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Solid waste disposal site selection with GIS and AHP methodology: a case study in Senirkent–Uluborlu (Isparta) Basin, Turkey

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Abstract The appropriate site selection for waste disposal is one of the major problems in waste management. Also, many environmental, economical, and political considerations must be adhered to. In this study, landfill site selection is performed using the Geographic Information System (GIS), the Analytical Hierarchy Process (AHP), and the remote sensing methods for the Senirkent–Uluborlu Basin. The basin is located in the Eğirdir Lake catchment area, which is one of the most important fresh water in Turkey. So, waste management must be regulated in the basin. For this aim, ten different criteria (lithology, surface water, aquifer, groundwater depth, land use, lineaments, aspect, elevation, slope, and distance to roads) are examined in relation to landfill site selection. Each criterion was identified and weighted using AHP. Then, each criterion is mapped using the GIS technique, and a suitability map is prepared by overlay analyses. The results indicate that 96.3% of the area in the basin is unsuitable; 1.6%, moderately suitable; and 2.1%, most suitable. Finally, suitable regions in the basin are determined for solid waste landfill disposal and checked in the field. The selected and investigated regions are considered to be suitable for the landfill.

Keywords Catchment area · Landfill · Remote sensing · Waste management

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Introduction

Solid wastes that are generated from industrial organizations and urban areas create serious environmental problems (Chaulya 2003; Mikkelsen et al. 1998). At present, there are various techniques being used for solid waste management such as landfilling, thermal treatment, biological treatment, and recycling (Kontos et al. 2005). Sanitary landfill is the most common mode of solid waste disposal used in many countries (Yeşilnacar and Cetin 2005). The first and most important step in planning solid waste landfill is the site selection for solid waste disposal (Waele et al. 2004; Mummolo 1996).

Siting landfill is a complicated process because it must combine social, environmental, and technical parameters. The disposal site must not cause damage to the biophysical environment and the ecology of the surrounding area (Siddiqui et al. 1996; Erkut and Moran 1991; Lober 1995). Also, economic factors and geomorphologic features must be considered during site selection for the solid wastes (Yeşilnacar and Cetin 2007). In addition to these factors, several techniques can be found in various literatures for site selection (Ehler et al. 1995; Yagoub and Buyong 1998; Lucasheh et al. 2001; Kontos et al. 2003, 2005; Sener et al. 2006; Simşek et al. 2005; Banar et al. 2007; Gemitzi et al. 2006; Mutlutürk and Karagüzel 2007). According to Mutlutürk and Karagüzel (2007), the site selection method is applied in two stages. In the first stage, the potential landfill sites are identified based on evaluations of geology, hydrogeology, and morphological properties using GIS techniques. In the second stage, a number of potential landfill sites are assessed considering various criteria in three fundamental dimensions such as site suitability, location factors, and public acceptability and plotted on a 3D graph with axes corresponding to the dimensions.

The overall GIS-supported landfill site selection process contains two primary screening steps: (1) exclusion of areas unsuitable for landfill (prescreening or GIS step) and (2) weighting (ranking) of remaining areas (i.e., decision analyses step; Allen et al. 2003; Siddiqui et al. 1996; Muttiah et al. 1996; Lin and Kao 1998). The major GIS map

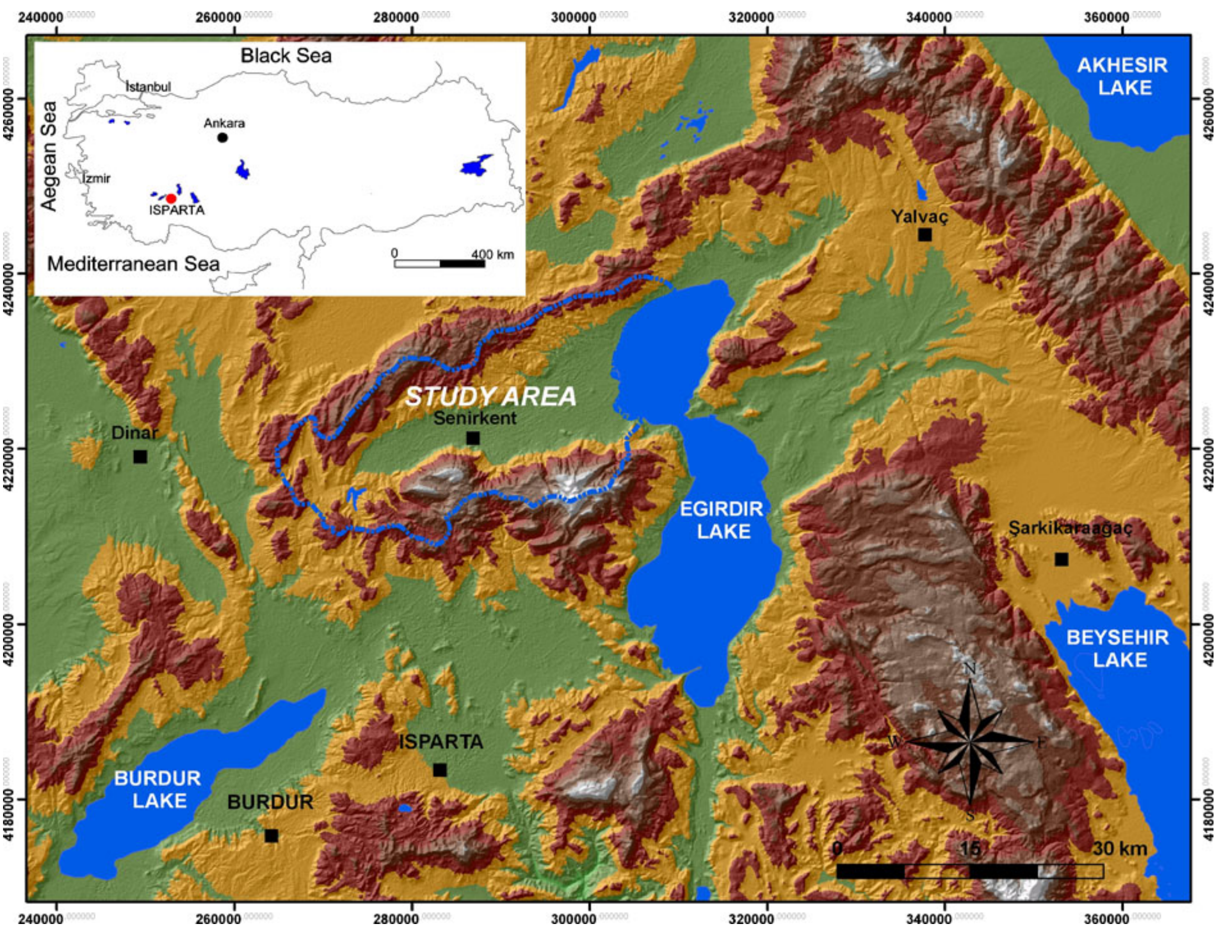

Fig. 1 Location map of the study area

analyses functions are buffer zoning, neighboring computation, cost distance, and overlay analysis, frequently used for landfill siting (Sarptaş et al. 2005). In order to find the most suitable area for landfill siting, GIS can be integrated with AHP. The integration of GIS and AHP is a powerful tool to solve the landfill site selection problem (Basağaoğlu et al. 1997; Sener et al. 2006).

In this study, GIS techniques were combined with AHP methods for solid waste disposal site selection. The method was applied to the Senirkent–Uluborlu Basin, which is located within the Lake District in the southwest of Turkey (Fig. 1). In addition to these techniques, lineament analysis of the basin was performed, which was taken into consideration for assessing groundwater movement of sanitary landfill areas. At the end of the analyses, determined areas were checked with field visits to confirm the results.

Materials and methods

The study area

The Senirkent–Uluborlu Basin was selected as an investigation area because of its location within the Lake District in the southwest of Turkey and Eğirdir Lake catchment (Fig. 1). The Eğirdir Lake is one of the most important fresh water with its 4 billion m^3 of water potential in Turkey. Also, Eğirdir Lake has a great importance for the region because of using drinking water, irrigation water, fishing, energy generation, and tourism. But, nowadays, the Eğirdir Lake is under the threat because of uncontrolled applications such as open dumps, fertilizer and pesticides, practices in agricultural areas, and uncontrolled sewerage system.

The Senirkent–Uluborlu Basin has wide agricultural plains and open dump areas located in the permeable units such as limestone and alluvium. The leachate generated from the open dump areas mix with groundwater and the Pupa stream. The Pupa stream is the most important surface water in the Senirkent–Uluborlu Basin and discharges to the Eğirdir Lake. Hydrogeological data show that surface and groundwater flow in the basin toward the Eğirdir Lake (Tay 2005). For this reason, all the contamination is transported to the lake via groundwater and surface water flow. Therefore, the appropriate landfill site selection should be performed for protection of the Eğirdir Lake.

Methodology

First, population in the residential areas is projected at 76,540 persons for the next 50 years. Then, waste inventory was calculated as 954,128 m^3. According to previous studies, recycled waste, compost, and landfill ratios in the region are determined as 27.31%, 44.97%, and 27.72%, respectively (Karagüzel et al. 2003). Hence, the total disposal waste volume was calculated as 264,484 m^3 for the next 50 years. In this study, with a landfill area of 1.76 ha, the average storing height was estimated at 15 m (Karagüzel et al. 2003). Field checks also confirm that the area of the selected sites agree with the determined 1.76 ha.

In this study, landfill site selection is performed using the GIS, the AHP, and the remote sensing methods. Geology, lineaments, and land use maps were prepared from satellite images and the remote sensing methods. The 1:25,000 scale topographical maps were digitized, and all the criteria maps were prepared from the related maps by scanning, digitizing, and geocoding the relevant information. Additionally, maps were prepared using the GIS techniques such as buffer zoning, interpolation, mapalgepra, and overlay analysis.

The AHP was selected for the decision rules to analyze the data for landfill site selection using GIS. The AHP divides the decision problems into understandable parts; each of these parts is analyzed separately and integrated in a logical manner as suggested by Saaty (1980) and Malczewski (1997). It is a powerful and comprehensive methodology designed to facilitate sound decision making by using both empirical data as well as subjective judgments of the decision maker. It combines tangible and intangible aspects in order to derive a ratio scale and the abstract scale of priorities, which is valid to make complex decisions (Al Khalil 2002; Solnes

2003). The AHP provides a proven, effective means to deal with complex decision making. It can assist with identifying and weighting of selection criteria, analyzing the collected data, and expediting the decision-making process.

A measurement methodology is used to establish priorities among the elements within each stratum of the hierarchy. This is accomplished by asking the participating decision makers (board members of environmental movements, rural women, and farmers in this study) to evaluate each set of elements in a pairwise fashion with respect to each of the elements in a higher stratum. This measurement methodology provides the framework for data collection and analysis and constitutes the heart of AHP. Structurally, the hierarchy is broken down into a series of pair comparison matrices, and the participants are asked to evaluate the off-diagonal relationship in one half of each matrix. The 9-point scale used in typical analytic hierarchy studies is ranging from 1 (indifference or equal importance) to 9 (extreme preference or absolute importance; Table 1). This pairwise comparison enables the decision maker to evaluate the contribution of each factor to the objective independently, thereby simplifying the decision making process (Rezaei-Moghaddam and Karami 2008).

In AHP, each pair of factors in a particular factor group is examined at a time, in terms of their relative importance. A pairwise comparison matrix is formed in which $a_{ii} = 1$ and $a_{ij} = 1/a_i$. The weight coefficients of the ranking criteria and the decision subcriteria are calculated using the right eigenvector, which is calculated from the maximum absolute eigenvalue (λ_{max}, 1,2). The grading values of all the criteria are normalized to 1.

$$\lambda_{max}=\frac{1}{n}\sum_{wi}^{n}\frac{(AW)\,i}{wi} \tag{1}$$

$$AW = \begin{pmatrix} a11 & a12 & \ldots\ldots & a1n \\ a21 & a22 & \ldots\ldots & a2n \\ \ldots & \ldots & \ldots\ldots & \ldots \\ \ldots & \ldots & \ldots\ldots & \ldots \\ an1 & an2 & \ldots\ldots & ann \end{pmatrix} \times \begin{pmatrix} w1 \\ w2 \\ \ldots \\ \ldots \\ wj \end{pmatrix}, \tag{2}$$

where $\boldsymbol{W}$ is the corresponding eigenvector of λ_{max} and wi $(i = 1, 2, \ldots, n)$ is the weight value for ranking. In this research, $\lambda_{max} = 10.236$.

Table 1 The comparison scale in AHP (Saaty 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored, and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between adjacent judgments the two	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

Table 2 Comparison matrix and significance weight of the site selection subcriteria

	A	B	C	D	E	F	G	H	I	J	Weights
A	1	1	0.500	0.500	0.333	0.250	0.250	0.200	0.143	0.125	0.02406
B	1	1	0.500	0.500	0.333	0.250	0.200	0.167	0.167	0.143	0.02412
C	2	2	1	0.500	0.333	0.250	0.250	0.200	0.167	0.167	0.03266
D	2	2	2	1	0.500	0.333	0.250	0.250	0.200	0.200	0.04161
E	3	3	3	2	1	0.500	0.333	0.333	0.250	0.250	0.06238
F	4	4	4	3	2	1	1	0.500	0.333	0.333	0.09643
G	4	5	4	4	3	1	1	0.500	0.333	0.333	0.14876
H	5	6	5	4	3	2	2	1	0.500	0.500	0.14876
I	7	6	6	5	4	3	3	2	1	0.500	0.20723
J	8	7	6	5	4	4	3	2	2	1	0.25430

$\lambda_{max} = 10.236$, CI = 0.02623, $RI_{10} = 1.49$, and CR = $0.03908 \leq 0.1$
The letters at the decision criteria are *A* aspect, *B* roads, *C* elevation, *D* slope, *E* land use, *F* lineaments, *G* lithology, *H* groundwater level, *I* aquifer type, and *J* surface water

The consistency of the judgment matrix should be tested with calculation of the consistency index (CI) which is defined as

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1}, \qquad (3)$$

where CI is the consistency index, λ_{max} is the largest or principal eigenvalue of the matrix and could be easily calculated from the matrix, and n is the order of the matrix (Ying et al. 2007). In this research, CI = 0.02623. The consistency ratio (CR) coefficients are calculated according to the methodology proposed by Saaty (1980). The CR coefficients should be less than 0.1, indicating the overall consistency of the pairwise comparison matrix (Kontos et al. 2003; Ying et al. 2007). In this research, CR = $0.03908 \leq 0.1$.

CR is defined as

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}, \qquad (4)$$

where RI is the average of the resulting consistency index depending on the matrix (Xu 2002; Ying et al. 2007). In this research, $RI_{10} = 1.49$ because of using ten criteria.

The pairwise comparison matrices are prepared for ten criteria (Table 2) and for each criterion (Tables 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12). After the pairwise comparison matrix is prepared, the composite weights are derived via a sequence of multiplication (Table 13). Then, the geoformula is used to generate the overall score of the alternatives in the GIS environment, and the landfill suitability index (LSI) was calculated by means

Table 3 Comparison matrix and significance weight of the lithologic units

	A	B	C	D	E	F	G	H	I	J	Weights
A	1	1	0.500	0.333	0.333	0.333	0.333	0.200	0.167	0.143	0.02617
B	1	1	0.500	0.333	0.333	0.333	0.333	0.200	0.167	0.143	0.02617
C	2	2	1	0.500	0.333	0.333	0.333	0.333	0.200	0.200	0.03850
D	3	3	2	1	0.500	0.333	0.333	0.333	0.333	0.333	0.05759
E	3	3	3	2	1	0.500	0.333	0.333	0.333	0.333	0.07025
F	4	4	3	3	2	1	0.500	0.333	0.333	0.333	0.08734
G	3	3	4	3	3	2	1	0.500	0.333	0.333	0.10594
H	5	5	3	4	3	3	2	1	0.500	0.333	0.14306
I	6	6	5	3	4	3	3	2	1	0.500	0.19133
J	7	7	6	5	3	4	3	3	2	1	0.25484

The letters at the decision criteria are *A* alluvium, *B* slope deposits, *C* conglomerate, *D* Kapidag limestone, *E* Yassıviran limestone, *F* Suuçandere limestone, *G* Sariyardere dolomite, *H* Zendevi pyroclastics, *I* Uluborlu flysch, and *J* terrestrial sediments

Table 4 Comparison matrix and significance weight of the distance from the lineaments

	A	C	C	D	E	Weights
A	1	0.500	0.250	0.200	0.167	0.05144
B	2	1	0.500	0.250	0.200	0.08268
C	4	2	1	0.500	0.250	0.15119
D	5	4	2	1	0.500	0.26905
E	6	5	4	2	1	0.44565

The letters at the decision criteria are *A* 0–50 m, *B* 50–100 m, *C* 100–150 m, *D* 150–200 m, and *E* > 200 m

Table 5 Comparison matrix and significance weight of distance from the surface water

	A	C	C	D	E	Weights
A	1	0.500	0.333	0.250	0.167	0.05884
B	2	1	0.500	0.333	0.250	0.09723
C	3	2	1	0.500	0.333	0.15898
D	4	3	2	1	0.500	0.25910
E	6	4	3	2	1	0.42584

The letters at the decision criteria are *A* 0–250 m, *B* 250–500 m, *C* 500–750 m, *D* 750–1,000 m, and *E* > 1,000 m

Table 6 Comparison matrix and significance weight of the aquifer type

	A	B	C	D	E	Weights
A	1	0.333	0.250	0.200	0.167	0.04681
B	3	1	0.333	0.250	0.200	0.08531
C	4	3	1	0.333	0.250	0.14998
D	5	4	3	1	0.333	0.25853
E	6	5	4	3	1	0.45936

The letters at the decision criteria are *A* porous permeable unit, *B* karstic permeable unit, *C* complex permeable unit, *D* semipermeable unit, *E* impermeable unit

Table 7 Comparison matrix and significance weight of groundwater depth

	A	B	C	D	E	Weights
A	1	0.500	0.250	0.167	0.143	0.04624
B	2	1	0.500	0.250	0.167	0.07667
C	4	2	1	0.500	0.250	0.14525
D	6	4	2	1	0.500	0.27049
E	7	6	4	2	1	0.46135

The letters at the decision criteria are *A* 0–10 m, *B* 10–20 m, *C* 20–30 m, *D* 30–40 m, and *E* > 40 m

Table 8 Comparison matrix and significance weight of elevation

	A	B	C	D	E	Weights
A	1	0.500	0.333	0.250	0.200	0.06283
B	2	1	0.500	0.333	0.250	0.09857
C	3	2	1	0.500	0.333	0.16105
D	4	3	2	1	0.500	0.26179
E	5	4	3	2	1	0.41621

The letters at the decision criteria are *A* > 2,300 m, *B* 1,950–2,300 m, *C* 1,600–1,950 m, *D* 1,250–1,600 m, and *E* 900–1,250 m

of multiplication of each criteria weight with each subcriteria weight.

LSI is defined as

$$\begin{aligned} \mathrm{LSI} = {} & (\mathrm{Ac_{wi}} \times \mathrm{Asc_{wi}}) + (\mathrm{Rc_{wi}} \times \mathrm{Rsc_{wi}}) \\ & + (\mathrm{Ec_{wi}} \times \mathrm{Esc_{wi}}) + (\mathrm{Sc_{wi}} \times \mathrm{Ssc_{wi}}) \\ & + (\mathrm{LANc_{wi}} \times \mathrm{LANsc_{wi}}) + (\mathrm{LINc_{wi}} \times \mathrm{LINsc_{wi}}) \\ & + (\mathrm{LITc_{wi}} \times \mathrm{LITsc_{wi}}) + (\mathrm{GDc_{wi}} \times \mathrm{GDsc_{wi}}) \\ & + (\mathrm{ATc_{wi}} \times \mathrm{ATsc_{wi}}) + (\mathrm{SWc_{wi}} \times \mathrm{SWsc_{wi}}) \end{aligned} \tag{5}$$

where

LSI	Landfill suitability index
$\mathrm{Ac_{wi}}$	Weight index of the aspect criteria
$\mathrm{Asc_{wi}}$	Weight index of the aspect subcriteria
$\mathrm{Rc_{wi}}$	Weight index of the roads criteria
$\mathrm{Rsc_{wi}}$	Weight index of the roads subcriteria
$\mathrm{Ec_{wi}}$	Weight index of the elevation criteria
$\mathrm{Esc_{wi}}$	Weight index of the elevation subcriteria
$\mathrm{Sc_{wi}}$	Weight index of the slope criteria
$\mathrm{Ssc_{wi}}$	Weight index of the slope subcriteria
$\mathrm{LANc_{wi}}$	Weight index of the land use criteria

Table 9 Comparison matrix and significance weight of slope

	A	B	C	D	E	Weights
A	1	0.500	0.333	0.250	0.200	0.06283
B	2	1	0.500	0.333	0.250	0.09857
C	3	2	1	0.500	0.333	0.16105
D	4	3	2	1	0.500	0.26179
E	5	4	3	2	1	0.41621

The letters at the decision criteria are *A* > 40°, *B* 40–30°, *C* 30–20°, *D* 20–10°, and *E* 0–10°

Table 10 Comparison matrix and significance weight of aspect

	A	B	C	D	E	F	G	H	Weights
A	1	1	0.500	0.500	0.500	0.333	0.250	0.200	0.04725
B	1	1	0.500	0.500	0.500	0.333	0.250	0.200	0.04725
C	2	2	1	0.500	0.500	0.500	0.333	0.250	0.07040
D	2	2	2	1	0.500	0.500	0.500	0.333	0.09139
E	2	2	2	2	1	0.500	0.500	0.333	0.10851
F	3	3	2	2	2	1	0.500	0.333	0.14116
G	4	4	3	2	2	2	1	0.500	0.19563
H	5	5	4	3	3	3	2	1	0.29842

The letters at the decision criteria are *A* east, *B* southeast, *C* south, *D* southwest, *E* northeast, *F* north, *G* west, and *H* northwest

$LANsc_{wi}$ Weight index of the land use subcriteria
$LINc_{wi}$ Weight index of the lineament criteria
$LINsc_{wi}$ Weight index of the lineament subcriteria
$LITc_{wi}$ Weight index of the lithology criteria
$LITsc_{wi}$ Weight index of the lithology subcriteria
GDc_{wi} Weight index of the groundwater depth criteria
$GDsc_{wi}$ Weight index of the groundwater depth subcriteria
ATc_{wi} Weight index of the aquifer type criteria
$ATsc_{wi}$ Weight index of the aquifer type subcriteria
SWc_{wi} Weight index of the surface water criteria
$SWsc_{wi}$ Weight index of the surface water subcriteria

The suitability map was created using the ten criteria layers in the GIS environment, and the LSI has been computed, which varies from 30 to 255. Then, landfill suitability classes of the basin were reclassified into three class schemes, i.e., unsuitable (181–255), moderately suitable (106–180), and most suitable areas (30–105). Reclassification was performed using the quantile classification method, which distributes a set of values into groups that contain an equal number of values and produces distinct map patterns. This method is the most suitable method for classification studies.

Table 11 Comparison matrix and significance weight of distance from roads

	A	B	C	D	E	Weights
A	1	0.333	0.250	0.250	0.200	0.05301
B	3	1	0.333	0.250	0.250	0.09421
C	4	3	1	0.333	0.250	0.15739
D	4	4	3	1	0.333	0.25599
E	5	4	4	3	1	0.43939

The letters at the decision criteria are $A > 400$ m, *B* 300–400 m, *C* 200–300 m, *D* 100–200 m, and *E* 0–100 m

Evaluation criteria

In this study, the evaluation criteria was determined and classified into four main categories according to how they are considered to affect the landfill site suitability. These are (1) geological and tectonic, (2) hydrological and hydrogeological, (3) morphologic, and (4) social criteria. The first category includes the constraining criteria that limits the analyses to particular geographic areas. The second category includes factors relevant to environmental parameters, whereas the third and forth categories comprise factors relevant to the design and the construction of the landfill and the social case of the region, respectively. In the four main categories, ten criteria such as lithology, lineament, surface water, aquifer, groundwater depth, aspect, elevation, slope, distance to roads, and land use,

Table 12 Comparison matrix and significance weight of land use

	A	B	C	Weights
A	1	0.500	0.333	0.16378
B	2	1	0.500	0.29726
C	3	2	1	0.53896

The letters at the decision criteria are *A* agricultural areas, *B* forest, and *C* uncultivated areas

Table 13 Total weights of the subcriteria

Criteria (C)	Subcriteria (SC)	Weight (Cwi)	Subweight (SCwi)	Total weight (Twi)
Aspect	E	0.02406	0.04725	0.001137
	SE		0.04725	0.001137
	S		0.07040	0.001694
	SW		0.09139	0.002199
	NE		0.10851	0.002611
	N		0.14116	0.003396
	W		0.19563	0.004707
	NW		0.29842	0.007180
Distance from road (m)	> 400	0.02412	0.05301	0.001279
	300–400		0.09421	0.002272
	200–300		0.15739	0.003796
	100–200		0.25599	0.006174
	0–100		0.43939	0.010598
Elevation (m)	> 2,300	0.03266	0.06283	0.002052
	1,950–2,300		0.09857	0.003219
	1,600–1,950		0.16105	0.005260
	1,250–1,600		0.26179	0.008550
	900–1,250		0.41621	0.013593
Slope (degree)	> 40	0.04161	0.06283	0.002614
	30–40		0.09857	0.004101
	20–30		0.16105	0.006701
	10–20		0.26179	0.010893
	0–10		0.41621	0.017318
Land use	Agricultural Areas	0.06238	0.16378	0.010217
	Forest		0.29726	0.018543
	Uncultivated Areas		0.53896	0.033620
Distance from lineaments (m)	0–50	0.09643	0.05144	0.004960
	50–100		0.08268	0.007973
	100–150		0.15119	0.014579
	150–200		0.26905	0.025944
	> 200		0.44565	0.042974
Lithology	Alluvium	0.14876	0.02617	0.003893
	Slope deposits		0.02617	0.003893
	Conglomerate		0.03850	0.005727
	Kapidag limestone		0.05759	0.008567
	Yassıviran limestone		0.07025	0.010450
	Suuçandere limestone		0.08734	0.012993
	Sariyardere dolomite		0.10594	0.015760
	Zendevi pyroclastics		0.14306	0.021282
	Uluborlu flysch		0.19133	0.028462
	Terrestrial sediments		0.25484	0.037910
Groundwater depth (m)	0–10	0.14876	0.04624	0.006879
	10–20		0.07667	0.011405
	20–30		0.14525	0.021607
	30–40		0.27049	0.040238
	> 40		0.46135	0.068630
Aquifer type	Porous permeable unit	0.20723	0.04681	0.009700
	Karstic permeable unit		0.08531	0.017679
	Complex permeable unit		0.14998	0.031080
	Semi permeable unit		0.25853	0.053575
	Impermeable unit		0.45936	0.095193

Table 13 (continued)

Criteria (C)	Subcriteria (SC)	Weight (Cwi)	Subweight (SCwi)	Total weight (Twi)
Distance from surface water (m)	0–250	0.25430	0.05884	0.014963
	250–500		0.09723	0.024726
	500–750		0.15898	0.040429
	750–1,000		0.25910	0.065889
	> 1,000		0.42584	0.108291

were selected for the computation process (Fig. 2). These are basic criteria using site selection of landfill and should be taken into account according to relevant international literature and Turkish law (Ministry of Environment and Forestry of Turkey 1991). Lithological properties

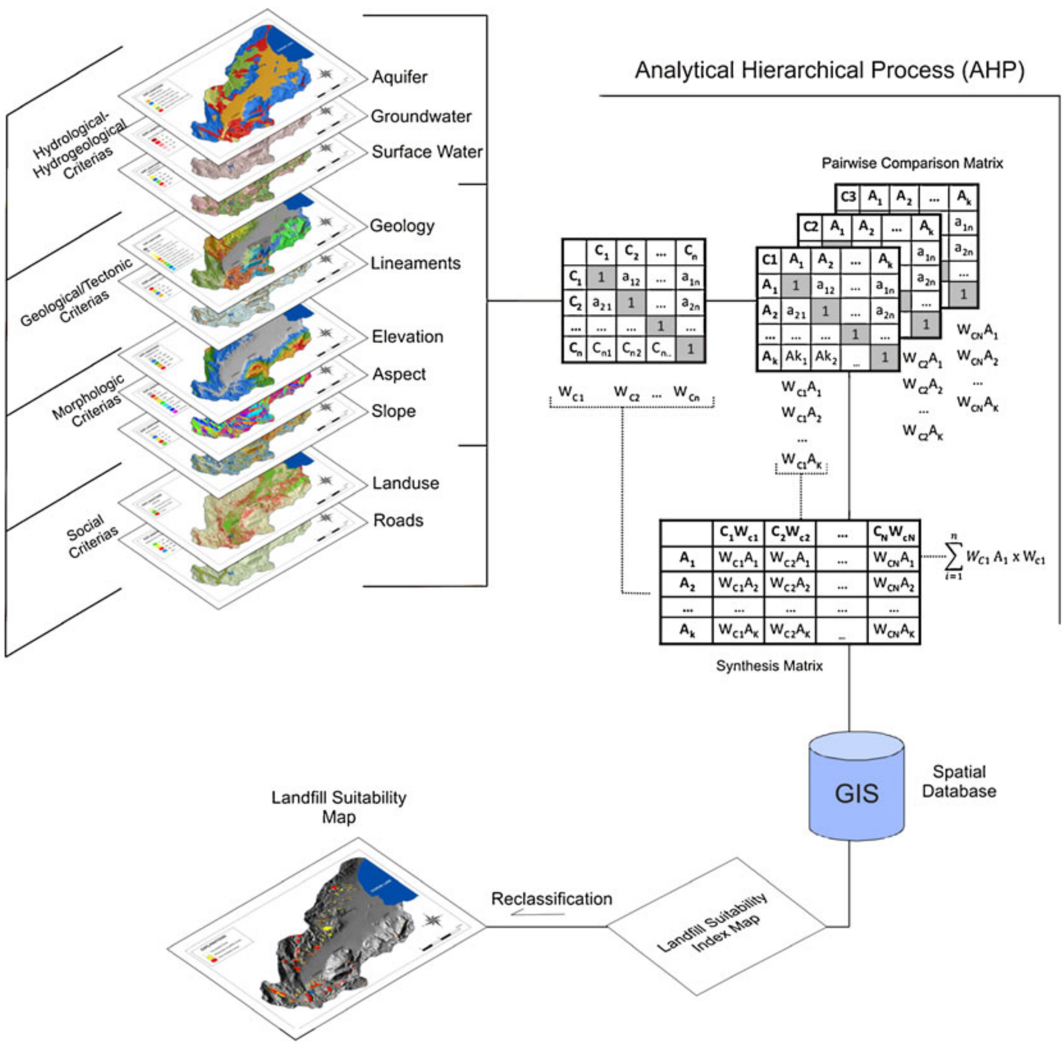

Fig. 2 Flow chart of the landfill site selection methodology

of geological units and aquifer types were examined as two different criteria. Especially petrographical properties of rocks and drilling data were taken into account in the lithology criterion, and weighting was performed depending on these data. Only the permeability properties of lithologic units were considered in the aquifer criteria. All the criteria were weighed using the AHP method and mapped by the GIS techniques. It is clear that the assignment of factor weights is based on previous knowledge of the factor characteristics and the particularities of the study area, as well as on the experience of the scientists involved in the weight assignment process. It was attempted, however, to develop the weight assigning process as objective as possible by applying techniques like the AHP (Gemitzi et al. 2006).

Geological and tectonic

Geological properties of a basin are quite complex with tectonic units. So, lithologic units and lineaments were examined and taken into consideration for site selection.

Lithology

A geology map of the basin was prepared to benefit from field studies and previous investigations (Tay 2005). Geological units have different ages and lithologies outcrop in the study area. The units are from bottom to top as follows: Mesozoic aged carbonate rocks, namely, Sariyardere dolomites, Yassiviran limestone, Suuçandere limestone, and Kapidag limestone;

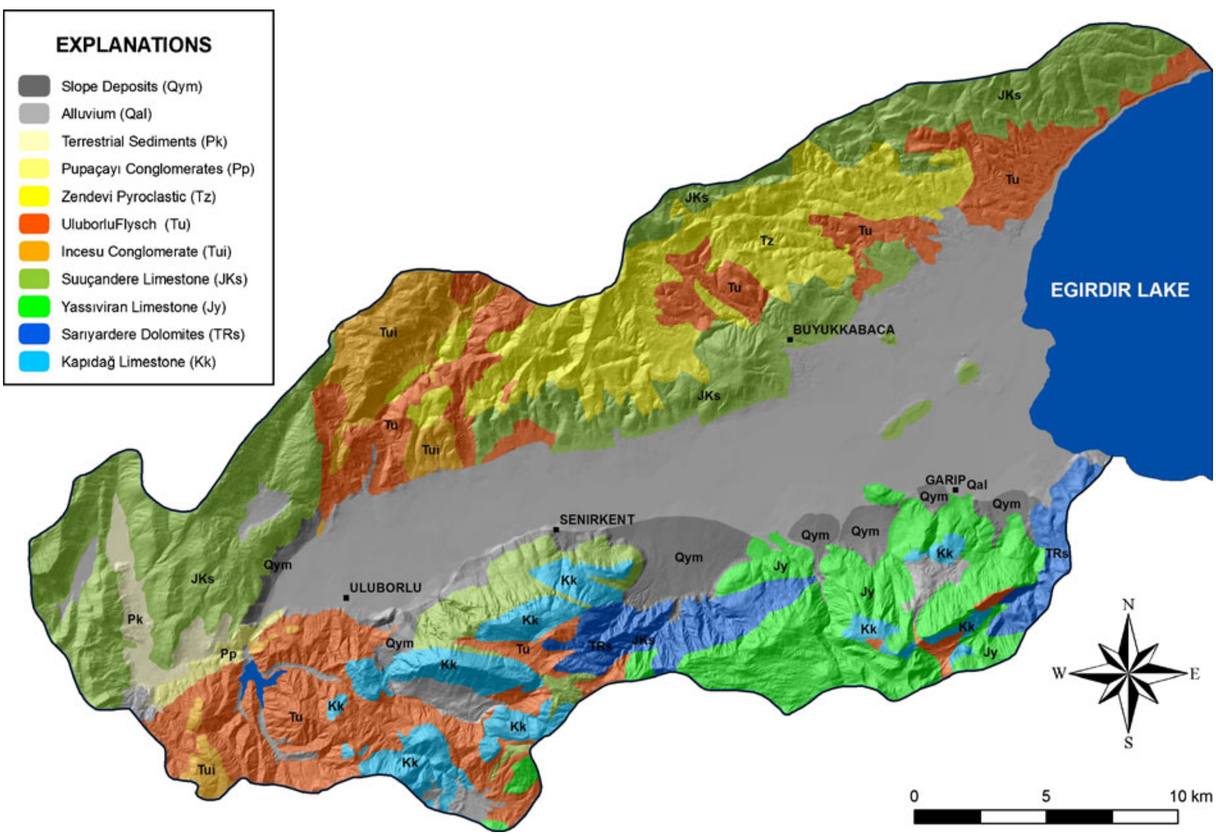

Fig. 3 Geology map of the basin (Tay 2005)

Cenozoic aged pyroclastics, namely, Zendevi pyroclastic; Paleocene–Eocene aged, namely, Uluborlu flysch and İncesu conglomerate; Pliocene aged Pupaçayi conglomerate and terrestrial sediments; and Quaternary aged alluvium and slope deposit. During the evaluation of the geologic units, the petrographical properties of the rocks and the drilling data were taken into consideration. The results indicate that limestones are massive without many karstic holes in the region. Alluvium and slope deposits are composed of materials such as silt, sand, and gravel and identified as the most unsuitable units. Terrestrial sediments consist of clay layers entirely. Therefore, according to the AHP calculations, the terrestrial sediments have the highest weight values and the alluvium and slope deposits have the lowest weight values (Table 3). Finally, the lithologic units are mapped, and the spatial results are represented in Fig. 3.

Lineaments

Lineament is one of the most important criterion for site selection. As contaminants can be strongly influenced by fracturing or by an interconnected series of solutions openings, these may provide pathways for easier flow (Lee 2003; Sener et al. 2005). Lineaments analyses of basin were made using Advance Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite images. All the lineaments are buffered by a distance varying from 0 to 200 m, and each buffer zone was weighted by AHP. Safe distance

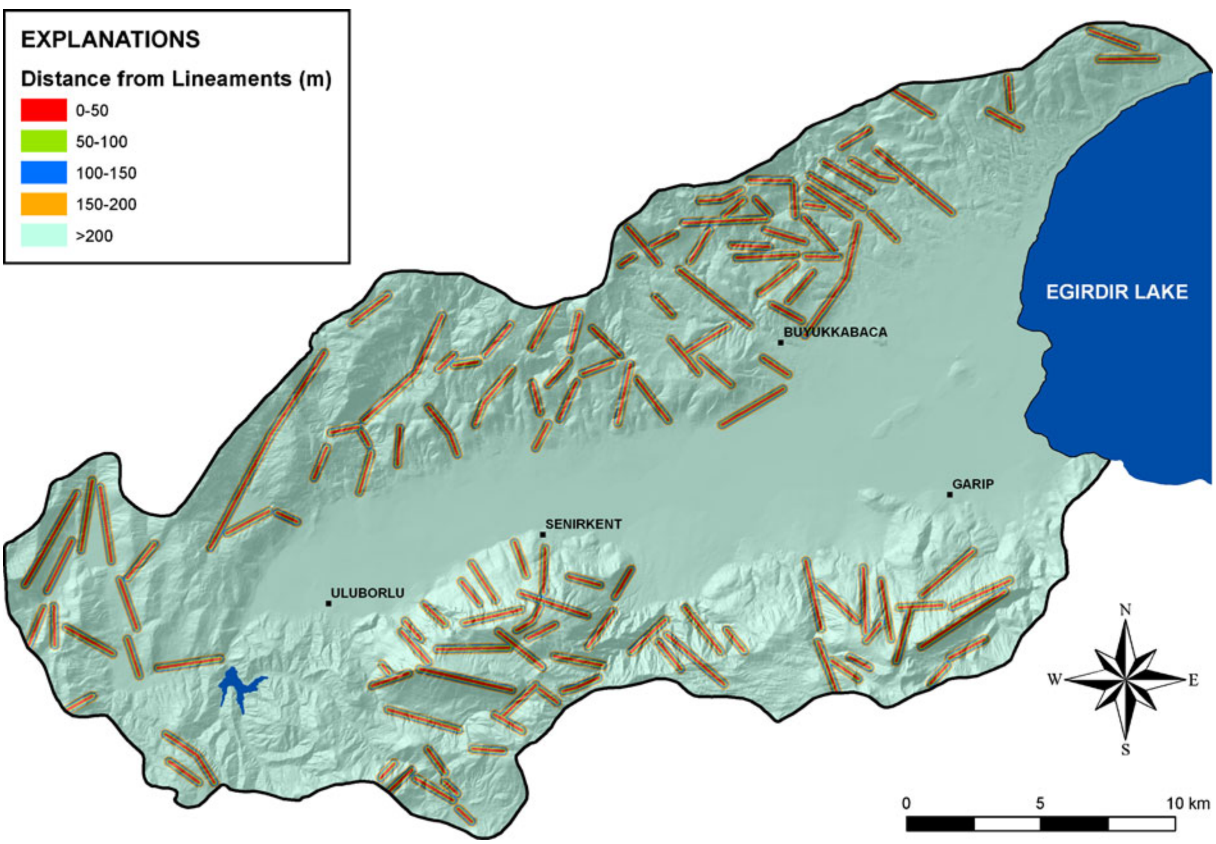

Fig. 4 Map of the distance from lineaments

information are compiled from related literature. According to the calculations, the areas that are 0–50 m away from the lineaments have the lowest weight values, but those > 200 m from the lineaments have the highest weight values (Table 4). The spatial results are shown in Fig. 4.

Hydrological and hydrogeological

The hydrological and hydrogeological properties of the basin such as surface waters, aquifer types, and groundwater depth were taken into account for the protection of the groundwater in the basin. Sanitary landfills cannot be located at the protection zones of the water catchment areas (Ministry of Environment and Forestry of Turkey 1991). Therefore, distance from the surface water, aquifer type, permeability, and depth of the groundwater were investigated in this study.

Surface waters

The study area is located in the Eğirdir Lake catchment area. The main aim of this research is the protection of the lake. The Eğirdir Lake is one of the most important fresh waters of Turkey, and its protection should be performed. According to the Turkish Waste Management Regulations, the waste disposal site should not be located in the protection zones of lakes (distance > 1,000 m) and springs. In addition, the selected site must not be adjacent to any streams or creeks. Information

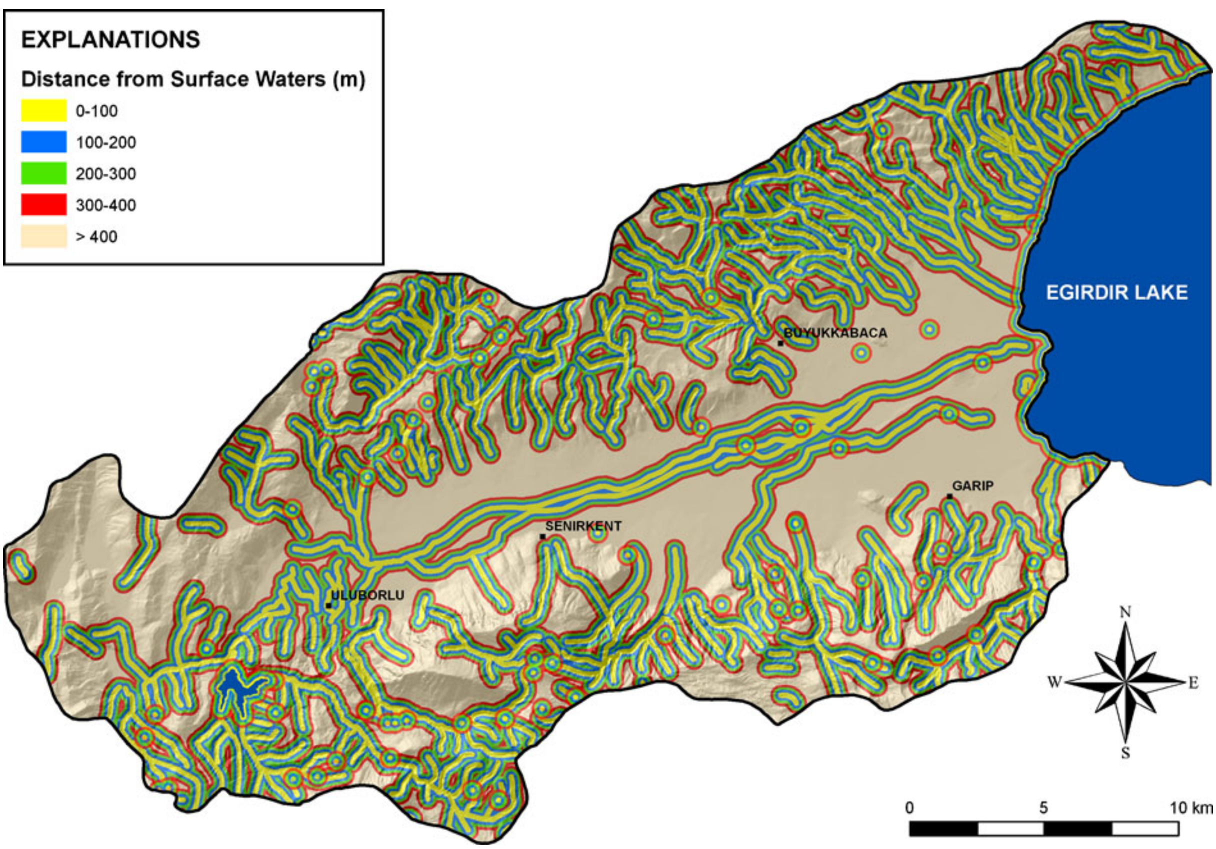

Fig. 5 Map of the distance from surface waters

compiled from literatures about safe distances from surface waters and buffer zones were formed from 1,000 m. All buffer zones were weighted by AHP (Table 5) and mapped by GIS. The spatial results of the surface waters are depicted in Fig. 5.

Aquifer

A landfill site should be located in an area having low groundwater pollution risk. Groundwater pollution depends on several factors such as aquifer properties and permeability of aquifer units. Hence, a hydrogeology map of the basin was prepared for evaluation of aquifer properties. According to the hydrogeology map of the basin, alluvium and slope deposits were classified as porous permeable unit, dolomite and limestone units were classified as karstic permeable unit, conglomerates were classified as complex permeable unit due to the karstic cement, pyroclastic units were classified as semipermeable unit, and flysch and clayey units were classified as impermeable unit. Each of them was weighted with the aid of AHP (Table 6). Clayey units have the highest weight value because of their impermeable properties, but alluvium units have the lowest weight value. The spatial results are shown in Fig. 6.

Groundwater depth

In this study, groundwater head measurements were made at 17 piezometers in October 2005 (Tay 2005). Then, the obtained data were recorded in a database by the ARCGIS software.

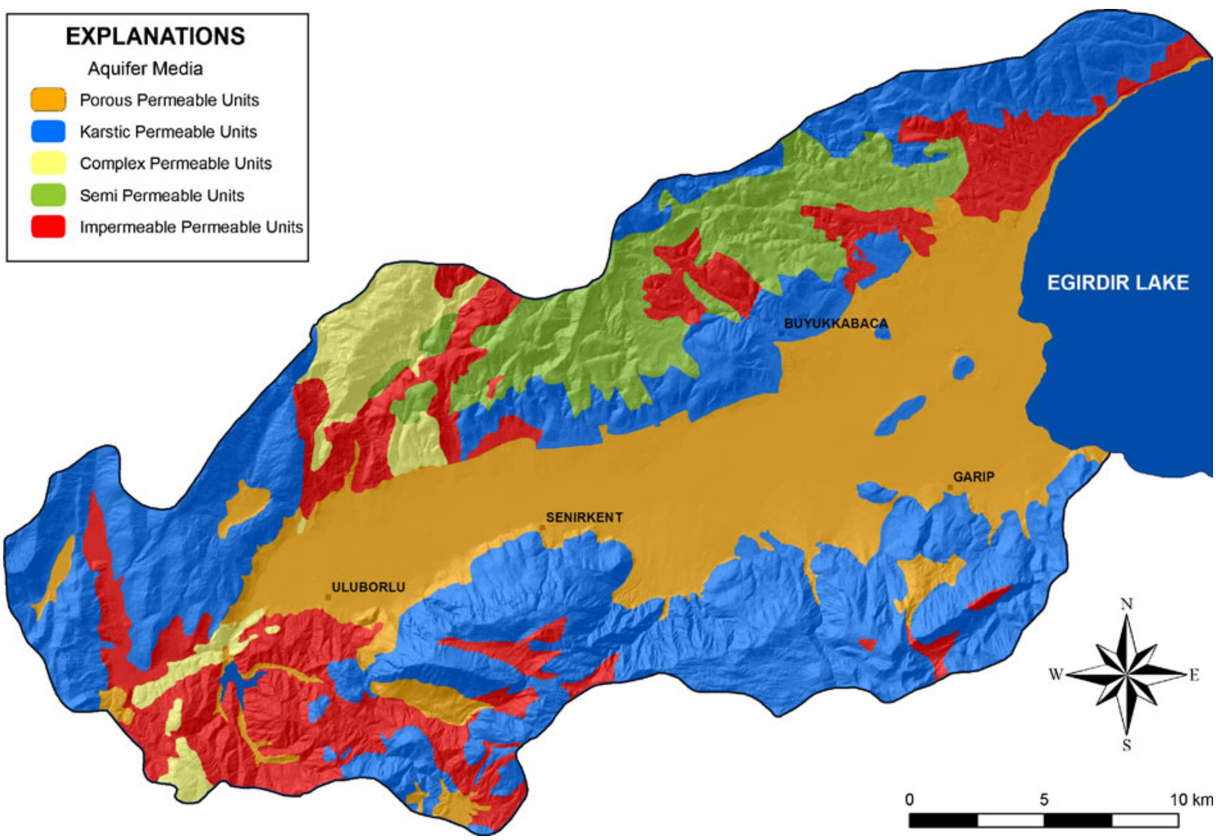

Fig. 6 Aquifer map of the basin (Sener et al. 2009)

A groundwater depth map was prepared using the inverse distance weighted interpolation method. The study area was discretized using a grid cell size of 10 × 10 m. Thus, field properties of the study area are indicated as most detailed, and more proper results can be obtained. Every grid weighted by AHP and is shown in Table 7. The area in which groundwater is deep has the highest weight value because of the lowest groundwater pollution risk. The spatial results of the groundwater depth of the basin are represented in Fig. 7.

Morphologic

The morphologic category comprises three criteria, namely, aspect, elevation, and slope. These criteria affect construction of landfill and must be taken into account in site selection.

First, 1:25,000 scale topographical maps with 10-m intervals were digitized. An elevation map was prepared with the Triangular Irregular Network (TIN) using digitized maps and the ArcGIS 3D Analyst. High regions such as hill and mount have the lowest weight values (Table 8). Slope and aspect maps were derived from the elevation map of the basin. Slope gradation was described in degrees, and slope grade was weighted using AHP (Table 9). Flat zones whose slopes are between 0°–10° were identified as most suitable areas for landfill siting.

A landfill site should not be exposed to wind because of odor effect. Therefore, the wind direction of the basin was taken into consideration in the research. The wind frequency percentages data obtained from the National Meteorological Agency of Turkey show that the east (E) and

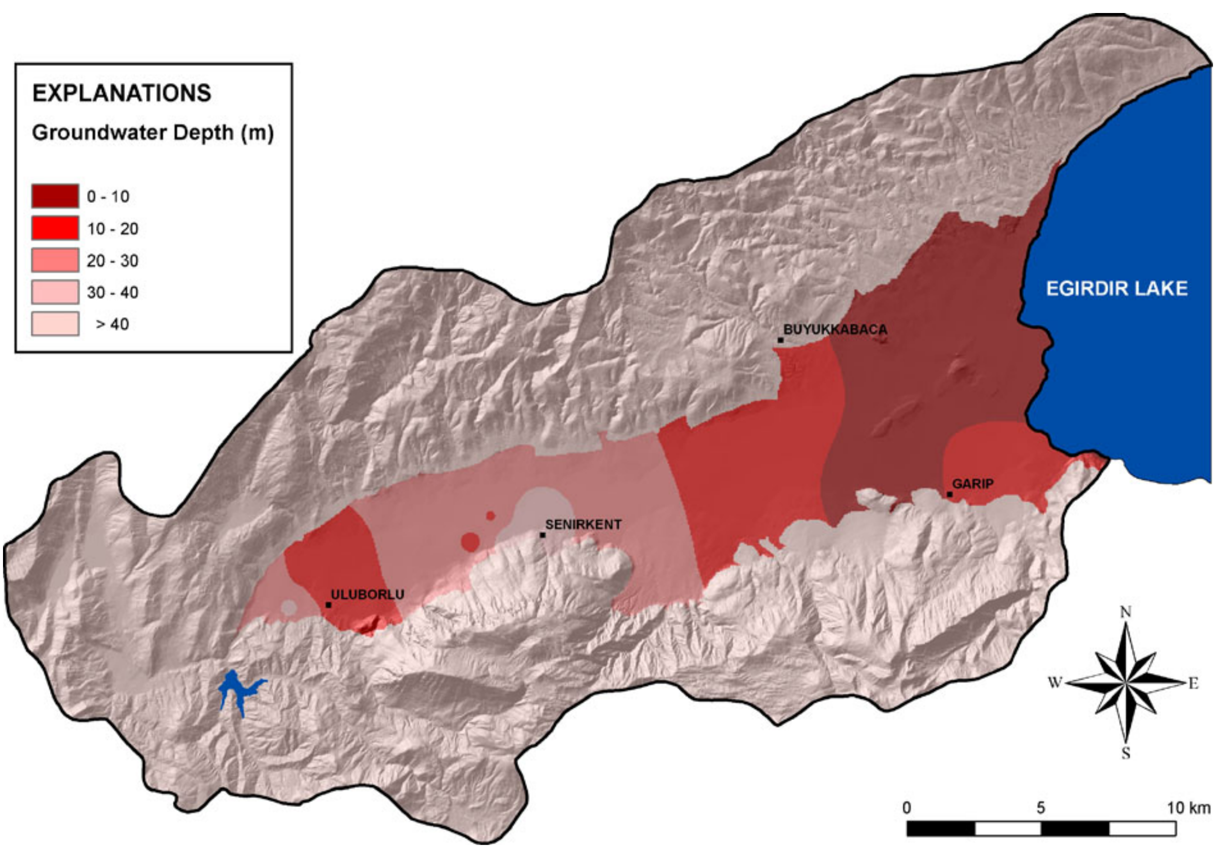

Fig. 7 Groundwater depth map of the basin (Sener et al. 2009)

southeast (SE) winds are the dominant winds in the basin. So, the areas under the common wind effect direction have the lowest weight values (Table 10). The criteria of elevation, slope, and aspect were mapped using the GIS techniques and represented in Figs. 8, 9a, and 10, respectively.

Social

The social category comprises two criteria in this research, namely, land use and distance to roads. Social criterion is not based on legal restrictions and can be varied according to the study area. In the Senirkent–Uluborlu Basin, land use and distance to roads must be considered for site selection of a sanitary landfill. Distance to road is important in the point of waste transportation, as the research is quite uneven and waste transportation can be a problem. The sanitary landfill should be located at a place where it can be reached by alternative roads under all weather conditions (Ministry of Environment and Forestry of Turkey 1991). The roads are buffered by a distance varying from 0 to 400 m according to the related literatures. The zones that are at a distance of 0–100 m from roads have the highest weight values. All the buffer zones were weighted by AHP (Table 11) and mapped using the GIS (Fig. 11).

Land use is important for the basin because agriculture is the widest mainstay in the basin. In the research area, cultivated land and rocky terrains are unsuitable for landfill. Uncultivated areas are classified as suitable for landfill in the basin. A land use map was prepared using ASTER satellite images. The Vegetation Index of the basin was derived by using Aster LIB images

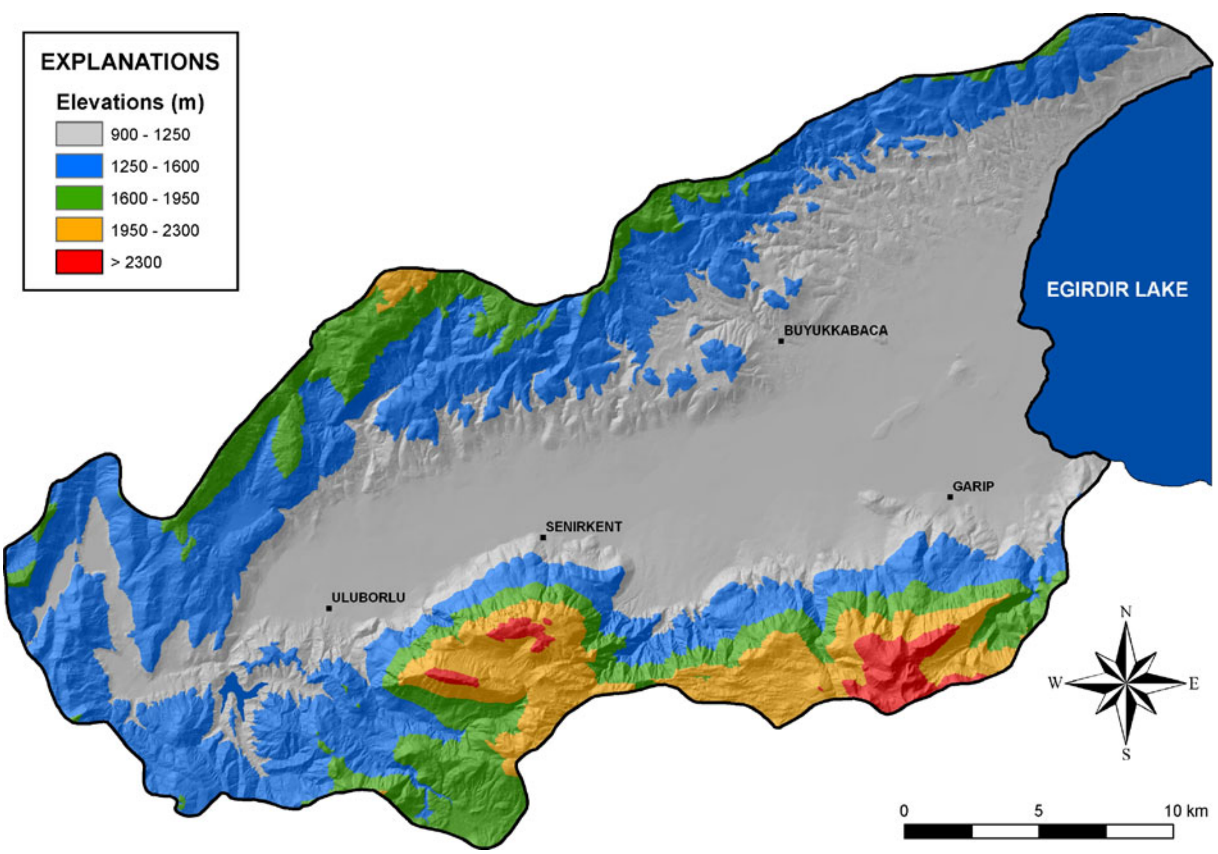

Fig. 8 Elevation map of the basin

with the Normalized Difference Vegetation Index (NDVI) band ratio (Eq. 6). Vegetation Index is related to the properties of vegetation and is extremely sensitive to the infrared band of an electromagnetic spectrum, absorb light in visible red band, and reflect backward.

NDVI is defined as

$$\mathrm{NDVI} = \frac{3\mathrm{N} - 2}{3\mathrm{N} + 2}, \qquad (6)$$

where

NDVI	Normalized Difference Vegetation Index
3N	Aster 3N (Nadir) band
2	Aster second band

Obtained images were then reclassified by supervised classification, and uncultivated agricultural and forest areas were therefore determined in the basin. Each area was defined and weighted by AHP (Table 12). The representation of land use can be seen in Fig. 12.

Analysis of landfill suitability in the basin

As mentioned, comparison matrices were developed for ten criteria and the corresponding subcriteria. Then, weights of the criteria and the subcriteria are appointed via a sequence of multiplication. The calculated weight of the subcriteria is represented in Table 13. According to Table 13, the subcriteria of the distance

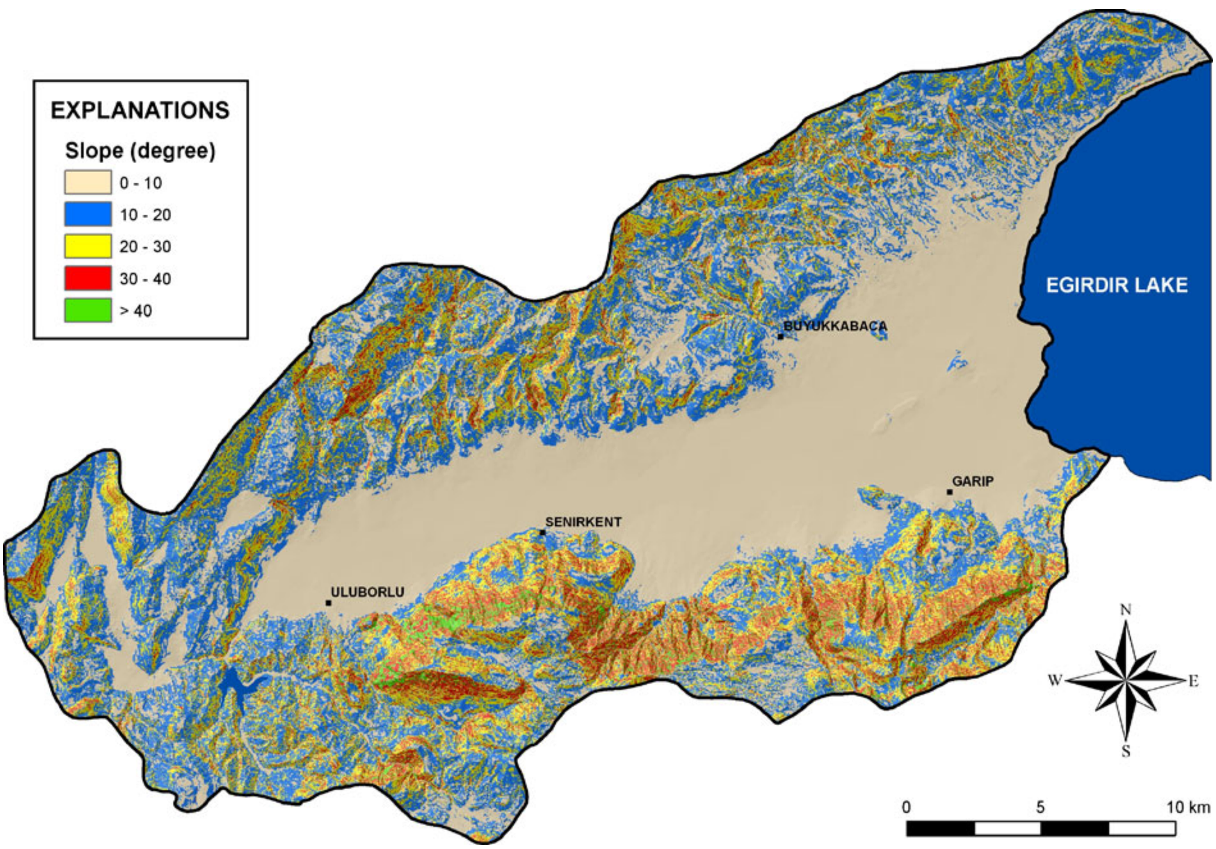

Fig. 9 Slope map of the basin

from the surface water (> 1,000) has the highest value of 0.108291, and the subcriteria of aspect (E, SE) has the lowest value of 0.001137. These results show that "distance from the surface water" is the most important criteria with the fact that the Eğirdir Lake is a legally protected area. Therefore, the Eğirdir Lake and other surface waters should be sheltered in the Senirkent–Uluborlu Basin. However, "aspect" is the least important criteria for a basin because other criteria are more significant than aspect.

All the layer maps were prepared with the aid of GIS. After all the maps were prepared, a resultant map was derived using overlay analysis of the ArcGIS Spatial Analyst (Fig. 13). According to the landfill suitability map, the areas grouped as unsuitable areas is 96.3%, moderately suitable areas is 1.6%, and most suitable areas is 2.1% of the basin. In order to check the suitability of the determined areas, field checks must be performed. Therefore, detailed field checks were performed to confirm the results. The field studies showed that determined areas have impermeable properties and are located on the terrestrial sediments and Uluborlu flysch. The distance from the surface water of the suitable areas is > 1,000 m, the groundwater level is fairly deep, and the distance from lineaments and the slope degrees of the determined areas have required properties. Uncultivated areas were selected for landfill related to land use. Additionally, aspect, elevation, and distance to roads of determined areas are quite suitable for landfill. At the end of the field study,

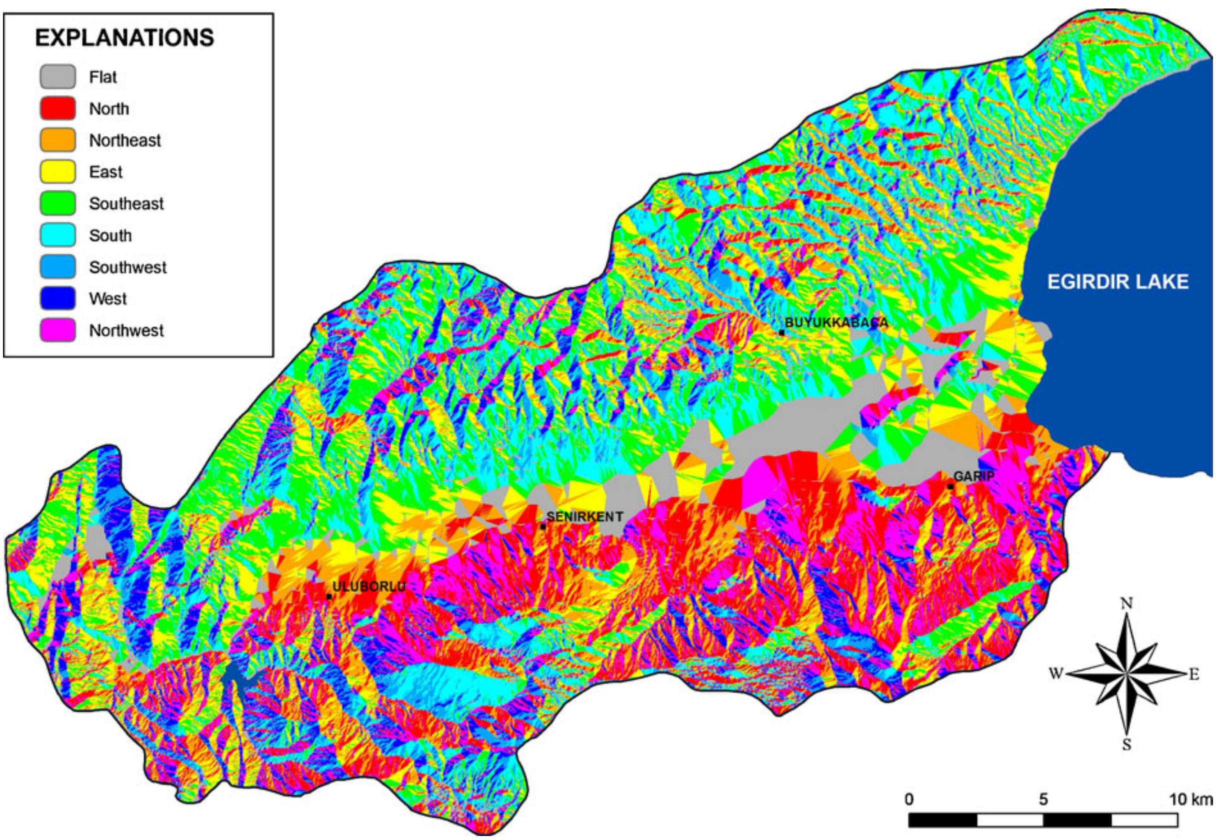

Fig. 10 Aspect map of the basin

desired results are obtained, and it can be concluded that when the results are compared with the field study, the focused points have suitable properties for landfill.

Discussion and conclusions

Site selection of waste disposal and waste management for developing countries always pose major problems. In Turkey, 67% of the generated municipal solid waste has been dumped at open dumps, and there has not been any systematic solid waste management strategy in place at the national level (Nas et al. 2008). Establishment of a national strategy is very important both for the protection of natural resources and the prevention of environmental pollution (Banar et al. 2007). Solid waste disposal site selection should be performed for every city in Turkey, but it is very difficult and expensive. Therefore, GIS and remote sensing techniques are becoming powerful tools for this kind of preliminary studies due to its ability to manage large volume of spatial data from a variety of sources. Additionally, the AHP method is used to deal with the difficulties that decision makers encounter in handling large amounts of complex. The integration of GIS and AHP is a powerful tool to solve landfill site selection problem (Sener et al. 2006). However, besides offering all the advantages of the abovementioned techniques, an important contribution has been achieved through the application of the order weights, on a pixel-by-pixel basis, which offers the full control over the level of risk and trade-off desired (Gemitzi et al. 2006). This kind

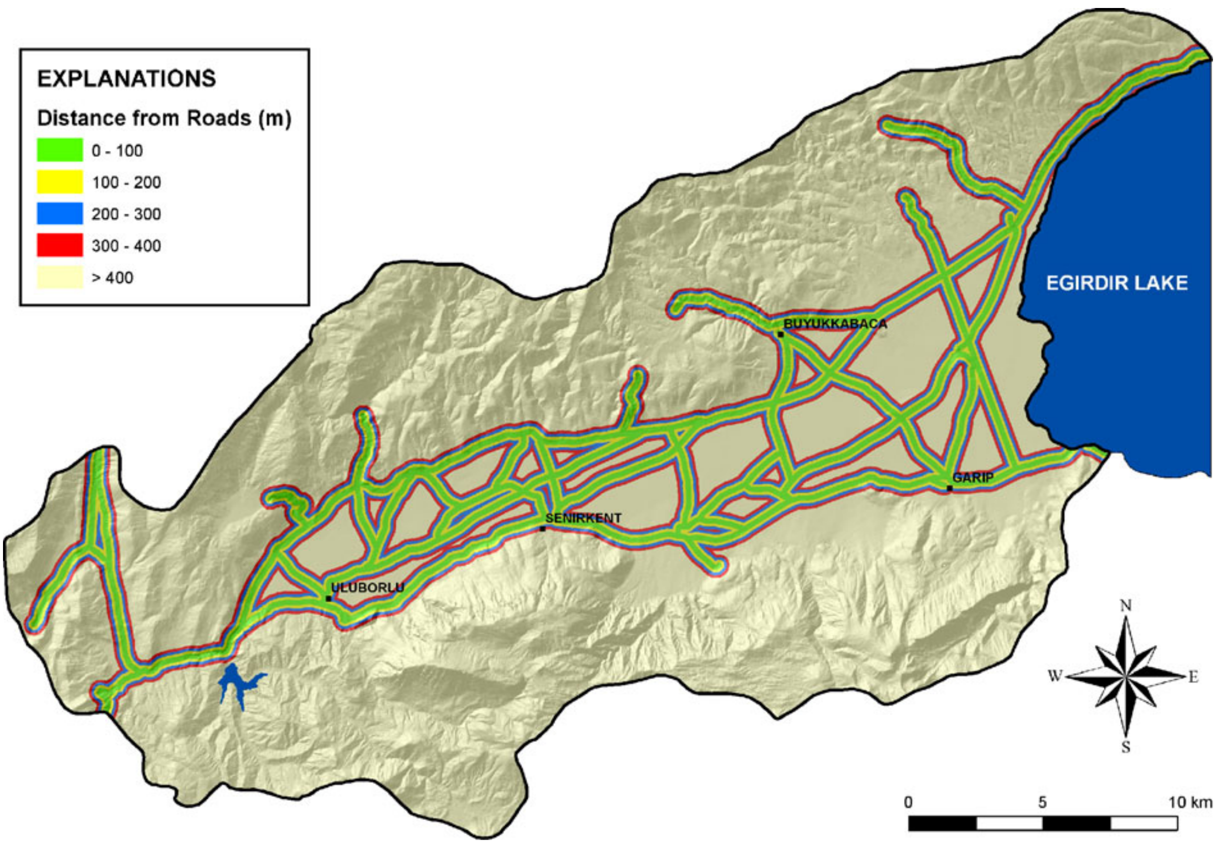

Fig. 11 Map of the distance from roads

of GIS and AHP integrations allow the decision maker to perform decision analysis functions such as ranking the alternatives to select the best option, specifically the best landfill site (Banar et al. 2007).

In the present study, a methodology for assessing location suitability for municipal solid waste landfill was developed using the GIS and remote sensing techniques with the AHP methods. Based on the results of this study, the most suitable locations were determined for solid waste landfill in the Senirkent–Uluborlu Basin. For this aim, ten criteria such as lithology, lineament, surface water, aquifer, groundwater depth, aspect, elevation, slope, distance to roads, and land use were determined depending on region properties. The evaluation criteria were determined according to the Turkish Waste Management Regulations. The criteria were then weighted using AHP, which offers an objective assignment process, and were mapped using the GIS and remote sensing techniques. GIS was used to prepare spatial statistics and clustering processes in order to reveal the most suitable areas for siting landfill. Used GIS techniques are buffer zoning, interpolation, and overlay analysis. The criteria map were prepared by using a 1:25,000 scale map. Additionally, lineaments and land use map of the basin were prepared using ASTER satellite images and the remote sensing techniques.

At the end of the analyses, a suitability map was created using the ten criteria layers in the GIS environment and the LSI has been computed, which varies from 30 to 255. Then, the landfill

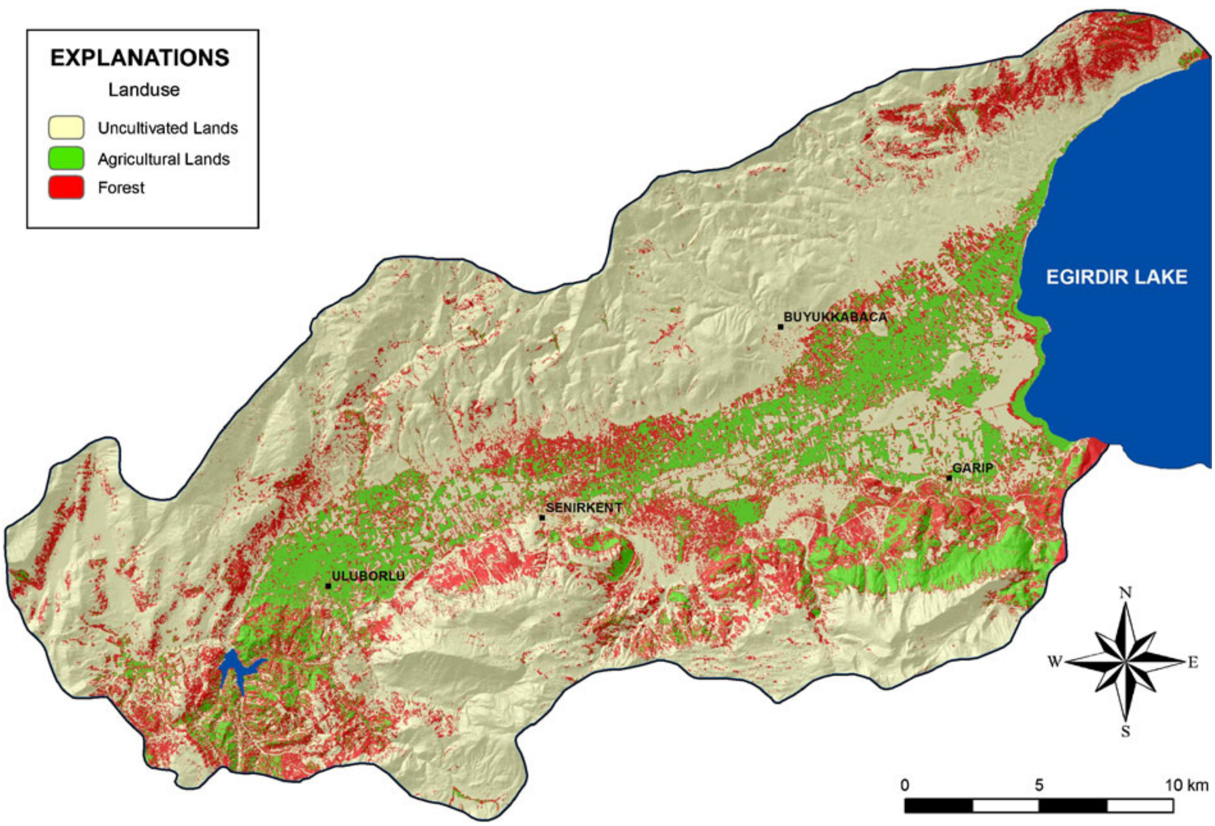

Fig. 12 Land use map of the basin

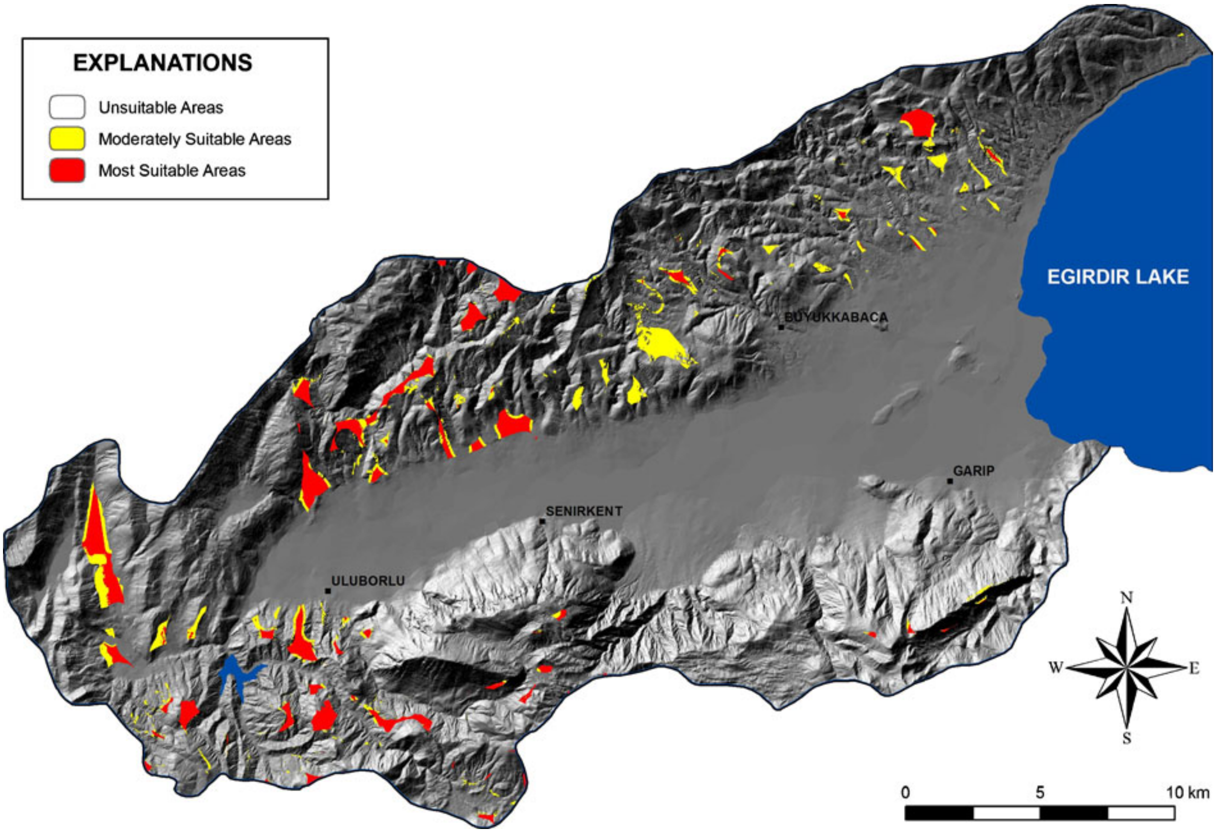

Fig. 13 Landfill suitability map of the basin

suitability classes of the basin were reclassified into three class schemes, i.e., unsuitable (181–255), moderately suitable (106–180), and most suitable areas (30–105). Additionally, unsuitable, moderately suitable, and most suitable areas in the basin were determined as 96.3%, 1.6%, and 2.1%, respectively. The analyses show that "distance from surface water" was designated as the most important criteria in this study due to the Eğirdir Lake. Therefore, the Eğirdir Lake and other surface waters should be sheltered in the Senirkent–Uluborlu Basin. However, "aspect" is the least important criteria for the basin. The sites determined as suitable for landfill were confirmed with field checks. Suitable areas generally comply with important properties for landfill. However, a detailed feasibility study should be carried out on the selected area and minimize all pollution risks with a view of environment protection.

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