In order to check the suitability of the candidate sites derived from the analyses, a field check is carried out. Four candidate sites are determined for further detailed geotechnical and hydrogeological investigations.

The candidate site 1 is characterized by gently rolling hills and flat hilltops (Fig. 11a). The area is found to be suitable as a landfill site based on the lithology, altitude and slope characteristics. However, some shallow flat hilltops are also indicated as suitable sites. This shows that the slope layer alone is not sufficient to eliminate such inconsistencies, whereas the location of the suitable slope interval within the slope profile should also be incorporated into the decision support systems. Apart from these flat hill tops, gently sloping wide valleys underlain by impervious strata can be used as a landfill site (Fig. 11).

Fig. 7 The comparison matrix developed for the landfill site selection problem

	Urban Centers	Villages	Surface Water	Flood	Swamp	Geology	Aquifer	Landuse	Slope	Pipeline	Electricity	Elevation	Eskisehir Road	Airport	Village Road	Railway
Urban Centers	1	2	3	3	3	4	4	5	5	5	7	7	7	7	9	9
Villages	1/2	1	2	2	2	3	3	4	5	5	7	7	7	7	9	9
Surface Water	1/3	1/2	1	1	1	2	2	3	4	4	5	5	5	5	7	7
Flood	1/3	1/2	1	1	1	2	2	3	4	4	5	5	5	5	7	7
Swamp	1/3	1/2	1	1	1	2	2	3	4	4	5	5	5	5	7	7
Geology	1/4	1/3	1/2	1/2	1/2	1	1	2	3	3	4	4	4	4	5	5
Aquifer	1/4	1/3	1/2	1/2	1/2	1	1	2	3	3	4	4	4	4	5	5
Landuse	1/5	1/4	1/3	1/3	1/3	1/2	1/2	1	2	2	3	3	3	3	4	4
Slope	1/5	1/5	1/4	1/4	1/4	1/3	1/3	1/2	1	1	2	2	2	2	3	3
Pipeline	1/5	1/5	1/4	1/4	1/4	1/3	1/3	1/2	1	1	2	2	2	2	3	3
Electricity	1/7	1/7	1/5	1/5	1/5	1/4	1/4	1/3	1/2	1/2	1	1	1	1	2	2
Elevation	1/7	1/7	1/5	1/5	1/5	1/4	1/4	1/3	1/2	1/2	1	1	1	1	2	2
Eskisehir Road	1/7	1/7	1/5	1/5	1/5	1/4	1/4	1/3	1/2	1/2	1	1	1	1	2	2
Airport	1/7	1/7	1/5	1/5	1/5	1/4	1/4	1/3	1/2	1/2	1	1	1	1	2	2
Village Road	1/9	1/9	1/7	1/7	1/7	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1/2	1	1
Railway	1/9	1/9	1/7	1/7	1/7	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1/2	1	1

Based on the geological, morphological and hydrological characteristics the candidate site 2 shown in Fig. 11b is found to be the most suitable among all candidate sites selected in this study. The only disadvantage of this site is that a small portion of it lies within an agricultural area.

Geologically and morphologically, the third candidate site (Fig. 11c) seems to be quite suitable for a landfill site. However, an access road of 3–4 km long will be required from E90 Highway.

The candidate site 4 (Fig. 11d) is located on a second and third grade agricultural land. Although the site is not determined as one of the most suitable areas for landfill site, during the field checks it is considered as suitable due to its overall score. This suggests that all

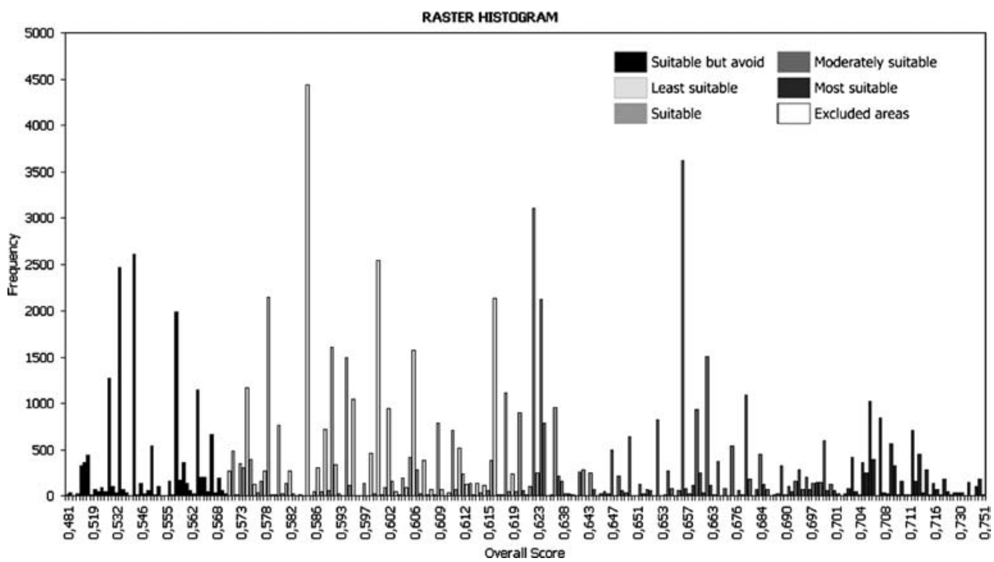


Fig. 8 The histogram of resultant map prepared by analytical hierarchy process

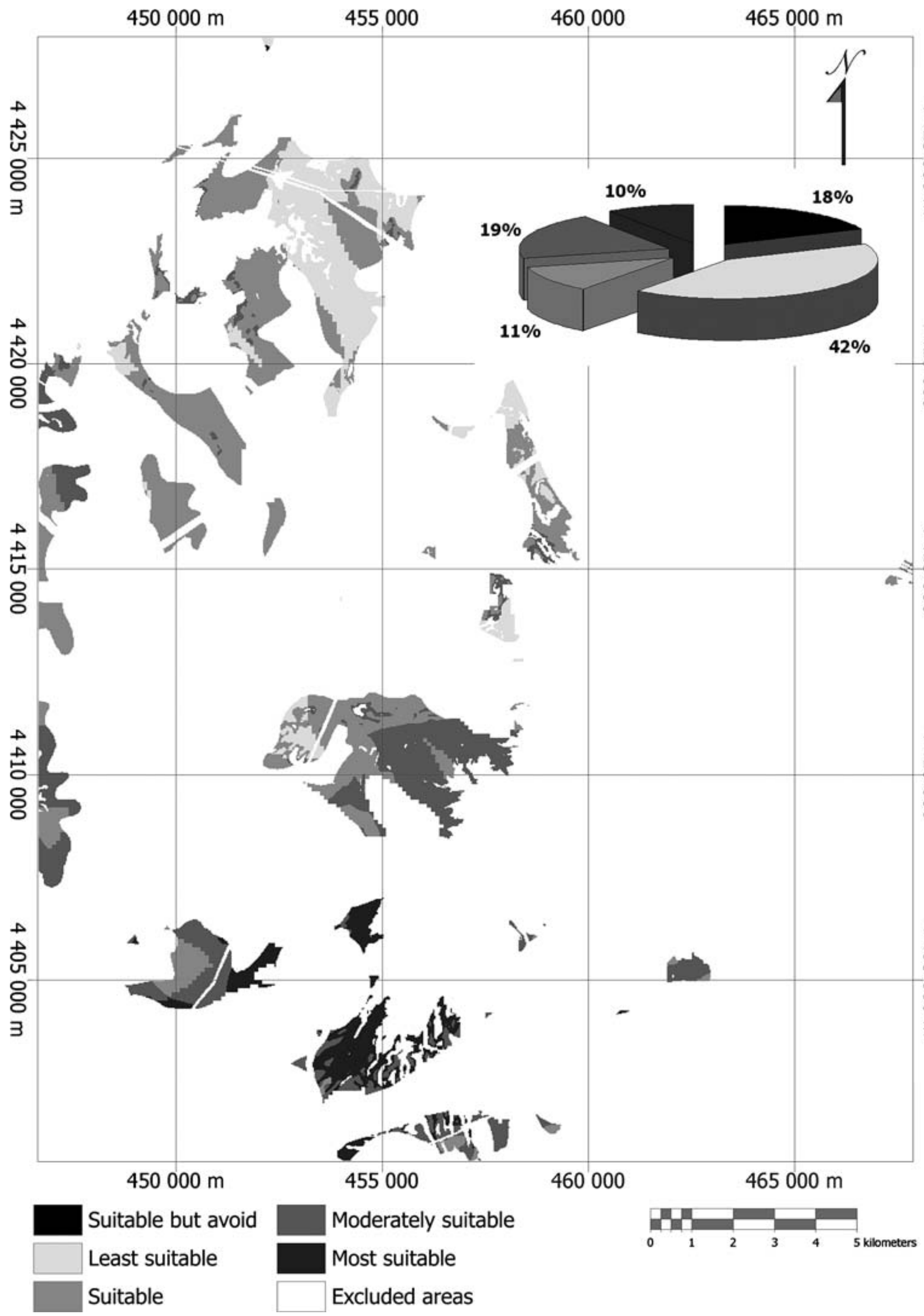


Fig. 9 The resultant map prepared by Analytical Hierarchy Process

Table 3 The matrix created for the comparison of two applied methods

Analytical hierarchy process (AHP)/SAW	1	2	3	4	5
10	11(0.07%)	12(18.33%)	13	14	15
20	21	22(19.83%)	23(21.90%)	24	25
30	31	32	33(10.00%)	34(1.01%)	35
40	41	42	43(4.23%)	44(11.77%)	45(3.31%)
50	51	52	53	54(0.03%)	55(9.51%)

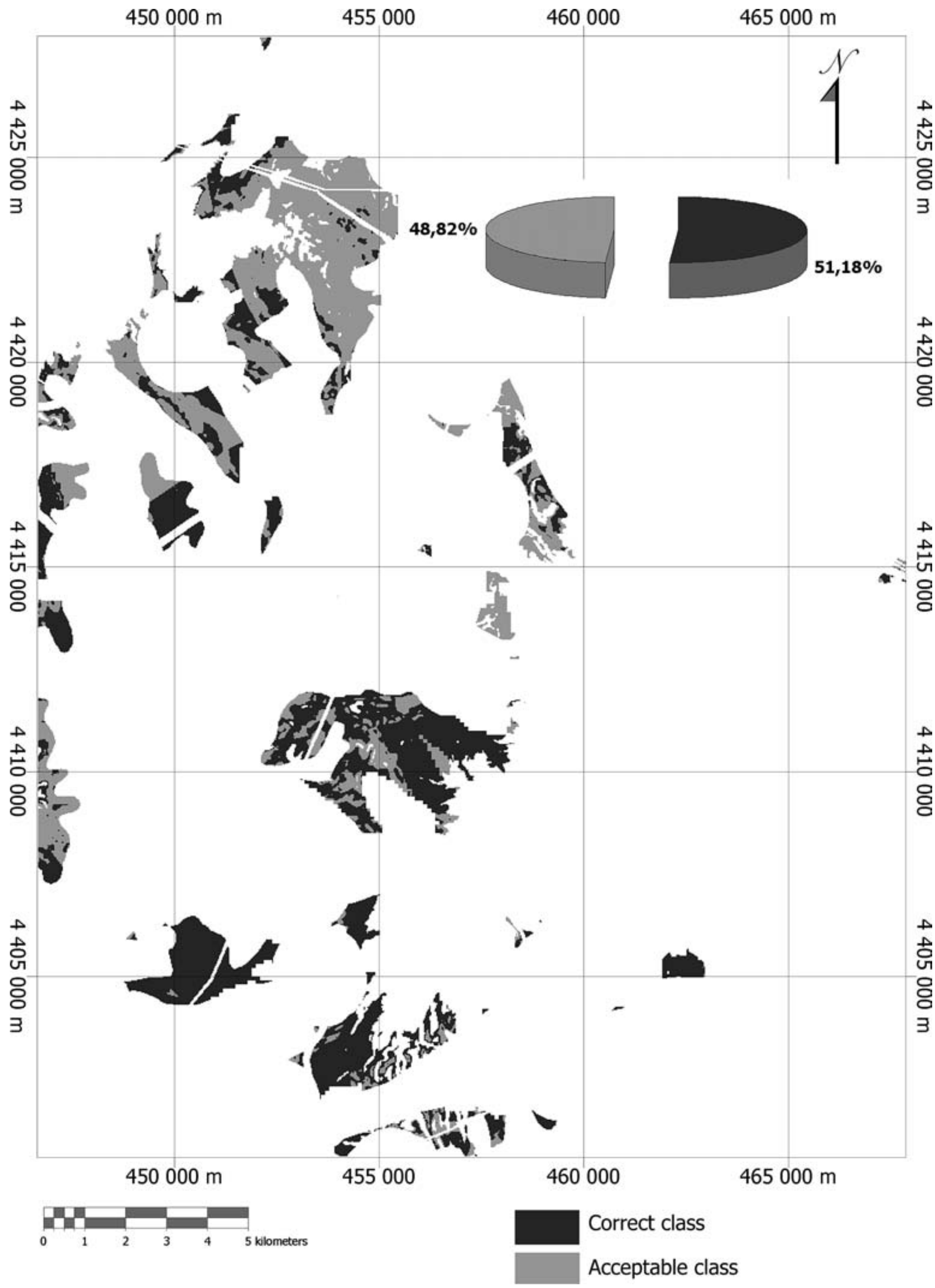


Fig. 10 The correct and acceptable areas of comparison

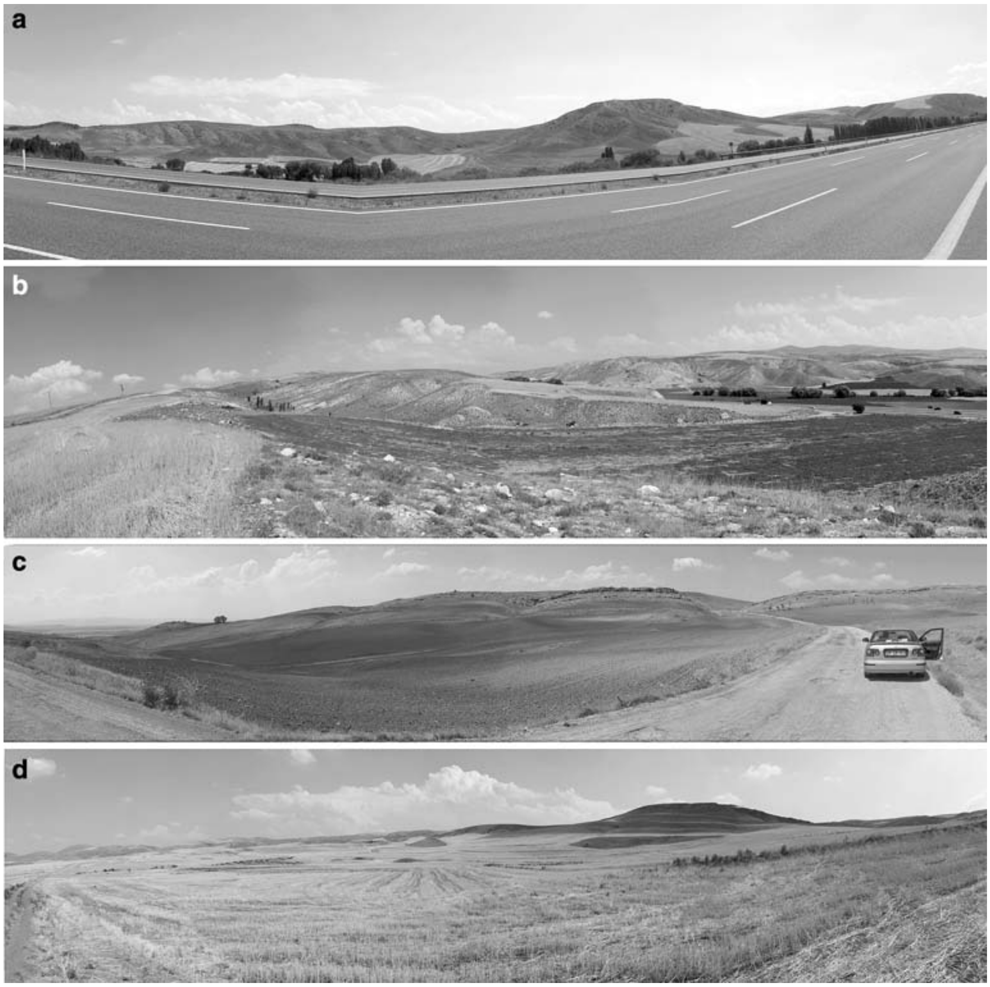
candidate sites should have to be field checked for the verification of model outputs.

Discussions and conclusions

In this study, all input data required for the analyses are generated from three map sources, which are topographical maps, geological maps and land use maps. The topographical maps are used to derive 12 input data layers such as surface water, wetlands, flood, slope, elevation, Highway E90, village roads, railway, natural gas pipeline, powerlines, urban centers, villages and airport. The lithological and hydrogeological data are derived from available geological maps and reports.

During the selection of the landfill siting criteria, the political and financial/economical constraints are not considered. At this stage the availability of suitable

Fig. 11 **a** Panoramic view of candidate site 1, **b** panoramic view of candidate site 2, **c** panoramic view of candidate site 3, **d** panoramic view of candidate site 4



cover material is not considered as a separate layer, however, during ranking of the lithological units this factor is taken into consideration.

The size of the pixels for all produced maps is selected as 25×25 m^2 and all the input data maps are resampled according to a reference raster which is the digital elevation model. Two different MCDA methods, SAW and the AHP method, are used to locate the candidate landfill sites with identical input data layers. The input layers are produced by ranking method which includes ranking of every class in a map under consideration in the order of decision maker's preferences. However, this method can be criticized for the lack of the theoretical foundation. The simple additive method has two assumptions of linearity and additivity, which are very difficult to apply in real world situations. The additivity assumption implies that there is no interaction or no complementary effect between the layers. In this study, the interaction between the layers was tried to be kept at a minimum. For example, geology has a direct control on topography, but they are used as different layers because geology and topography layers have different impacts on the site selection process. When applying the GIS-based SAW procedure, which is an expert dependent method, the weights are directly assigned between 1 and 10 by the expert.

The AHP decomposes the complex decision problem into simpler decision problems which provides easiness during decision making. Furthermore, it uses pairwise comparisons for determining the weights of the criteria by which two components are considered at a time which resulted in the reduction of complexity. The pairwise comparison for the determination of weights is more suitable than direct assignment of the weights, because one can check the consistency of the weights by calculating the consistency ratio in pairwise comparison; however, in direct assignment of weights, the weights are depending on the preference of decision maker. One difficulty encountered in this study was the number of criteria which were set as 16, where too many criteria yield in large amount of pairwise comparisons.

After the production of the output maps by two methods, a comparison is made and it is seen that

AHP method creates more conservative results. During field checks, some interesting results are obtained. It is seen that additional parameters need to be included in the model which have not been thought before the field work. Some of the parameters were given more credit than they actually deserve. One of the candidate sites is located at the plane surface of a hill top. Although the lithology, altitude and slope are suitable in terms of values, it is not practical to transport the wastes to this site. This shows that the slope layer needs to be refined to avoid such inconsistencies. It is important to realize that GIS analysis is not a substitute for field analysis; however, it does identify areas that are more suitable and directs efforts to these areas rather than areas that are unsuitable or restricted by regulations or constraints. The use of GIS during the study provides objective zone exclusion based on a set of screening criteria and effective graphical representation.

At the end of the analyses, a number of candidate sites are identified. These sites generally satisfy the minimum requirements of the landfill sites. Among these candidate sites ‘‘potential landfill’’ sites are selected through careful field checks. The selection of the final site, however, requires further geotechnical and hydrogeological analyses.

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