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ORIGINAL ARTICLE

Landfill site selection using combination of fuzzy logic and multi-attribute decision-making approach

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Abstract During the last decades, growth of urbanization and industrialization led to an increase in solid waste generation. Landfilling is the most prevalent ultimate disposal method for the municipal solid wastes in developing countries. The rapid municipal solid waste generation in Markazi province (central part of Iran) causes the need for precision in finding a suitable landfill site selection. In the present study, 12 factors (environmental and socioeconomic factors) have been applied to select the landfill site in Markazi province, Iran. The different methods including the analytic network process (ANP) combined with fuzzy linguistic quantifier, ordered weighted average (OWA), and weighted linear combination (WLC) approach in geographic information system was applied to find an appropriate landfill site. The OWA operator function permits the evaluation of the wide spectrum of consequences (with different scenario) obtained from different management strategies. Results revealed that integration of fuzzy logic, ANP, and OWA provides flexible and better ideas compared to the Boolean logic and WLC to select a suitable landfill site.

Keywords Landfill site selection · Ordered-Weighted Average · Analytic Network Process · Geographic information systems · Multi-attribute decision-making

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Introduction

Millions of tons of solid waste are produced annually in the world. Thus, the correct management and disposal of generated solid waste is considered as a crucial issue (Beskese et al. 2015; Motlagh and Sayadi 2015). Thus, an integrated municipal solid waste (MSW) management plan, including all stages from waste generation to ultimate disposal, is considered an important environmental issue. Landfilling is a viable and common ultimate disposal method for MSW in many developing countries. However, landfilling may have adverse effects on the surrounding environment such as infiltration of leachate to surface and ground waters, releasing toxic gases (CH_4, CO_2, aromatics, and chlorocarbons). Many researchers believe that the proper site selection for a landfill may reduce its negative environmental impacts (Beskese et al. 2015; Isalou et al. 2013; Motlagh and Sayadi 2015; Shahabi et al. 2014). All the environmental effects of a landfill should be taken into account during the siting process. In other words, different environmental criteria and socioeconomic aspects should be considered to select an optimal option to achieve the least possible adverse effects (Arkoc 2014; Motlagh and Sayadi 2015; Kharat et al. 2016).

Geographical Information Systems (GIS) is useful and computer-based tools for the spatial operations like entry, storage, manipulation, analysis, and display of geographical data. As GIS can manage a large amount of spatial data, it can serve as an ideal tool in the siting studies (Isalou et al. 2013; Shahabi et al. 2014). The analytic hierarchy process (AHP) considered as one of the most prevalent decision-making techniques was introduced by Saaty (1996). The AHP process makes possible combination of quantitative and qualitative metrics simultaneously. It considers different indexes, criteria, and multiple standards with priority multi-level structures to rank or determine the importance of various options of a complex decision-making process using a systemic network. Although the AHP is considered as a prevalent method in MADM, its application in some cases, such as non-class and feedback problems, is suspecting. The necessity of having a tiered structure is the possible priority of an existing level that may be independent of the lower level elements. Otherwise, the available decision-making system considers non-class and feedback and the application of AHP method will be suspecting (Saaty and Vargas 2006). Due to the wide range and variety of feedback decision systems, a method known as analytic network process (ANP) based on the super matrix approach is presented to modify AHP method. This method can be applied to solve complex feedback structure problems. Considering the interrelations between different levels of the decisions and their interconnection in one level are the main advantages of ANP (Khan and Faisal 2008).

The combination of MCDM and GIS technique was studied by many researchers to select a suitable landfill site. Alexakis and Sarris (2014) applied a combination of GIS, AHP, and remote sensing analyses for landfill site selection in Crete, Greece. Uyan (2014) used a combination of GIS and AHP for urban landfill site selection in Khonya, Turkey. Shahabi et al. (2014) used 13 information layers in the ARC GIS for landfill site selection in Saghez, Kurdistan Province (Iran), using combination of Boolean logic and fuzzy logic based on WLC via AHP. They also used IDRISI software to process the satellite images. Afzali et al. (2014) used a combination of Boolean logic, fuzzy logic, and ANP with GIS for landfill site selection in Khomeini shahr, Isfahan, Iran. Abd-El Monsef (2015) used GIS, AHP, and remote sensing techniques for urban landfill site selection in Egypt. Eskandari et al. (2015) used the SAW method and AHP weighting for landfill site selection in Marvdasht, Fars Province. Beskese et al. (2015) carried out the landfill site selection for Istanbul, Turkey, using fuzzy AHP and fuzzy TOPSIS. Motlagh and Sayadi (2015) used the OWA method and ANP weighting for landfill site selection in Birjand, Iran. Kharat et al. (2016) in a research used fuzzy AHP and TOPSIS methodology for MSW landfill site selection. Bahrani et al. (2016) used fuzzy logic based on WLC and weighting by AHP for landfill site selection in Shabestar, Iran. Rahmat et al. (2017) carried out the landfill site selection for Behbahan, Khouzestan, Iran, using fuzzy AHP and GIS.

In the present study, a novel technique including the ANP and OWA was applied to landfill site selection to prevent loss of valuable resources (for example land) in an accurate manner in Markazi province, Iran. It should be mentioned that despite the increase in solid waste production in Markazi province, there is no landfill site in the province. Thus, the landfill site selection in the study area considering the complexity of the problems to select the best location is a crucial issue. Combination of ANP and OWA may have better results including different levels of risk to select the best landfill site to minimize the negative impact of landfilling as one of the ultimate disposal methods in the Markazi province.

Materials and methods

The case study

Markazi province is located between 35°30 to 35°35′N latitude and 48°57 to 51°E longitude in the central part of Iran with an area about 29,530 km^2 occupying less than 2% of the total area of Iran (Fig. 1). The lowest place in the Markazi province is Saveh Plain with 1200 m above the sea level and the highest place is Shahbaz Summit (in Rasvand Mountains) in the southwest of the province with 3388 m above the sea level. The topography of the Markazi province shows that around 75% of the province is mountainous and 25% is plain. The population of the province is around 1326,826 (Iranian Statistics Center 2015). The average daily solid waste production per capita in Arak (capital of Markazi province) in 2015 was reported about 800 gr/capita/day and also total daily solid waste production of Markazi province estimated around 1500 tons (Iranian Statistics Center 2015). It should be noted that, although considerable amounts of solid wastes are produced in Markazi province, there is not any integrated MSW management plan. However, the regional authority decided to select landfilling as the ultimate disposal method of MSW in the Markazi province. Due to sophisticated topography of the Markazi province and lack of the suitable land, selection of the landfill site is impossible for an individual city. Thus, the regional authority decided to find some limited landfill site according to environmental and economic factors in the whole province to overcome the mentioned limitations. Therefore, landfill site selection in a precise manner considered as crucial issue to reduce potential environmental adverse effects and prevent loss in valuable land in the Markazi province.

Analytic network process (ANP)

The ANP based on an analysis of how the human brain resolves complex issues with feedback structure was introduced to modify the AHP. The comparison between analytical hierarchy process (AHP) and analytical network process (ANP) structures is depicted in Fig. 2.

In the ANP method, a feedback structure is developed and logical relationship between different levels of

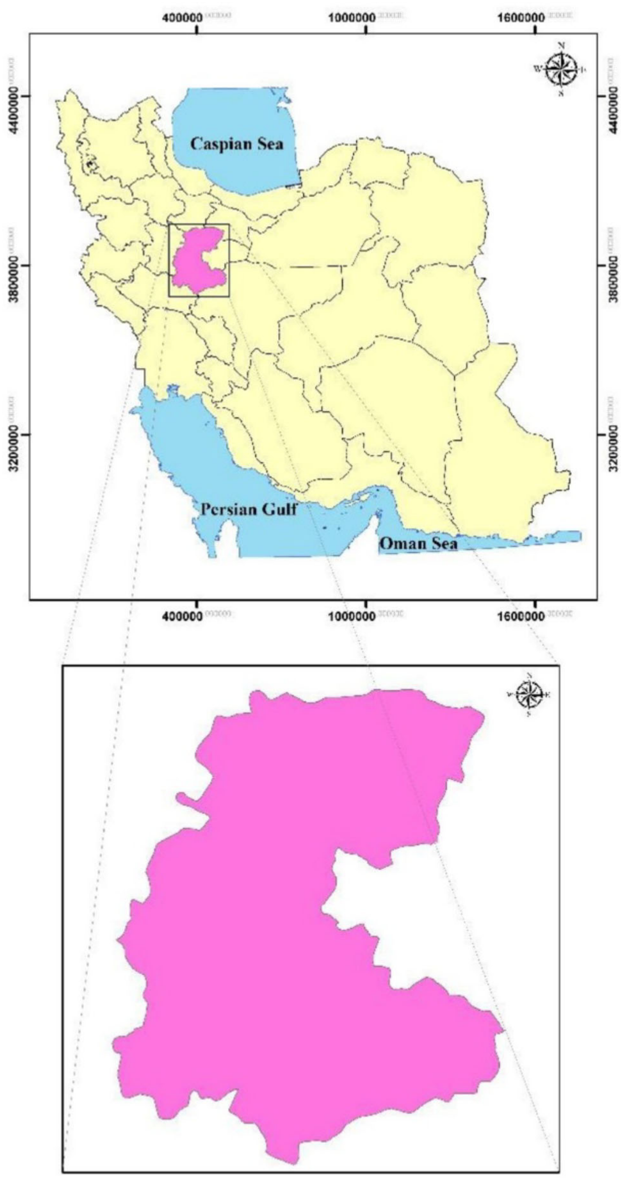

Fig. 1 The case study area location in Iran

decision is determined. Existing structure is divided to N sub-components, and then judgment matrix will be resulted through paired comparison for feedback system. Thus, determination of pairwise comparison matrix with pairwise comparison of criteria and sub-criteria is necessary (Afzali et al. 2014). The consistency ration (CR) is an important factor and should be assessed to consistency of decisions. The CR is calculated using Eq. 1, in which a value of approximately 0.1 or less should be acceptable; otherwise, the pairwise comparison of criteria should be reconsidered (Saaty and Vargas 2006):

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{1}$$

where CI is the consistency index of the pairwise comparison matrix and is estimated using the largest eigenvector ($\lambda_{\max}$) value and the size of matrix (n) as shown in Eq. 2:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

Table 1 presents the mean random consistency index (RI) for matrixes with different magnitude.

Weight of each element is determined by the eigenvector method (Eq. 3) after ensuring compatibility matrixes of pairwise comparisons.

$$W_i = \frac{1}{\lambda_{\max}} \sum_{i=1}^{n} a_{ij} w_j \quad i = 1, 2, \ldots, n \tag{3}$$

where $\lambda_{\max}$ is the largest eigenvector and a_{ij} is the relative importance of each element compared to the other elements. Therefore, assuming n_i represents the number of sub-criteria in S_i criteria and w_{ik}^{jt} indicates the weight of kth sub-criterion from ith criteria compared to the first sub-criterion from jth criterion. The judgment matrix for element of ith sub-criteria related to the elements in jth sub-criteria is presented in Fig. 3.

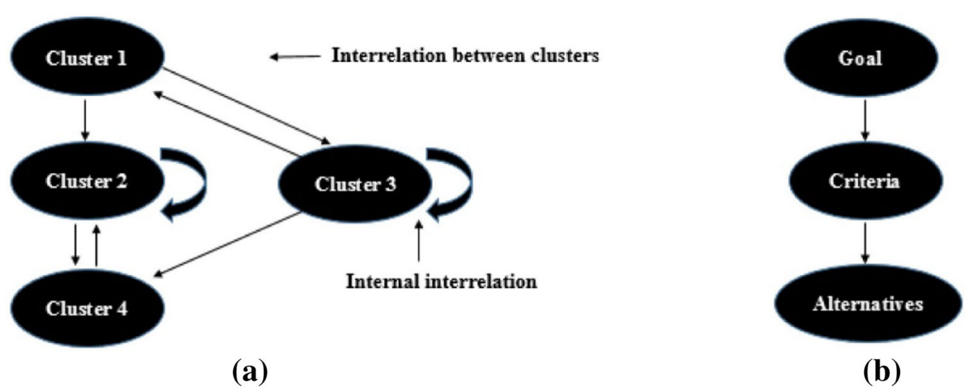

Fig. 2 Comparison ANP (a) and AHP (b) (Saaty 1996)

Table 1 Average RI for corresponding matrix size (Saaty and Vargas 2006)

(*n*)	1	2	3	4	4	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	1.48	1.56	1.57	1.59

$$W_{ij} = \begin{pmatrix} w_{i1}^{j1} & w_{i1}^{j2} & \cdots & w_{i1}^{jnj} \\ w_{i2}^{j1} & w_{i2}^{j2} & \cdots & w_{i2}^{jnj} \\ \vdots & \vdots & & \vdots \\ w_{ini}^{j1} & w_{ini}^{j2} & \cdots & w_{ini}^{jnj} \end{pmatrix}$$

Fig. 3 Judgment matrix (Saaty and Vargas 2006)

$$W = \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & & W_{2N} \\ & & & \\ W_{N1} & W_{N2} & & W_{NN} \end{bmatrix}$$

Fig. 4 Super matrix (Saaty and Vargas 2006)

The final priority for each element is expressed through the following limit matrix (super matrix):

$$w_c = \lim_{l \to \infty} w^{2l+1} \quad (4)$$

The standard form of a super matrix is presented in Fig. 4. The elements of super matrix converge to a single value which their value will be equal at the each row of super matrix. Thus, prioritizing elements can be determined by comparing and reforming determined matrix component (w_c) at each column (Saaty and Vargas 2006).

Standardization of factors

In the present study, 12 different environmental and socioeconomic factors were used for the landfill site selection (slope, geological organization, soil texture, erosion, distance from the surface water and ground water, distance from the rivers, distance from the protected areas, distance from the faults, distance from the roads, distance from the urban and rural areas).

Fuzzy logic

Fuzzy logic is a strong logic for the standardization of information layers, first time introduced by Zadeh (1965) to resolve the uncertainty due to ambiguity and imprecision in decision-making. This theory places the membership degree of each element in the interval (0, 1) as a kind of logic (in contrast to the Boolean). In IDRISI, the module named fuzzy has been prepared for the standardization of factors using a whole range of fuzzy set membership functions. The module is quick and easy to use, and provides the option of standardizing factors to either a 0–1 real number scale or a 0–255 byte scale. In use, the fuzzy module in IDRISI is designed for the construction of fuzzy set membership functions. Fuzzy offers four types of membership function: sigmoidal (S-shape), J-shape, linear, and user-defined (Eastman 2003). In the present study, the sigmoidal, J-shape and user-defined function are used (Table 2 and Fig. 5).

1. *Sigmoidal* The sigmoidal (S-shape) membership function is the more commonly used. In use, fuzzy requires the positions of four inflection points governing the shape of the curve (Fig. 5a). Points a, b, c, and d represent the inflection points as the membership function rises above 0, approaches 1, falls below 1 again, and finally approaches 0.
2. *J-Shaped* The J-shaped function is another common function. Figure 5b indicates the different possibilities of J-shaped functions and the positions of the inflection points.
3. *User-defined* When the relationship between the value and fuzzy membership does not follow any of the above three functions, the user-defined function is most applicable. The fuzzy membership between any two control points is linearly interpolated (Fig. 5c).

Boolean logic

In the Boolean logic, the selection of the ideal site is based on the True or False (or 0 and 1). In this method, the spatial desirability is based on suitability or unsuitability and the ultimate map for the parameter will be used. The Boolean logic defined as the follows (Shahabi et al. 2014):

$$C = \{1 \text{ if class } A > \text{or} < X\} \text{ and } c = \text{class } A > \text{or} < X \quad (5)$$

WLC method

One of the most common evaluation methods is the spatial MADM in which the desirability is based on the relative importance of the criteria in the site selection process. This

Table 2 Factors with their suitability range for landfill site selection

Criteria	Sub-criteria	Alternative	Suitability	Control point a	Control point b	Fuzzy function/ membership
Environmental factors	Hydrology	Distance from G. W	10–100 m	10	100	S-shape—increasing
		Distance from S. W	500–1500 m	500	1500	S-shape—increasing
	Geomorphology	Soil texture	Clay soil, silty clay	–	–	User-defined
		Slope	Less than 15%	15	30	S-Shape—reducing
		Erosion	Erosion polygon layer	–	–	User-defined
		Distance from fault	500–1000 m	500	1000	S-Shape—increasing
		Geology	Clay soil-type geological formations	–	–	User-defined
	Land use	Land use	The unutilized lands, the areas with low concentration range, the lands with no vegetation and stone extrusion	–	–	User-defined
	Protected areas	Distance from protected areas	500–1000 m	500	1000	S-shape—increasing
Socioeconomic factors	Accessibility	Distance from urban areas	2000–5000 m	2000	5000	J-shape—increasing
		Distance from villages	1000–3000 m	1000	3000	J-shape—increasing
		Distance from roads	100–1000 m	100	1000	J-shape—reducing

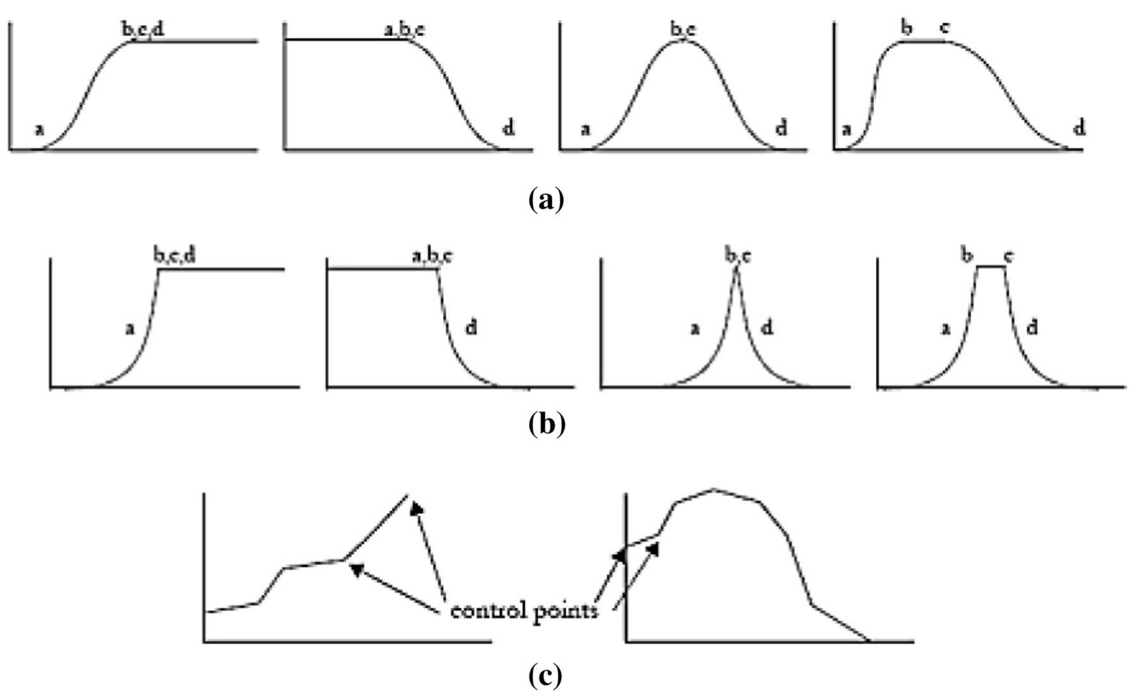

Fig. 5 **a** Sigmoidal membership function, **b** J-shaped membership function and **c** User-defined membership function (Eastman 2003)

method is one of the techniques for ranking the importance of site selection criteria based on the relative weights of the criteria. In this method, the higher values are more ideal candidates for site selection. It treats as an ideal goal the determination of suitability for each activity or the potential evaluation for each performance. In this method, each standardized factor is multiplied by its respective weight. Then, the layers are added. The final map of calculating the desirability in the range of 0–1 indicates the sites considered as suitable. This method is based on Eq. 6 (Moeinaddini et al. 2010):

$$S = \sum_{i=1}^{n} X_i W_i \tag{6}$$

In this equation, S is the index of spatial suitability for the area, W_i is the relative importance of the criterion weight, X_i is the standardized value of the criteria, and n indicates the number of the criteria.

Factors weight determination

In the present study, Super Decision software was used to weighting the factors by ANP method. Based on Fig. 6, the criteria and sub-criteria were identified and the model was designed, and it states that the ANP model is made up of four levels.

Ordered-weighted averaging (OWA)

The OWA method considered as one of the combining methods in MADM approach was developed based on fuzzy sets. The OWA is a generalization of the Boolean overlay operations and WLC (Yager 1988). It is a complete spectrum of space strategy decision along the primary dimensions of the trade-off degree between the criteria involved and the degree of risk in the solution. Figure 7 demonstrates the decision-making strategy space where the x-axis indicates a continuum from maximum caution, where no type of risk is run, to the point where the risk factor is completely accepted. The y-axis indicates a continuum from no trade-off between the criteria to the point of maximum trade-off (Eastman 2003). The trade-off is a degree that a criterion can compensate for another and risk may be understood as the likelihood that the decision made will be wrong. Weighted average method is an interesting method because by reordering and changing criterion parameters, an expansive spectrum of different maps and predictive scenarios could be produced. The use of the OWA method permits the evaluation of the wide spectrum of consequences obtained from different management strategies (Ferretti and Pomarico 2013).

The OWA approach consists of two weight vectors: the weights of relative criterion (w_j, $j = 1, 2,\ldots, n$) and the order weights (v_j). The first collection, factor or criteria weights, controls the relative contribution of single criterion, whereas the second collection, controls the criteria set (Malczewski 1999). Through specifying a suitable set of order weights it is possible to produce an expansive spectrum of outcome maps that represent the derived results from different decision-maker attitudes toward risk (Malczewski 2006).

The OWA combination operator associates with the ith location and a set of order weights $V = (v_1, v_2,\ldots, v_n)$ where, $v_j \in [0, 1]$ for $j = 1, 2,\ldots, n$ and $\sum_{j=1}^{n} v_j = 1$, and

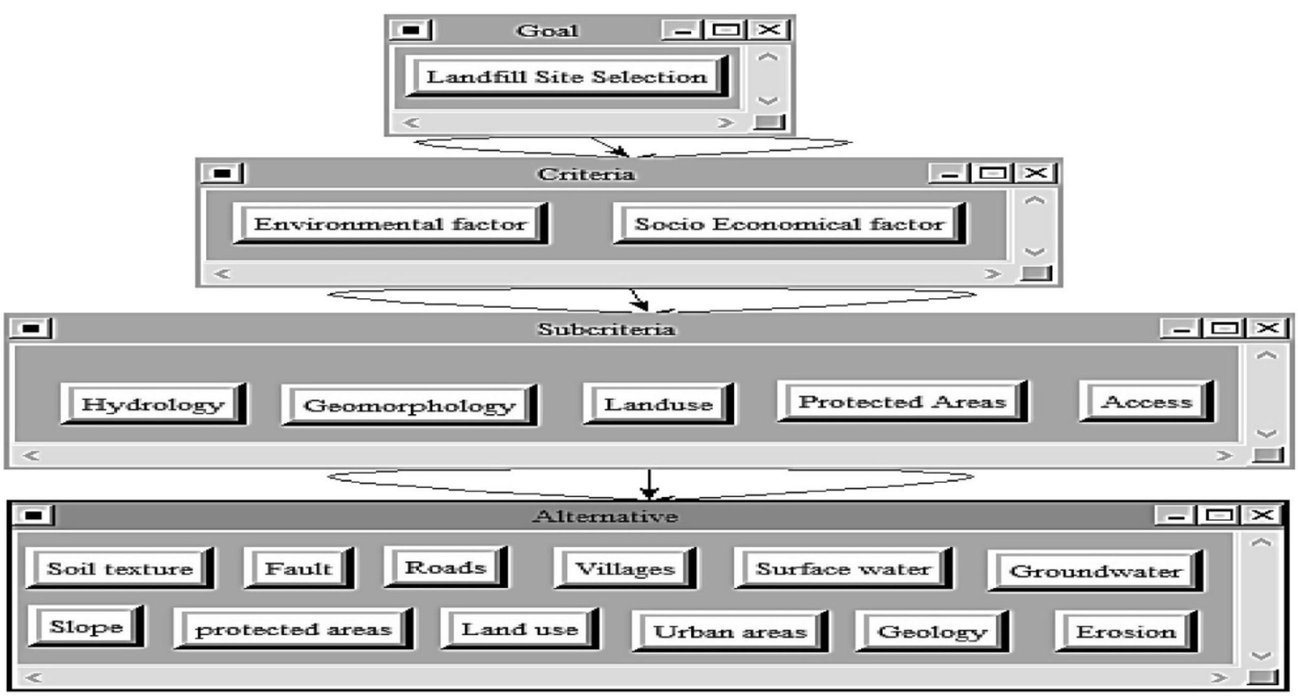

Fig. 6 Structure of the ANP model in the Super Decision software for Markazi province landfill site selection

Fig. 7 Decision strategy space in OWA (Eastman 2003)

the operator OWA is defined as follows (Malczewski 2006; Malczewski and Rinner 2005; Yager 1988):

$$\mathrm{OWA}_i = \sum_{j=1}^{n} \left(\frac{w_j v_j}{\sum_{j=1}^{n} w_j v_j} \right) Z_{ij} \tag{7}$$

where $Z_{i1} \geq Z_{i2} \geq \ldots \geq Z_{in}$ is obtained by reordering the criterion values $x_{i1}, x_{i2}, \ldots, x_{in}$. v_j is the order weight and w_j is the same criteria weight that is ordered based on the order of Z.

Main characters of OWA

The OWA can be changed in a complete spectrum from "At least one" quantifier to "All" quantifier. It uses two operators including: (1) ORness and (2) permutation trade-off relation measure. An ORness defines the position of the operator OWA between AND (minimum) and OR (maximum). ORness is defined as follows:

$$\mathrm{ORness} = \frac{1}{n-1} \sum_{i=1}^{n} (n-i).v_i, \quad 0 \leq \mathrm{ORness} \leq 1 \tag{8}$$

Moreover, the trade-off indicates the change measure or effectiveness of one index from the other indexes. Trade-off is defined as follows:

$$\text{Trade off} = 1 - \sqrt{\frac{n}{n-1} \sum_{i=1}^{n} \left(v_i - \frac{1}{n} \right)^2}, \quad 0 \leq \text{Tradeoff} \leq 1 \tag{9}$$

where v_i is the criterion order weight with degree r, and n is the criterion number (Makropoulos and Butler 2006; Motlagh and Sayadi 2015).

Quantifier-guided OWA combination

Concept of fuzzy linguistic quantifiers has been introduced by Zadeh (1997). It permits for the conversion of natural language arrangements into formal mathematical formulations, right to the formulation of the MADM functions. Two general classes of the linguistic quantifiers are existed: (1) absolute quantifiers and (2) relative quantifiers. The first class one, Absolute quantifiers, can be defined as fuzzy subsets of $[0, +\infty)$. It can be used to indicate linguistic terms. The second one, relative quantifiers, is closely related to imprecise proportions. It can be indicated as fuzzy subsets over the unit interval, with proportional fuzzy terms. In the present study, the class of the relative quantifiers is used (Table 3).

Table 3 Final weights and priorities assigned to the environmental and socioeconomic factors using ANP method for Markazi province landfill site selection

Priority	Factor	Weight
1	Distance from G. W	0.178
2	Distance from S. W	0.136
3	Land use	0.120
4	Soil texture	0.106
5	Distance from protected areas	0.099
6	Urban areas	0.076
7	Villages	0.068
8	Geology	0.057
9	Fault	0.046
10	Roads	0.043
11	Slope	0.036
12	Erosion	0.03

The Eq. 10 is used to define applied linguistic quantifiers.

$$Q(p) = p^{\alpha}, \alpha > 0 \tag{10}$$

With the change of α, different types of linguistic quantifiers could be obtained. If $\alpha = 1$, the $Q(p)$will be proportionate with α and accordingly correspondent to 'half' quantifier (Boroushaki and Malczewski 2008; Motlagh and Sayadi 2015). The concept of linguistic quantifiers provides an approach for produce ordered weights based on

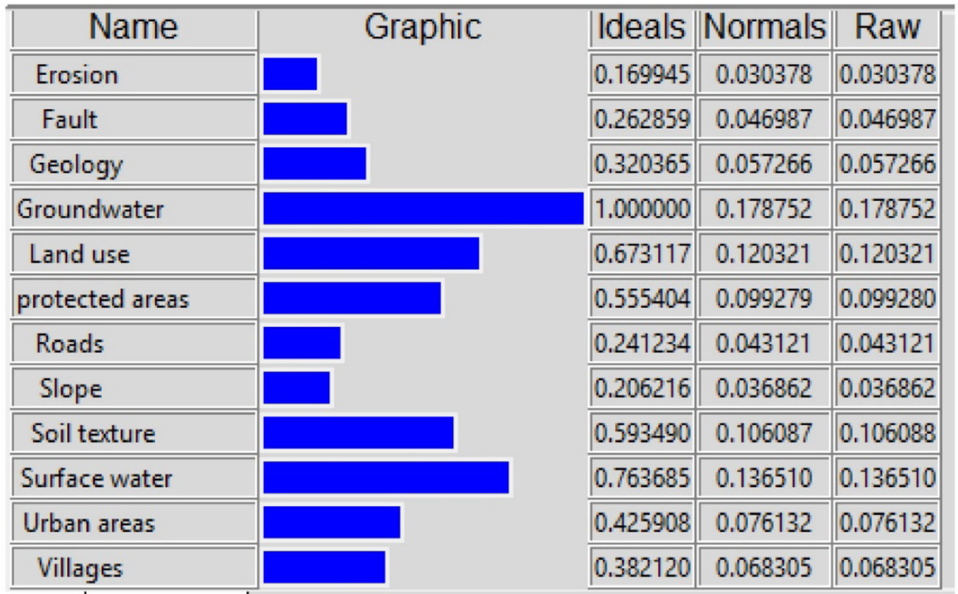

Fig. 8 Factors weight in the Super Decision software for Markazi province landfill site selection

the Regular Increasing Monotone (RIM) linguistic quantifiers (Yager 1988).

In the present study, considering the obtained criterion weights from ANP method (Fig. 8 and Table 3) and choosing linguistic quantifier (Table 4) are carried out using Eq. 11. The order weights are presented in Table 5.

$$v_j = \left(\sum_{j=1}^{n} w_j\right)^{\alpha} - \left(\sum_{j=1}^{n-1} w_j\right)^{\alpha} \quad (11)$$

Results and discussion

Factors weight determination

Final weights and priorities assigned to the environmental and socioeconomic factors using ANP method is presented in Table 3. The outputs of Super Decision software are presented in Tables 6, 7, 8, and Fig. 8.

Table 4 Selected linguistic quantifiers and corresponding parameters

Linguistic quantifier (LQ)	At least one	Few	Some	Half	Many	Most	All
α	0.0001	0.1	0.5	1	2	10	1000

Table 5 Order weights obtained from the fuzzy linguistic quantifier Q

	$\alpha = 0.0001$ Scenario 1	$\alpha = 0.1$ Scenario 2	$\alpha = 0.5$ Scenario 3	$\alpha = 1$ Scenario 4	$\alpha = 2$ Scenario 5	$\alpha = 10$ Scenario 6	$\alpha = 1000$ Scenario 7
Order weights							
$v1$	1	0.841	0.422	0.178	0.032	0	0
$v2$	0	0.05	0.141	0.139	0.068	0	0
$v3$	0	0.029	0.098	0.12	0.091	0	0
$v4$	0	0.019	0.076	0.106	0.104	0.002	0
$v5$	0	0.016	0.064	0.099	0.117	0.009	0
$v6$	0	0.01	0.046	0.076	0.104	0.024	0
$v7$	0	0.009	0.039	0.068	0.103	0.054	0
$v8$	0	0.007	0.031	0.057	0.093	0.092	0
$v9$	0	0.0054	0.025	0.047	0.081	0.131	0
$v10$	0	0.0051	0.023	0.043	0.078	0.188	0
$v11$	0	0.004	0.019	0.037	0.071	0.238	0
$v12$	0	0.003	0.015	0.03	0.059	0.263	1

Table 6 Unweighted Super matrix obtained in Super Decision software

	Erosion	Fault	Geology	Groundwater	Land use	Protected areas	Roads	Slope	Soil texture	Surface water	Urban areas	Villages	Environmental factors	Socioeconomic factors
Erosion	0	0.03667	0.03299	0.03648	0.03427	0.03319	0.02988	0.02777	0.0266	0.02805	0.02683	0.02666	0	0
Fault	0.04204	0	0.04942	0.05573	0.05109	0.04867	0.04184	0.04268	0.04947	0.04879	0.04603	0.04608	0	0
Geology	0.06269	0.05974	0	0.06554	0.05286	0.06057	0.06731	0.05413	0.0586	0.05992	0.06349	0.06349	0	0
Groundwater	0.21883	0.21183	0.2133	0	0.21899	0.22286	0.20811	0.20138	0.2124	0.22523	0.21758	0.22285	0	0
Land use	0.1158	0.1052	0.11809	0.14866	0	0.12931	0.1298	0.13078	0.13531	0.15233	0.13955	0.13902	0	0
Protected areas	0.08768	0.0881	0.10406	0.12445	0.11327	0	0.09835	0.0948	0.11417	0.119	0.10328	0.09792	0	0
Roads	0.04224	0.04916	0.04648	0.04931	0.05194	0.04278	0	0.03978	0.04483	0.04204	0.03875	0.03874	0	0
Slope	0.04053	0.04336	0.04237	0.04144	0.03792	0.03768	0.03604	0	0.03946	0.03597	0.03343	0.03307	0	0
Soil texture	0.09387	0.11265	0.09873	0.13037	0.12524	0.11389	0.11162	0.11076	0	0.12637	0.11426	0.11366	0	0
Surface water	0.14225	0.14466	0.15752	0.17925	0.15759	0.15018	0.15	0.15112	0.15369	0	0.15195	0.15442	0	0
Urban areas	0.08715	0.07755	0.07135	0.08976	0.08074	0.08553	0.06753	0.07952	0.08799	0.08753	0	0.06409	0	0
Villages	0.06692	0.07108	0.06569	0.07902	0.07609	0.07533	0.05951	0.0673	0.07747	0.07477	0.06486	0	0	0
Environmental factors	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Socioeconomic factors	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Table 7 Weighted Super matrix obtained in Super Decision software

	Erosion	Fault	Geology	Groundwater	Land use	Protected areas	Roads	Slope	Soil texture	Surface water	Urban areas	Villages	Environmental factors	Socioeconomic factors
Erosion	0	0.03667	0.03299	0.03648	0.03427	0.03319	0.02988	0.02777	0.0266	0.02805	0.02683	0.02666	0	0
Fault	0.04204	0	0.04942	0.05573	0.05109	0.04867	0.04184	0.04268	0.04947	0.04879	0.04603	0.04608	0	0
Geology	0.06269	0.05974	0	0.06554	0.05286	0.06057	0.06731	0.05413	0.0586	0.05992	0.06349	0.06349	0	0
Groundwater	0.21883	0.21183	0.2133	0	0.21899	0.22286	0.20811	0.20138	0.2124	0.22523	0.21758	0.22285	0	0
Land use	0.1158	0.1052	0.11809	0.14866	0	0.12931	0.1298	0.13078	0.13531	0.15233	0.13955	0.13902	0	0
Protected areas	0.08768	0.0881	0.10406	0.12445	0.11327	0	0.09835	0.0948	0.11417	0.119	0.10328	0.09792	0	0
Roads	0.04224	0.04916	0.04648	0.04931	0.05194	0.04278	0	0.03978	0.04483	0.04204	0.03875	0.03874	0	0
Slope	0.04053	0.04336	0.04237	0.04144	0.03792	0.03768	0.03604	0	0.03946	0.03597	0.03343	0.03307	0	0
Soil texture	0.09387	0.11265	0.09873	0.13037	0.12524	0.11389	0.11162	0.11076	0	0.12637	0.11426	0.11366	0	0
Surface water	0.14225	0.14466	0.15752	0.17925	0.15759	0.15018	0.15	0.15112	0.15369	0	0.15195	0.15442	0	0
Urban areas	0.08715	0.07755	0.07135	0.08976	0.08074	0.08553	0.06753	0.07952	0.08799	0.08753	0	0.06409	0	0
Villages	0.06692	0.07108	0.06569	0.07902	0.07609	0.07533	0.05951	0.0673	0.07747	0.07477	0.06486	0	0	0
Environmental factors	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5
Socioeconomic factors	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0

Table 8 Limit Super matrix obtained in the Super Decision software

	Erosion	Fault	Geology	Groundwater	Land use	Protected areas	Roads	Slope	Soil texture	Surface water	Urban areas	Villages	Environmental factors	Socioeconomic factors
Erosion	0.03038	0.03038	0.03038	0.03038	0.03038	0.03038	0.03038	0.03038	0.03038	0.03038	0.03038	0.03038	0.03038	0.03038
Fault	0.04699	0.04699	0.04699	0.04699	0.04699	0.04699	0.04699	0.04699	0.04699	0.04699	0.04699	0.04699	0.04699	0.04699
Geology	0.05727	0.05727	0.05727	0.05727	0.05727	0.05727	0.05727	0.05727	0.05727	0.05727	0.05727	0.05727	0.05727	0.05727
Groundwater	0.17875	0.17875	0.17875	0.17875	0.17875	0.17875	0.17875	0.17875	0.17875	0.17875	0.17875	0.17875	0.17875	0.17875
Land use	0.12032	0.12032	0.12032	0.12032	0.12032	0.12032	0.12032	0.12032	0.12032	0.12032	0.12032	0.12032	0.12032	0.12032
Protected areas	0.09928	0.09928	0.09928	0.09928	0.09928	0.09928	0.09928	0.09928	0.09928	0.09928	0.09928	0.09928	0.09928	0.09928
Roads	0.04312	0.04312	0.04312	0.04312	0.04312	0.04312	0.04312	0.04312	0.04312	0.04312	0.04312	0.04312	0.04312	0.04312
Slope	0.03686	0.03686	0.03686	0.03686	0.03686	0.03686	0.03686	0.03686	0.03686	0.03686	0.03686	0.03686	0.03686	0.03686
Soil texture	0.10609	0.10609	0.10609	0.10609	0.10609	0.10609	0.10609	0.10609	0.10609	0.10609	0.10609	0.10609	0.10609	0.10609
Surface water	0.13651	0.13651	0.13651	0.13651	0.13651	0.13651	0.13651	0.13651	0.13651	0.13651	0.13651	0.13651	0.13651	0.13651
Urban areas	0.07613	0.07613	0.07613	0.07613	0.07613	0.07613	0.07613	0.07613	0.07613	0.07613	0.07613	0.07613	0.07613	0.07613
Villages	0.06831	0.06831	0.06831	0.06831	0.06831	0.06831	0.06831	0.06831	0.06831	0.06831	0.06831	0.06831	0.06831	0.06831
Environmental factors	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Socioeconomic factors	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Factors fuzzification

In the present study, the different environmental and socioeconomic factors are applied for the landfill site selection. It should be noted that the Iranian and international constraints for landfill site selection in Markazi Province are presented in Table 2. Some of the main considered factors in the present study are:

Urban areas

Constructing landfill sites in the adjacency of residential areas can have negative environmental effects such as bad odor, sound pollution due to garbage cars and mechanical equipment, and dust for the inhabitants of those areas. The minimum distance of 2000 m from urban areas is considered as appropriate distance for landfill site selection in Markazi Province (increasing membership function).

Faults

The areas with no fault lines or with a safe distance from fault lines are considered as suitable for landfill selection. In fact, fault lines allow leachate to secrete and penetrate into ground water resources. The minimum distance of 200 m from faults is intended as appropriate (increasing membership function).

Slope

Slope is a key factor in landfill site selection. In fact, the selection of a higher-slope site will increase the digging and the best areas for landfill are the flat areas without slope. The slope <15% is suggested (decreasing membership function).

Surface water (Rivers)

The landfill site should be as far as possible from surface water resources. The pollution of surface water resources presents a main concern in the urban landfill facilities. The minimum distance of 500 m from surface water (rivers) is considered as appropriate (increasing membership function).

Land use

The unutilized lands and the areas with low concentration range are appropriate for landfill site selection (user-defined membership function).

Soil texture

Since the soils with low penetrability and fine-grained texture are less capable of passing leachate, they are more

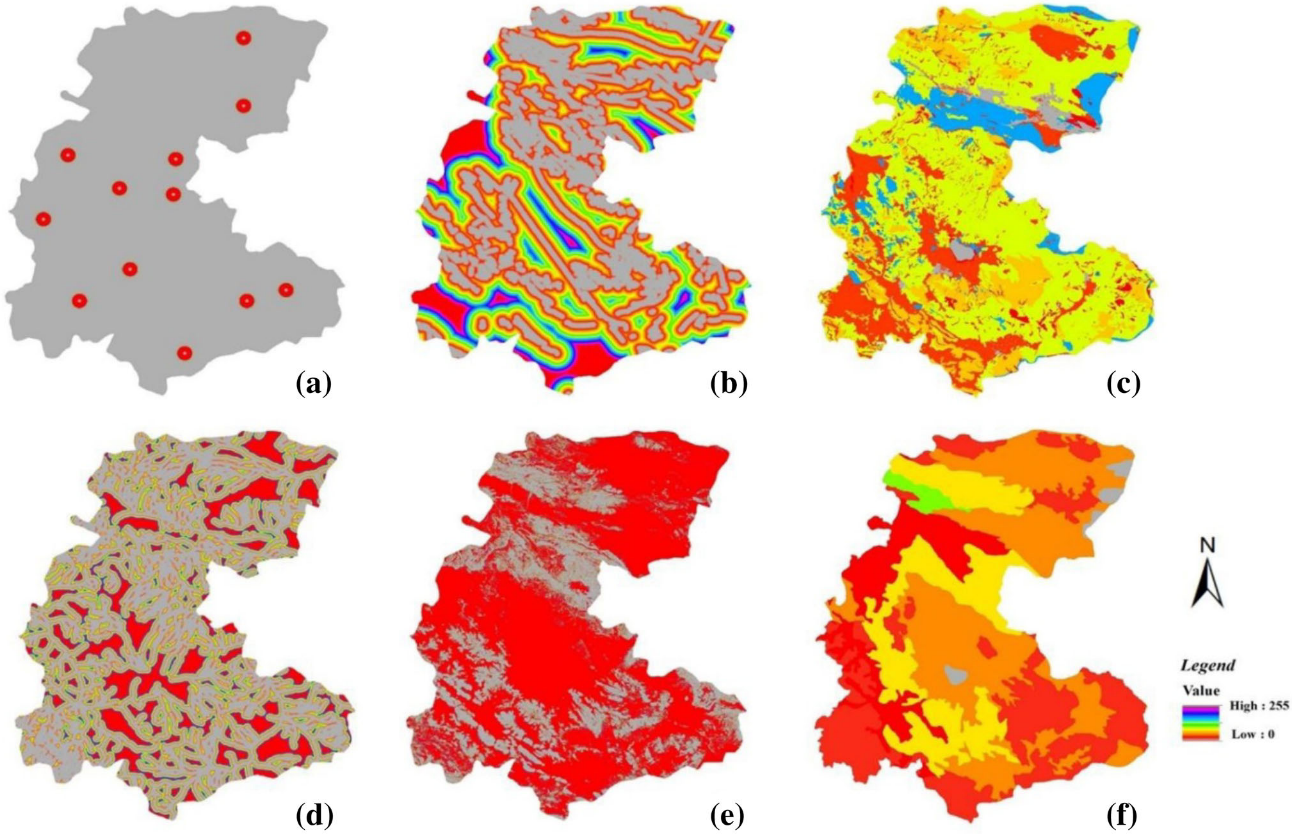

Fig. 9 Standardized criteria maps: **a** distance from urban areas, **b** distance from fault, **c** land use, **d** surface water, **e** slope, **f** soil texture

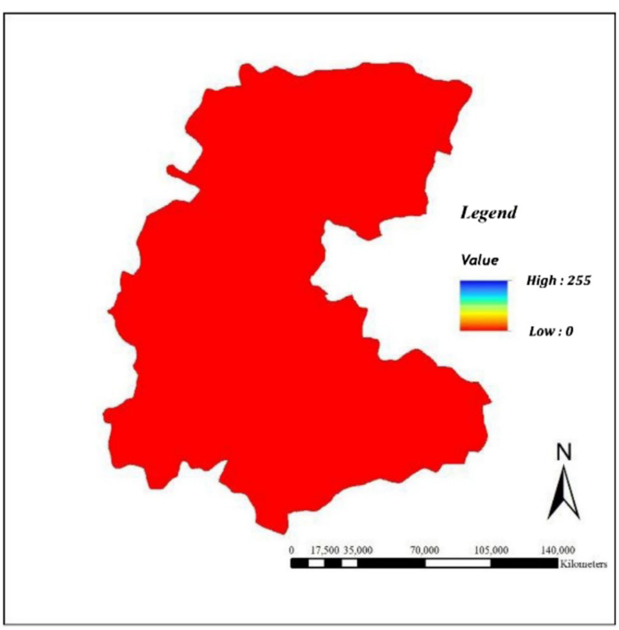

Fig. 10 Final Boolean map for landfill site selection in Markazi province

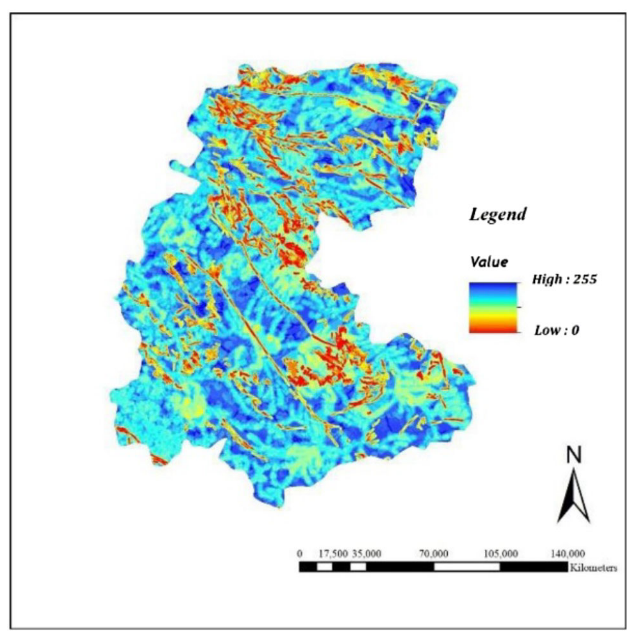

Fig. 11 Final map resulted from application of fuzzy logic method based on WLC in Markazi province

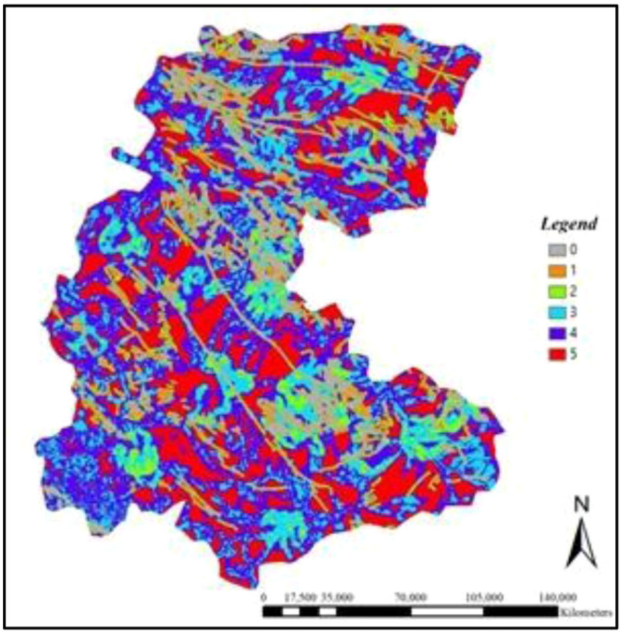

Fig. 12 The classified final map resultant from the fuzzy logic and WLC method

ideal for landfill site selection when compared to other soil types with high penetrability. The clay soils are considered as the best for landfill site selection and in the next step silty clay (user-defined membership function).

The fuzzy maps of distance from urban areas (a), distance from fault (b), land use (c), surface water (d), slope (e) and soil texture (f) are depicted in Fig. 9.

Boolean logic

The Boolean logic (0 and 1) was used with the AND operator (multiplying of layers) in an ARC GIS software environment. The final map (Fig. 10) with one spatial unsuitability class was not appropriate for landfill site selection in the Markazi province.

WLC method

The final map based on WLC method is depicted in Fig. 11. According to Fig. 12, the final map from WLC method is divided into five classes. The results reveal the fuzzy logic method based on WLC is more flexible and precise than the Boolean logic method for the selection of the best choice for sanitary landfill site in Markazi province.

OWA method

In the present study, the influence of criteria and their weighted degree for the site selection in different situations is extracted based on Table 5. Suitability maps was

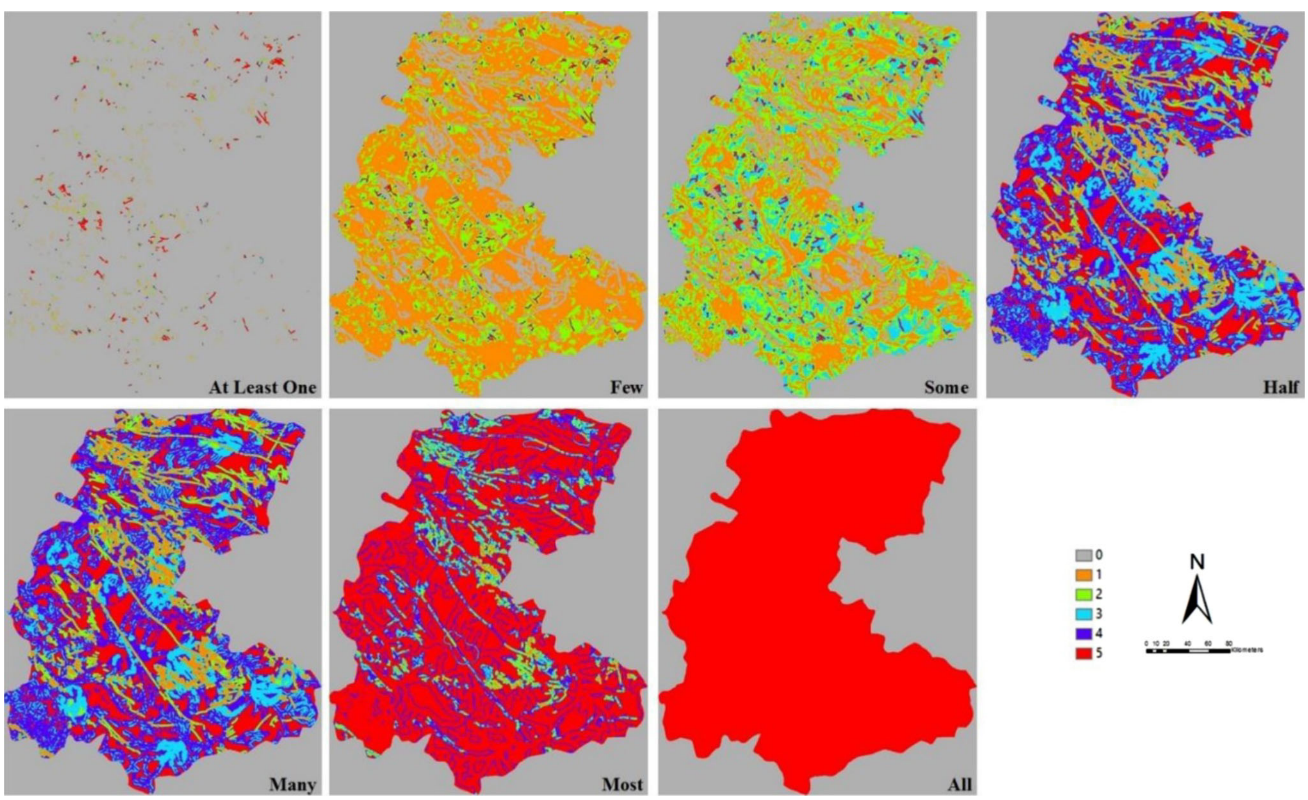

Fig. 13 The suitability maps for each decision strategy for the landfill site selection using the OWA model

Table 9 Landfill site selection arena area in different conditions (hectares)

	Class 1	Class 2	Class 3	Class 4	Class 5
First scenario	2,778,510	582,480	286,350	198,977	360,730
Second scenario	456,955	1799,162	577,620	439,165	437,077
Third scenario	439,715	1041,825	932,177	448,855	587,880
Fourth scenario	748,057	301,910	257,962	1,404,532	882,150
Fifth scenario	273,927	256,330	638,675	672,577	1,079,850
Sixth scenario	12,207	836,047	261,160	555,930	2,011,950
Seventh scenario	–	–	–	–	2,921,365

generated with consideration of different OWA method and ORness weights situations and the spatial desirability was divided into 5 classes (low, moderate, strong, very strong, and extremely strong class, respectively) (Fig. 13). These maps illustrate different evaluation scenarios to analyses site selection within the decision strategy space obtained by the relationship between the ORness parameter and the trade-off measure. The spatial desirability for landfill sites is presented in Table 8.

The evaluation scenario for $\alpha = 0$ represents a risk averse solution. This scenario represents no trade-off between factors and thus coincides with the AND Boolean operator. This strategy indicates the worst case scenario in which the lowest suitability value is assigned to each location. With the increasing in the values of α, the area of the extremely suitable classes will be increased. Finally, the decision-making scenario associated with $\alpha = 1$ generate the other end of the decision strategy space spectrum. This strategy coincides with the OR Boolean operator and generates the extreme optimist strategy. This solution assigns a probability of 1 to the highest value at each location in which leads almost the entire area as suitable for landfill site selection. Based on Table 8, according to scenarios 1–7, 8.57, 11.78, 17.03, 24.54, 36.96, 54.71, and 100% of region area is in the very suitable class, respectively (Table 9).

Conclusion

Analytic network process (ANP) is a flexible approach with the possibility of considering the interaction of different levels of decision relative to each other and also internal communication of decision criteria on one level which in other methods of decision-making is virtually ignored. The complexity and feedback structure of the best location problems makes obvious the necessity of using this method to prioritize them. In the present study, a comparison of Boolean (AND operation) and WLC procedure (middle of the AND and OR operations) was conducted. The WLC aggregation approach offers much more flexibility than the Boolean method. The use of the OWA method permits several decision scenarios to be evaluated to help planners to achieve the most satisfied solution considering both risk and trade-off measures involved in the decision-making assessment process. The obtained final suitability maps illustrate a decision-making support tool that is able to spatially identify the suitable areas for the waste disposal site. Thus, the integration of GIS with the ANP method and the OWA operator, considered as the useful tool for the analysis and the aggregation of environmental and socioeconomic factors to select the suitable landfill site with the different risk level classes. In a general manner, it could be concluded that OWA scenarios are dependent on the quality of risk acceptance level (optimistic, pessimistic and neutral) and are involved in the decision-making process for the best facility and understanding of the patterns that originated from the decision-making displacements. The results of our research represented that the aforementioned method is a beneficial tool to support evaluation of the space decision-making programs.

References

Abd-El Monsef H (2015) Optimization of municipal landfill siting in the Red Sea coastal desert using geographic information system, remote sensing and an analytical hierarchy process. Environ Earth Sci 74(3):2283–2296. doi:10.1007/s12665-015-4220-2

Afzali A, Sabri S, Rashid M, Samani JM, Ludin AN (2014) Intermunicipal landfill site selection using analytic network process. Water Resour Manag 28(8):2179–2194. doi:10.1007/s11269-014-0605-3

Alexakis DD, Sarris A (2014) Integrated GIS and remote sensing analysis for landfill sitting in Western Crete, Greece. Environ Earth Sci 72(2):467–482. doi:10.1007/s12665-013-2966-y

Arkoc O (2014) Municipal solid waste landfill site selection using geographical information systems: a case study from Çorlu, Turkey. Arab J Geosci 7(11):4975–4985. doi:10.1007/s12517-013-1107-y

Bahrani S, Ebadi T, Ehsani H, Yousefi H, Maknoon R (2016) Modeling landfill site selection by multi-criteria decision making and fuzzy functions in GIS, case study: Shabestar, Iran. Environ Earth Sci 75(4):1–14. doi:10.1007/s12665-015-5146-4

Beskese A, Demir HH, Ozcan HK, Okten HE (2015) Landfill site selection using fuzzy AHP and fuzzy TOPSIS: a case study for Istanbul. Environ Earth Sci 73(7):3513–3521. doi:10.1007/s12665-014-3635-5

Boroushaki S, Malczewski J (2008) Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS. Comput Geosci 34(4):399–410. doi:10.1016/j.cageo.2007.04.003

Eastman JR (2003) IDRISI Kilimanjaro: guide to GIS and image processing. Clark Labs, Clark University, Worcester

Eskandari M, Homaee M, Mahmoodi S, Pazira E, Van Genuchten MT (2015) Optimizing landfill site selection by using land classification maps. Environ Sci Pollut Res 22(10):7754–7765. doi:10.1007/s11356-015-4182-7

Ferretti V, Pomarico S (2013) Ecological land suitability analysis through spatial indicators: an application of the Analytic Network Process technique and ordered weighted average approach. Ecol Indic 34:507–519. doi:10.1016/j.ecolind.2013.06.005

Isalou AA, Zamani V, Shahmoradi B, Alizadeh H (2013) Landfill site selection using integrated fuzzy logic and Analytic Network Process (F-ANP). Environ Earth Sci 68(6):1745–1755. doi:10.1007/s12665-012-1865-y

Khan S, Faisal MN (2008) An Analytic Network Process model for municipal solid waste disposal options. Waste Manag 28(9):1500–1508. doi:10.1016/j.wasman.2007.06.015

Kharat MG, Kamble SJ, Raut RD, Kamble SS, Dhume SM (2016) Modeling landfill site selection using an integrated fuzzy MCDM approach. Model Earth Syst Environ 2(2):1–16. doi:10.1007/s40808-016-0106-x

Makropoulos CK, Butler D (2006) Spatial ordered weighted averaging: incorporating spatially variable attitude towards risk in spatial multi-criteria decision-making. Enviro Model Software 21(1):69–84. doi:10.1016/j.envsoft.2004.10.010

Malczewski J (1999) GIS and multicriteria decision analysis. Wiley, London

Malczewski J (2006) Ordered weighted averaging with fuzzy quantifiers: GIS-based multicriteria evaluation for land-use suitability analysis. Int J Appl Earth Obs Geoinf 8(4):270–277. doi:10.1016/j.jag.2006.01.003

Malczewski J, Rinner C (2005) Exploring multicriteria decision strategies in GIS with linguistic quantifiers: a case study of residential quality evaluation. J Geogr Syst 7(2):249–268. doi:10.1007/s10109-005-0159-2

Moeinaddini M, Khorasani N, Danehkar A, Darvishsefat AA (2010) Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj). Waste Manag 30(5):912–920. doi:10.1016/j.wasman.2010.01.015

Motlagh ZK, Sayadi MH (2015) Siting MSW landfills using MCE methodology in GIS environment (Case study: Birjand plain, Iran). Waste Manag 46:322–337. doi:10.1016/j.wasman.2015.08.013

Rahmat ZG, Niri MV, Alavi N, Goudarzi G, Babaei AA, Baboli Z, Hosseinzadeh M (2017) Landfill site selection using GIS and AHP: a case study: Behbahan, Iran. KSCE J Civ Eng 21(1):111–118. doi:10.1007/s12205-016-0296-9

Saaty TL (1996) Decision making with dependence and feedback: the analytical network process. RWS Publications, Pittsburgh

Saaty TL, Vargas LG (2006) Decision making with the Analytic Network Process: economic, political, social and technological applications with benefits, opportunities, costs and risks. Springer Science & Business Media, Berlin

Shahabi H, Keihanfard S, Ahmad BB, Amiri MJ (2014) Evaluating Boolean, AHP and WLC methods for the selection of waste landfill sites using GIS and satellite images. Environ Earth Sci 71(9):4221–4233. doi:10.1007/s12665-013-2816-y

Uyan M (2014) MSW landfill site selection by combining AHP with GIS for Konya, Turkey. Environ Earth Sci 71(4):1629–1639. doi:10.1007/s12665-013-2567-9

Yager RR (1988) On ordered weighted averaging aggregation operators in multicriteria decision making. IEEE Trans Syst Man Cybernet 18(1):183–190. doi:10.1109/21.87068

Zadeh LA (1965) Fuzzy sets. Inf Control 8(3):338–353. doi:10.1016/S0019-9958(65)90241-X

Zadeh LA (1997) Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic. Fuzzy Sets Syst 90(2):111–127. doi:10.1016/S0165-0114(97)00077-8