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ORIGINAL ARTICLE

Landfill site selection by decision-making tools based on fuzzy multi-attribute decision-making method

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Abstract Landfill site selection is a complex and time-consuming process, which requires evaluation of several factors where many different attributes are taken into account. Decision makers always have some difficulties in making the right decision in the multiple attribute environments. After identifying candidate sites, these sites should be ranked using decision-making methods. This study applies Chang's fuzzy AHP-based multiple attribute decision-making (MADM) method for selection of the best site of landfills based on a set of decision criteria. The Fuzzy Analytic Hierarchy Process (FAHP) was designed to make pairwise comparisons of selected criteria by domain experts for assigning weights to the decision criteria. Analytic Hierarchy Process (AHP) is used to make pairwise comparisons and assign weights to the decision criteria. It is easier for a decision maker to describe a value for an alternative by using linguistic terms and fuzzy numbers. In the fuzzy-based AHP method, the rating of each alternative was described using the expression of triangular fuzzy membership functions. Once the global weights of the criteria is calculated by AHP, they are incorporated into the decision matrices composed by decision maker and passed to fuzzy-AHP method which is used to determine preference order of siting alternatives. In this study, a computer program based on the Chang's fuzzy method was also developed in MATLAB environment for ranking and selecting the landfill site. As an example of the proposed methodology, four different hypothetical areas were chosen and implemented to demonstrate the effectiveness of the program. By using this program, the precision was improved in comparison with traditional methods and computational time required for ranking and selecting the suitable landfill site was significantly reduced.

Keywords Multiple attribute decision making · Landfill · Waste management · Fuzzy analytic hierarchy process · Site selection

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Introduction

The disposal of waste material is a problem of ever-increasing concern. A wide variety of waste materials are being disposed of in the atmosphere because of urbanization and industrialization enhancements. In simple terms, landfilling is the disposal of solid waste in voids on the land (Baban and Flannagan 1998) and has been used for many years as the most common method for the disposal of solid waste generated by different communities (Komilis et al. 1999). Selecting the most suitable site is the first and in fact, the most important step for pollution control and minimizing environmental hazards. Siting a sanitary landfill requires an extensive evaluation process in order to identify the best available disposal location. This location must comply with the requirements of governmental regulations and at the same time must minimize economic, environmental, health, and social costs (Siddiqui et al. 1996; Al-Yaqout et al. 2002). Selecting a landfill site is a multi-attribute decision process where various attributes are considered and imply the assessment and selection of suitable areas, among several possible alternatives, based on certain criteria (Melo et al. 2006; Javaheri et al. 2006).

Generally, landfill site selection can be divided into four main phases: the first phase is the identification of potential sites through preliminary screening based on constraints (exclusionary criteria) and usually in this phase, three to five sites are selected. In the second phase, candidate sites are evaluated based on attributes, ranked, and appropriate sites are selected and identified (2–3 sites). The third phase is the evaluation of their suitability based on environmental impact assessment, economic feasibility, engineering design, and cost comparison. In the final phase, the best site is selected. Figure 1 illustrates the phases in selection of landfill sites and the proposed methodology for siting in the second phase.

A number of methods for location selection have been developed and used for landfill site selection process. Siddiqui et al. (1996) used Geographical Information Systems (GIS) and AHP procedure to aid in preliminary site selection. The GIS was used to manipulate and present spatial data, while the AHP was used to rank potential landfill areas based on a wide variety of criteria, such as hydrogeology, land use, and proximity from urban centers. Charnpratheep et al. (1997) explored the prospect of coupling fuzzy set theory with GIS for the preliminary screening of landfill sites in Thailand. Proximity of geographic objects, slope and elevation were the criteria used for the investigation. Javaheri et al. (2006), Mahini and Gholamalifard (2006) presented weighted linear combination (WLC) method by using GIS as a practical instrument to evaluate the suitability of landfill sites in Iran. Kao and Lin (1996) proposed a siting model that was explored for using with raster-based GIS. A mixed integer programming model was developed to obtain a landfill site with optimal compactness of the site, which refers to the ratio of perimeter to site area. Several techniques for landfill siting also can be found in the literature (Sener et al. 2006; Sadek et al. 2006; Gemitzi et al. 2007; Soltanmohammadi et al. 2009; Mahler and Lima 2003; Zamorano et al. 2008; Sumathi et al. 2008; Serwan and Flannagan 1998; Vatalis and Manoliadis 2002; Chau 2005; Banar et al. 2007; Hatzichristos and Giaoutzi, 2006; Al-Jarrah and Abu-Qdais, 2006; Chang et al. 2008; Ojha et al. 2007; Golestanifar and Aghajani Bazzazi 2010).

Different quantitative and qualitative attributes influence the selection of the landfill site at each phase of the process. Attributes such as public acceptance, ecosystem quality, aesthetic quality, and infrastructure conditions are some of the qualitative factors. Since in GIS, qualitative factors cannot be used appropriately, in most literature, GIS has been used for preliminary siting and selecting the candidate sites in the first phase. After identification of candidate sites, in second phase, candidate sites should be ranked and the best sites should be identified. Therefore, in this phase of landfill siting process, it is necessary to gather exact qualitative and quantitative data; subsequently, the multi-attribute decision-making methods should be used for identifying the best sites. Many potential criteria should be considered in the selection of landfill sites; therefore, the problem of landfill siting can be viewed as a multi-attribute decision-making (MADM) problem.

The analytic hierarchy process (AHP) was developed by Saaty (1990), based on an axiomatic foundation that has established its mathematical viability. The widespread

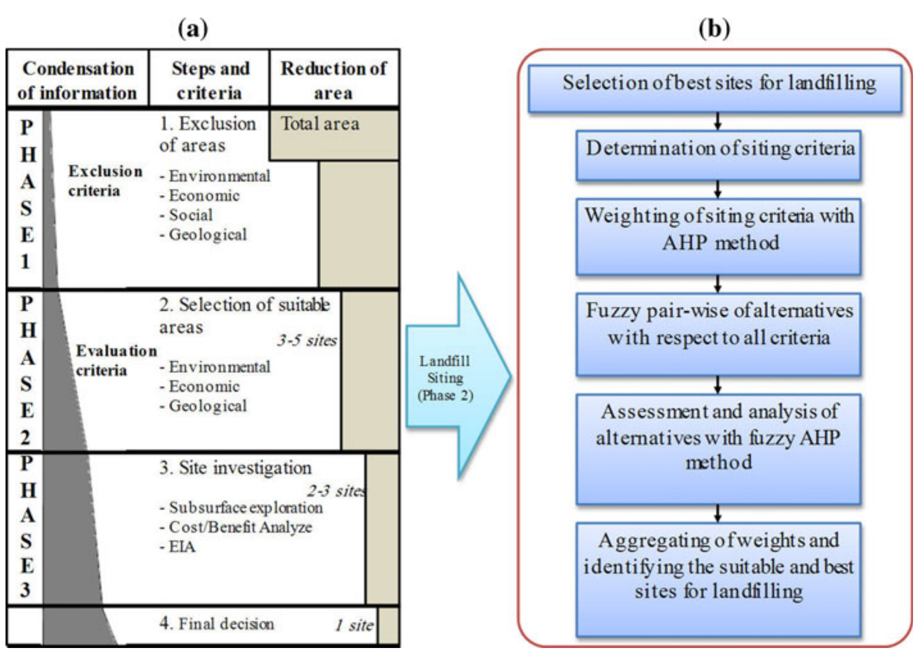


Fig. 1 Proposed Landfill site selection process (**a**) Landfill site selection phases (**b**) proposed methodology for site ranking

applications of the technique are due to its simplicity and ability to cope with complex decision-making problems. For a long time, the AHP technique attracted the interest of many researchers because of its easy applicability and interesting mathematical properties. In this paper also, AHP was used which allows users to specify the landfill siting through consideration of specific relative importance of each one of governing attributes.

However, due to the availability and uncertainty of information in decision process as well as the vagueness of human feeling and recognition, it is easier for a decision maker to describe a value for an alternative by using linguistic terms. Fuzzy set theory can play a significant role in this kind of decision situation (Zadeh 1965). Humans are unsuccessful in making quantitative predictions, whereas they are comparatively efficient in qualitative forecasting. Further, humans are more prone to interference from biasing tendencies if they are forced to provide numerical estimates since the elicitation of numerical estimates forces an individual to operate in a mode which requires more mental effort than that required for less precise verbal statements (Karwowski and Mital 1986). Since fuzzy linguistic models permit the translation of verbal expressions into numerical ones, thereby dealing quantitatively with imprecision in the expression of the importance of each object, some multi-attribute methods based on fuzzy relations are used. One of the most suitable fuzzy methods for solving MADM problems is fuzzy-AHP method. In this method, the pairwise comparisons in the judgment matrix are fuzzy numbers that are modified by the designer's emphasis. Various authors have proposed a number of fuzzy-AHP methods. These methods are systematic approaches to the alternative selection and justification problem by using the concepts of fuzzy set theory and hierarchical structure analysis (Kahraman et al. 2003a). Some of the fuzzy-AHP methods are in the literature (Laarhoven and Pedrycz, 1983; Buckley 1985; Chang 1992, 1996; Leung and Cao 2000). In this study, we prefer Chang's (1996) extent analysis method since the steps of this approach are relatively easier than the other fuzzy-AHP approaches and similar to the crisp AHP and has been used in many other decision-making problems (Bozdag et al. 2003; Kahraman et al. 2003, 2004; Kwong and Bai 2003; Dagdeviren et al. 2008; Buyukozkan et al. 2004; Gumus 2009; Naghadehi et al. 2009; Celik et al. 2009; Chan and Kumar 2007). There are many parameters that influence landfill siting, and as a result, using fuzzy decision-making methods in siting process manually is tedious and time consuming, and also, errors-prone. Therefore, a program is provided for ranking of candidate sites, based on receiving data and main criteria and use of fuzzy decision-making method, and finally selection of suitable sites in second phase of landfill site selection process. An example has been prepared to show the validity of the program and the proposed methodology in solving landfill site selection problems.

Therefore, a model for landfill site selection in the second phase of siting process is suggested that consists of two MADM methods. AHP is preferred for criteria weighting and Chang's fuzzy-AHP method is chosen to derive preference order of alternatives that would provide the optimum landfill sites from decision maker's point of view.

This paper is organized as follows. In "Theory review", we will express theory review and some introductions to AHP method, fuzzy numbers and concepts of fuzzy analytic hierarchy process methods. In "Site selection process and methodology", siting model, methodology and main siting criteria are introduced. Consequently, this section presents illustrative example for solving the landfill siting problem and introduces the "Ranking program" and its application in landfill site selection. Finally, discussion in "Discussion", and conclusion in "Conclusion" are listed.

Theory review

Analytic hierarchy process

The weights of attributes are calculated by means of AHP method developed by Saaty (1990). The procedure of AHP weighting can be summarized as follows:

Firstly, pairs of elements of the n-attribute hierarchical framework are compared within pairwise comparison matrixes A, according to Eq. 1:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{11} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

$$a_{ij} = 1/a_{ji} \qquad a_{ii} = 1, \qquad i, j = 1, 2, \ldots, n.$$

where, a_{ij} can be interpreted as the degree of preference of ith attribute over jth attribute; and vice versa. Secondly, each column of the pairwise comparison matrix is divided by sum of entries of the corresponding column to obtain the normalized comparison matrix. The eigenvalues λ_i of this matrix would give the relative weight of attribute i.

Finally, the obtained relative weight vector is multiplied by the weight coefficients of the elements at the higher levels, until the top of the hierarchy is reached. The result is global weight vector W of the attributes and can be shown as Eq. 2:

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \tag{2}$$

Since the comparison is based on the subjective evaluation, a consistency ratio is required to ensure the selection accuracy. The consistency index (CI) of the comparison matrix is computed as follows:

$$\mathrm{CI} = (\lambda_{\max} - n)/(n - 1) \tag{3}$$

Where, $\lambda_{\max}$ is the highest eigenvalue of the pairwise comparison matrix. The closer the inconsistency index is to zero, the greater the consistency so the relevant index should be lower than 0.10 to accept the AHP results as consistent (Saaty 1990).

Fuzzy sets

In order to deal with vagueness of human thought, Zadeh (1965) first introduced the fuzzy set theory. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function which assigns to each object a grade of membership ranging between zero and one. Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling: uncertain systems for common sense reasoning in decision-making in the absence of complete and precise information. Fuzzy sets theory providing a more widely frame than classic sets theory, has been contributing to capability of reflecting real world. Modeling using fuzzy sets has proven to be an effective way for formulating decision problems where the information available is subjective and imprecise (Kahraman et al. 2003b; Ertuğrul and Karakaşoğlu 2008).

It is possible to use different fuzzy numbers according to the situation. In applications, it is often convenient to work with triangular fuzzy numbers (TFNs) because of their computational simplicity; moreover, they are useful in promoting representation and information processing in a fuzzy environment. Therefore, in this paper, we use triangular fuzzy numbers.

Triangular fuzzy number is a special kind of fuzzy sets. A triangular fuzzy number can be denoted as: $N = (a, b, c)$. Figure 2 is an illustration of the membership function of a triangular fuzzy number.

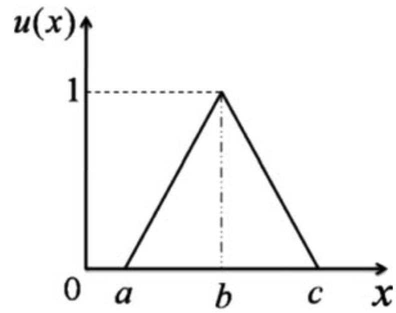


Fig. 2 Triangular fuzzy number

The membership function of triangular fuzzy numbers is:

$$u(x) = \begin{cases} \frac{x-a}{b-a}, & \text{if} \quad a \le x \le b; \\ \frac{c-x}{c-b}, & \text{if} \quad b \le x \le c; \\ 0, & \text{else} \end{cases} \tag{4}$$

Particularly, when $a = b = c$, triangular fuzzy numbers become crisp numbers. That is, crisp numbers can be considered as a special case of fuzzy numbers.

Fuzzy analytic hierarchy process

The analytic hierarchy process, since its invention, has been a tool at the hands of decision makers and researchers, becoming one of the most widely used multiple attribute decision-making tools. Although the purpose of AHP is to capture the expert's knowledge, the traditional AHP still cannot really reflect the human thinking style. The traditional AHP method is problematic as it uses an exact value to express the decision maker's opinion in a comparison of alternatives. AHP method is often criticized, due to its use of unbalanced scale of judgments and its inability to adequately handle the inherent uncertainty and imprecision in the pairwise comparison process. To overcome all these shortcomings, fuzzy analytical hierarchy process was developed for solving the hierarchical problems. Decision makers usually find that it is more accurate to give interval judgments than fixed value judgments. Fuzzy-AHP method is a popular approach for multiple attribute decision-making and has been widely used in the literature (Kahraman et al. 2003b; Ertuğrul and Karakaşoğlu 2008). In this study the extent fuzzy-AHP is utilized, which was originally introduced by Chang (1996).

Let $X = \{x_1, x_2, \ldots, x_n\}$ be an object set, and $G = \{g_1, g_2, \ldots, g_n\}$ be a goal set. According to the method of Chang's (1996) extent analysis, each object is taken and an extent analysis for each goal is performed respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$M_{gi}^1, M_{gi}^2, \ldots, M_{gi}^n \quad i = 1, 2, \ldots, n$$

Where all the $M_{gi}^1 (j = 1, 2,\ldots, m)$ are triangular fuzzy numbers. The steps of Chang's extent analysis can be given as in the following:

Step 1: The value of fuzzy synthetic extent with respect to the ith object is defined as

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \tag{5}$$

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{6}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \quad (7)$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right). \quad (8)$$

Step 2: As $S_1 = (l_1, m_1, u_1)$ and $S_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $S_2 = (l_2, m_2, u_2) \geq S_1 = (l_1, m_1, u_1)$ is defined as:

$$V(S_2 \geq S_1) = \sup_{y \geq x}\left[\min\left(\mu_{S_1}(x), \mu_{S_2}(y)\right)\right] \quad (9)$$

So it can be expressed as follows:

$$V(S_1 \geq S_2) = hgt(S_1 \cap S_2) = \mu_{S_2}(d) = \left\{\begin{array}{ll} 1 & if(m_1 \geq m_2) \\ 0 & if(l_2 \geq u_1) \\ \frac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)} & \text{otherwise} \end{array}\right\}. \quad (10)$$

Figure 3 illustrates Eq. 10 where d is the ordinate of the highest intersection point D between μS_1 and μS_2. To compare S_1 and S_2, we need both the values of $V(S_1 \geq S_2)$ and $V(S_2 \geq S_1)$.

Step 3: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy M_i $(i = 1, 2, k)$ numbers can be defined by

$$V(S_1 \geq S_2) = hgt(S_1 \cap S_2) = \mu_{S_2}(d) = \left\{\begin{array}{ll} 1 & if(m_1 \geq m_2) \\ 0 & if(l_2 \geq u_1) \\ \frac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)} & \text{otherwise} \end{array}\right\}. \quad (11)$$

Assume that $d(A_i) = \min V(S_i \geq S_k)$ for $k = 1, 2, \ldots, n;\ k \neq i$. Then the weight vector is given by:

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \quad (12)$$

where $A_i = (i = 1, 2, \ldots n)$ are n elements.

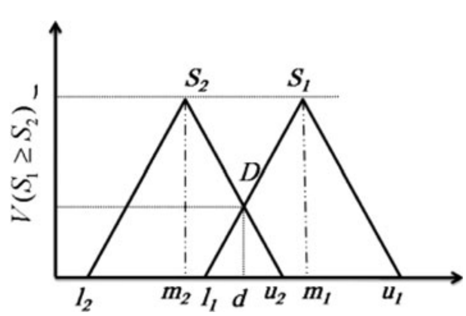


Fig. 3 The intersection between S_1 and S_2

Step 4: Via normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T \quad (13)$$

where W is a non-fuzzy number.

Site selection process and methodology

As mentioned earlier, landfill site selection can generally be divided into four main phases. The first phase, is the identification of potential sites through preliminary screening based on constraints (exclusionary criteria); in the second phase, the candidate sites are evaluated based on main attributes (evaluation criteria), ranked and appropriate sites are identified. Result of the first phase is exclusion of inappropriate areas and identification of candidate sites. In the second phase, candidate sites are ranked and the best sites are determined.

The approach proposed in this study for landfill siting in second phases of selection process comprises the following steps:

Determination of landfill siting criteria

Before applying the proposed model for landfill siting, main attributes should be defined. Most of these attributes were extracted from regulation, legislation, and expertise (Kao and Lin 1996). In assessing a site as a possible location for solid waste landfilling, many factors should be considered. These factors may be presented in many ways; however, the most useful way is the one that may be easily understood by the community (Tchobanoglous et al. 1993). Also, the process of siting solid waste landfills involves a number of stakeholders and sets of requirements such as legislation, restrictions, rules, local expertise and experience. This implies that attributes may vary from one region or country to another. In order to propose the most reasonable criteria, a literature research and a survey conducted among the target group and the experiences of the environmental sector experts have been combined. Therefore, five experts (two academia and three engineers) from areas of environmental and landfill engineering were selected. Based on the previous mentioned literature review in introduction and other researches such as (Baban and Flannagan 1998; Komilis et al. 1999; Mahini and Gholamalifard 2006; Siddiqui et al. 1996; Al-Yaqout et al. 2002), and the opinions of experts, the attributes associated with landfill siting were grouped into five main categories (Table 1).

Weighting of criteria by AHP

In this step, the hierarchical structure of siting process is developed (Fig. 4). Hierarchical structure is used for

Table 1 Landfill siting criteria

No.	Main groups	Criteria	Abbreviations
1	Environmental	Wetland	WET
2		Floodplain	FLD
3		Groundwater table	GWT
4		Groundwater quality	GWQ
5		Thickness of the saturated zone	TSZ
6		Groundwater resource	GWR
7		Surface water resource	SWR
8		Sensitive ecosystems	SEC
9		Rainfall	RNF
10		Wind	WND
11		Residential area	RES
12	Economic	Waste transport cost	WTC
13		Excavation cost	EXC
14		Operator cost	OPC
15		Land value	LDV
16		Soil and liner transport cost	STC
17		Number of equipment and operators	NEO
18		Restoration cost	RSC
19	Technical	Site capacity	CPC
20		Airport	ARP
21		Highway and railway	HRW
22		Infrastructure	IFS
23		Land use	LDU
24		Accessibility	ACS
25		Snow and glacial period	SGP
26		Special disposal location such as Abandoned mines, wells and old quarries	SDL
27	Social	Public acceptance	PAC
28		Military, industrial and sports areas	MIS
29		Historical areas	HIS
30		Aesthetic quality (visibility)	ASQ
31		Job opportunity	JOP
32		Local legislation	LEG
33		Requirement for restoration	RRS
34	Geological	Permeability	PRM
35		Fault area	FLT
36		Seismic zone	SSZ
37		Surface geology	SGE
38		Topography (slope and altitude)	TPG
39		Anticline and syncline	ASC

weighting of criteria with AHP method. With standing to the fact that, such a procedure is common in mathematics, Expert Choice software was used in this study, which is a multi objective decision support tool.

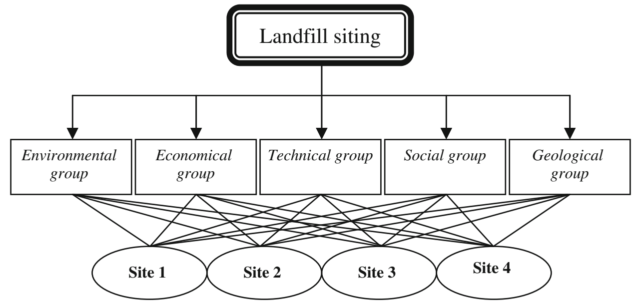


Fig. 4 Hierarchical structure of siting process

According to Eq. 3, an acceptable overall inconsistency index of 0.03 motivated the authors to accept final weighting result of the AHP method. Descending order of the calculated weights for the studied example according to subjective judgments of decision maker has been illustrated in Fig. 5.

Alternatives determination and assessments

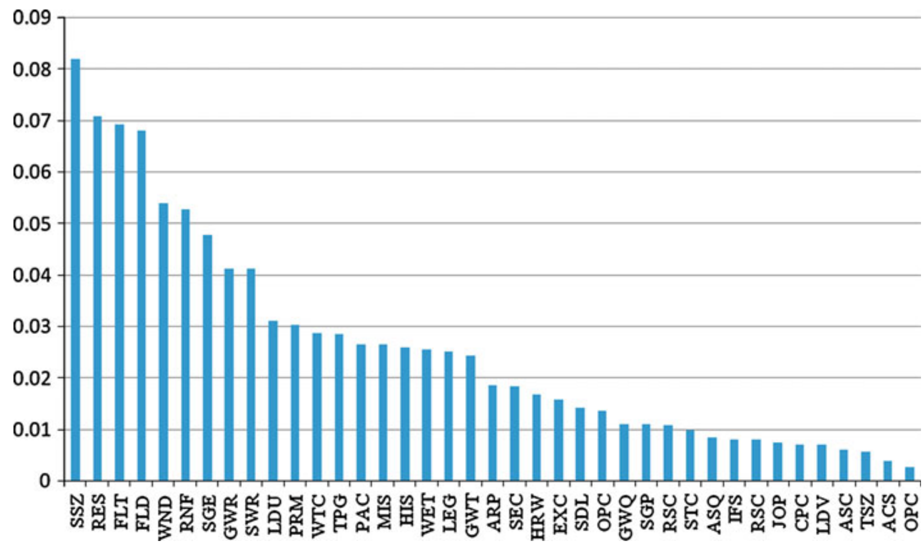
The selection of disposal sites is carried out through a multi level screening process. For example, a GIS-based constraint mapping is employed to eliminate the environmentally unsuitable sites and to narrow down the number of sites for further consideration. Therefore, the result of first phase of landfill site selection process is determination of suitable sites (usually 3–5 sites) for locating landfill sites. To illustrate the methodology, four hypothetical sites have been chosen that are suitable to be selected as landfill and thus was chosen from the first phase of siting process. The next step is assessment of alternatives based on 39 criteria. A program is developed to solve this kind of multi-attribute decision-making problems.

"Ranking program" and its application in landfill site selection

Many parameters influence landfill siting; as a result, using decision-making methods in siting process manually is time consuming, and error-prone. Therefore, a program is developed in MATLAB environment that increases the accuracy and speeds up the ranking and selection process. This program ranks candidate sites and is based on the fuzzy set theory and application of linguistic terms. The fuzzy scale for relative importance used to measure the relative weights is given in Fig. 6 and Table 2. This scale which is proposed by Kahraman et al. (2006) can be used for solving fuzzy decision-making problems.

One of the most important specifications of this program is its simple application, so in pairwise comparison, user applies the simple linguistic terms (i.e., preference of site 1

Fig. 5 Global weight of landfill siting criteria



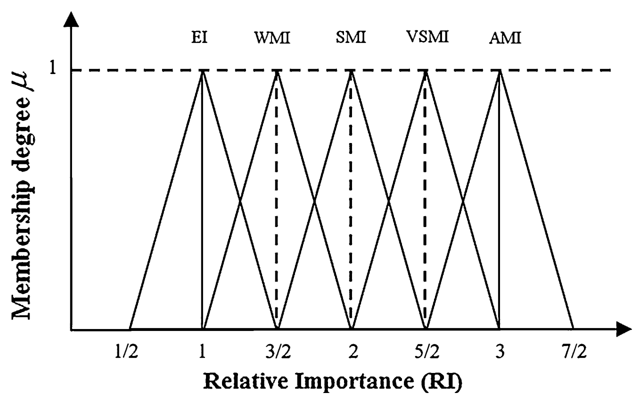


Fig. 6 Linguistic scale for relative importance

Table 2 Linguistic scale for importance

Linguistic scale for importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal	(1, 1, 1)	(1, 1, 1)
Equally important (EI)	(1/2, 1, 3/2)	(2/3, 1, 2)
Weakly more important (WMI)	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly more important (SMI)	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Very strongly more important (VSMI)	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Absolutely more important (AMI)	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

rather than site 2 is strongly more important). After the completion of the pairwise comparisons, program converts linguistic terms to fuzzy numbers and ranks the alternatives by using Chang's fuzzy-AHP method. The algorithm of the proposed method and the programming algorithm are illustrated in Fig. 7.

Steps of program application

Four hypothetical sites are selected to show how the steps are applied in the 'Ranking program' landfill siting process. The applied steps in the program can be expressed as follows:

Step 1: "siting" program is run at first in MATLAB. In this window, all of ranking attributes has been shown (Fig. 8).

Step 2: In this step, the user selects the number of alternatives (i.e., four alternatives in this example). By selecting this quantity, the program identifies the required matrix size for pairwise comparisons.

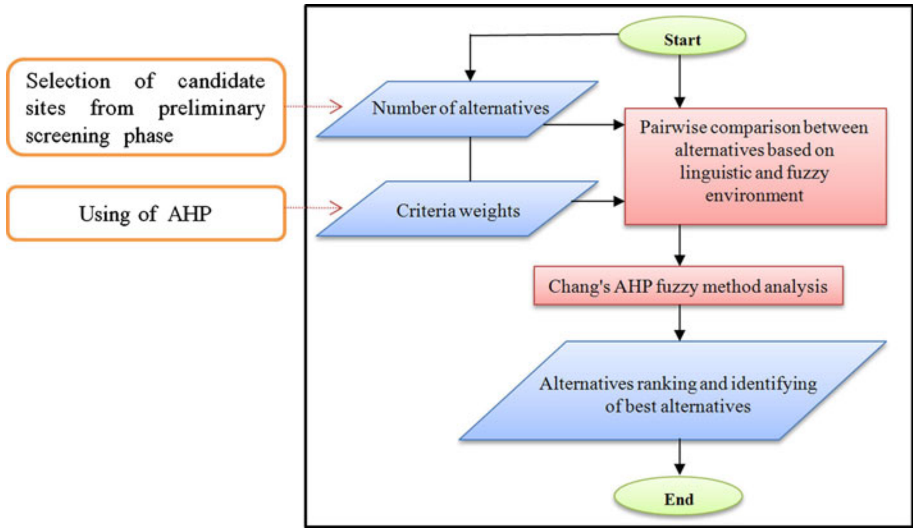
Step 3: After selecting the number of alternatives, based on the available data, the user should import attribute weights into the empty box beside the attribute name. Then, user should go to fuzzy pairwise comparison phase for the same attribute by pushing the attribute button.

Step 4: Then, a new page is opened in which a matrix is presented. The matrix size is equal to the number of alternatives. The user must complete fuzzy pairwise comparison between alternatives for the selected attribute. Fuzzy pairwise comparisons are carried out using the linguistic terms illustrated in Table 1. For example, Fig. 9 shows completed fuzzy matrix for "distance to wetland" criterion. After completion of the matrix, the user returns to the previous page and the latter steps should be accomplished for all attributes and alternatives.

Calculation and ranking methodology

After completion of all matrices for all attributes and alternatives, the program converts linguistic terms to fuzzy numbers based on Table 1, and then calculates alternative

Fig. 7 "Ranking program" algorithm



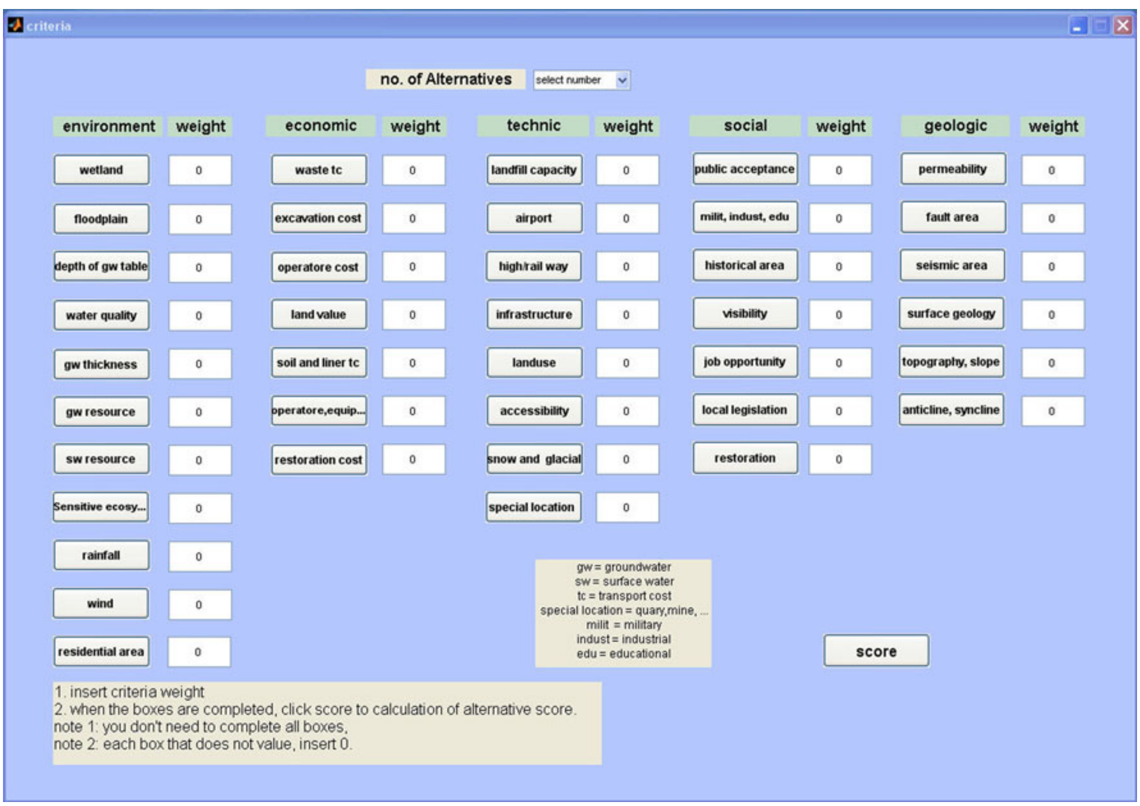


Fig. 8 Criteria and pairwise comparison page

weights by means of Chang's fuzzy-AHP method. The steps included in this approach are relatively easier than the other fuzzy-AHP approaches, and therefore, similar to the crisp AHP it is used in many decision-making problems. Tables 3 illustrate pairwise comparison values of four alternatives for "distance to wetland" criterion that are transformed into triangular fuzzy numbers.

According to Table 3, the extent that the analysis synthesizes the values with respect to "distance to wetland" criterion is calculated such as:

$$\sum_{j=1}^{4} M_{g1}^{j} = (1,1,1) \oplus \left(\frac{2}{5},\frac{1}{2},\frac{2}{3}\right) \oplus \left(1,\frac{3}{2},2\right) \oplus \left(\frac{1}{3},\frac{2}{5},\frac{1}{2}\right)$$
$$= (2.73, 3.4, 4.16)$$

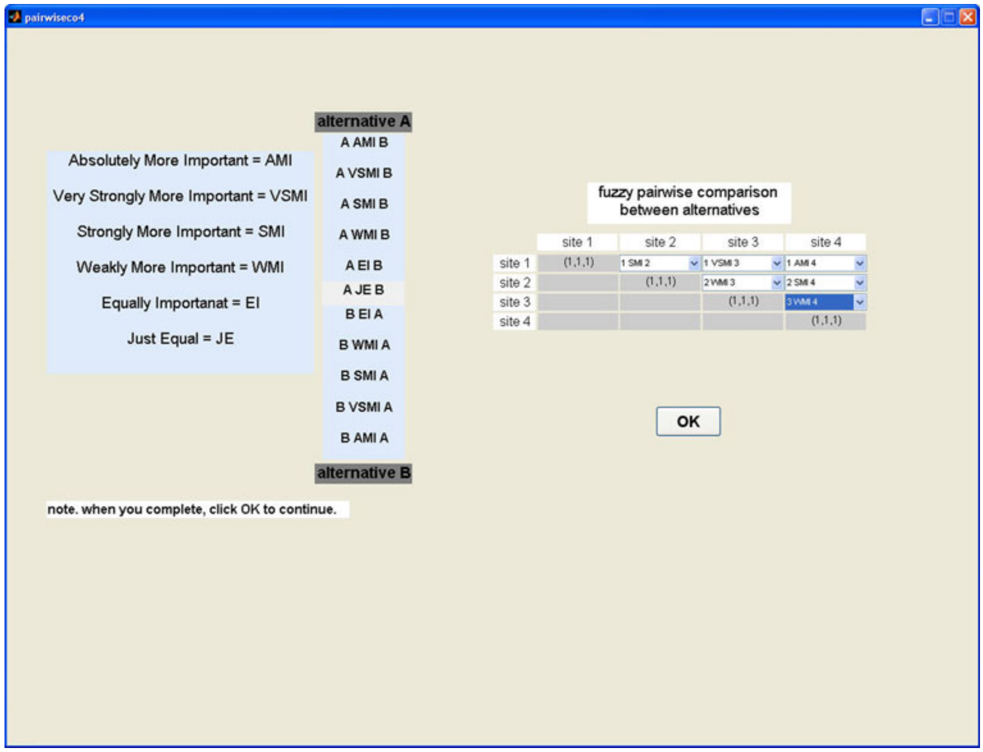


Fig. 9 Carrying out the pairwise comparison between alternatives for distance to wetland criterion

Table 3 The fuzzy evaluation matrix of alternatives with respect to "distance to wetland" criterion

Wetland	*Site 1*	*Site 2*	*Site 3*	*Site 4*
Site 1	(1,1,1)	(2/5,1/2,2/3)	(1,3/2,2)	(1/3,2/5,1/2)
Site 2	(3/2,2,5/2)	(1,1,1)	(2,5/2,3)	(1/2,2/3,1)
Site 3	(1/2,2/3,1)	(1/3,2/5,1/2)	(1,1,1)	(2/7,1/3,2/5)
Site 4	(2,5/2,3)	(1,3/2,2)	(5/2,3,7/2)	(1,1,1)

$$\sum_{j=1}^{4} M_{g2}^{j} = \left(\frac{3}{2},2,\frac{5}{2}\right) \oplus (1,1,1) \oplus \left(2,\frac{5}{2},3\right) \oplus \left(\frac{1}{2},\frac{2}{3},1\right) = (5,6.17,7.5)$$

$$\sum_{j=1}^{4} M_{g3}^{j} = \left(\frac{1}{2},\frac{2}{3},1\right) \oplus \left(\frac{1}{3},\frac{2}{5},\frac{1}{2}\right) \oplus (1,1,1) \oplus \left(\frac{2}{7},\frac{1}{3},\frac{2}{5}\right) = (2.16,2.4,2.9)$$

$$\sum_{j=1}^{4} M_{g4}^{j} = \left(2,\frac{5}{2},3\right) \oplus \left(1,\frac{3}{2},2\right) \oplus \left(\frac{5}{2},3,\frac{7}{2}\right) \oplus (1,1,1) = (6.5,8,9.5)$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = (2.73,3.4,4.16) \oplus (5,6.17,7.5) \oplus (2.16,2.4,2.9) \oplus (6.5,8,9.5) = (16.4,19.97,24.06)$$

$$\left[\sum_{i=1}^{4}\sum_{j=1}^{4} M_{gi}^{i}\right]^{-1} = \left(\frac{1}{24.06},\frac{1}{19.97},\frac{1}{16.4},\right)$$

$$S_1 = (2.73,3.4,4.16) \otimes \left(\frac{1}{24.06},\frac{1}{19.97},\frac{1}{16.4}\right) = (0.111,0.170,0.254)$$

$$S_2 = (5,6.17,7.5) \otimes \left(\frac{1}{24.06},\frac{1}{19.97},\frac{1}{16.4}\right) = (0.208,0.309,0.457)$$

$$S_3 = (2.16,2.4,2.9) \otimes \left(\frac{1}{24.06},\frac{1}{19.97},\frac{1}{16.4}\right) = (0.090,0.120,0.177)$$

$$S_4 = (6.5,8,9.5) \otimes \left(\frac{1}{24.06},\frac{1}{19.97},\frac{1}{16.4}\right) = (0.270,0.401,0.579).$$

These fuzzy values are compared by using Eq. 10, and these values are obtained:

$$V(S_1 \geq S_2) = 0; \quad V(S_1 \geq S_3) = 1; \quad V(S_1 \geq S_4) = 0$$

$$V(S_2 \geq S_1) = 1; \quad V(S_2 \geq S_3) = 1; \quad V(S_2 \geq S_4) = 0.67$$

$$V(S_3 \geq S_1) = 0.569; \quad V(S_3 \geq S_2) = 0; \quad V(S_3 \geq S_4) = 0$$

$$V(S_4 \geq S_1) = 1; \quad V(S_4 \geq S_2) = 1; \quad V(S_4 \geq S_3) = 1.$$

Then priority weights are calculated by using Eq. 11:

$$V(S_1 \geq S_2, S_3, S_4) = \min(0.639, 1, 0) = 0$$

$$V(S_2 \geq S_1, S_3, S_4) = \min(1, 1, 0.67) = 0.67$$

$$V(S_3 \geq S_1, S_2, S_4) = \min(0.569, 0, 0) = 0$$

$$V(S_4 \geq S_1, S_2, S_3) = \min(1, 1, 1) = 1$$

Priority weights form $W' = (0, 0.67, 0, 1)^{\mathrm{T}}$ vector, Where W' is a non-normal weight vector. Weight vector should be normalized. There are several methods for normalization as vector normalization, linear normalization, and non-monotonic normalization and for its simplicity (Shih et al. 2007); we use linear normalization in this proposed method. The weight vector are normalized by setting each $w' = w$, where

$$w_i = \frac{w'_i}{\sum_{i=1}^{m} w'_i}. \tag{14}$$

With $\sum_{i=1}^{m} w_i = 1$. m is the number of attributes. Via linear normalization method that applied in this research, the priority weight regarding the main goal is calculated as $W = (0, 0.401, 0, 0.599)^{\mathrm{T}}$.

Then, priority weights of alternatives for each criterion are determined by making the same calculation. At last, by aggregating the alternative and attribute weights, final results are obtained.

Let w_j be weight of jth criteria and l_{ij} be weight of alternative i for jth criteria, then the final weight of alternative weights (W) are:

$$W_i = \sum_{j=1}^{39} l_{ij} \times w_j \qquad i = 1, \ldots, 4; \tag{15}$$

Step 5. Final score (weight) of alternatives was calculated and site 3 has become the most desirable site among four alternatives with final performance value of 0.305 for this hypothetical landfill site selection problem. Similarly the sites 4, 1 and 2 have been positioned at the second, third and fourth ranks with final performance value of 0.241, 0.238 and 0.214, respectively. Results of the program with manual calculations were identical; therefore the program's capability was confirmed.

Discussion

In this study a methodology for assessment and identification of suitable locations for MSW landfill is developed that takes into account all of the qualitative and quantitative attributes, with the aid of multi-attribute evaluation techniques and fuzzy logic. This paper presented an effective Fuzzy MADM method, which is very suitable for solving the multiple attributive decision-making problems in a fuzzy environment where the available information is subjective and imprecise.

Landfill selection process can lead to situations in which certain attributes may cause increased ambiguities in the decision-making process due to lack of sufficient information. The candidate sites obtained in the first phase of landfill siting can be narrowed down using a MADM method. In response to the vague (fuzzy) conditions, domain experts in the second phase got involved for identification of attributes and structuring the decision problem. The advantage of fuzzy methods are placed upon the capability to incorporate the knowledge of the domain experts in the uncertain decision-making process when there is a lack of crisp information related to certain attributes. However, the selection of the best candidate site is dependent on the judgments of the domain experts and can be sensitive to changes in the decision weights associated with the attributes.

In this study, significant contribution has been achieved through the application of the AHP and Chang's Fuzzy-AHP methods. The AHP decomposes the complex decision problems easiness during decision-making process. Furthermore, it uses pairwise comparisons to determine the weights of the attributes by which two components are considered at a time which results 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 dependent on the preference of decision maker. One difficulty encountered in this study was the number of attributes, which was set as 39, where too many attributes yield a large amount of pairwise comparisons. From the result of weights of the attributes, we know that "seismic zone", "Residential area", and "fault area" factors are more important in the evaluation model, respectively. Attribute weights were assigned to all the criteria involved in the calculation process by AHP. It is clear that assignment of weights is based on previous knowledge of the attribute characteristics and the particularities of the study area, as well as on the experience of the scientists involved in the weight assignment process.

Chang's fuzzy AHP-based MCDM method (2008), which offers the full control over the level of desired risk and trade off and increases the total flexibility is used for selection and ranking of fuzzy numbers and is developed in the program for ease of use. The fuzzy-AHP approach used in this study shows that the fuzzy-AHP helps to resolve disparity among experts.

To test whether the developed rating program is reliable, a set of 39 data sets for four hypothetical sites are generated. These sites generally satisfy the minimum requirements of the landfill sites. Among these sites, appropriate landfill sites are identified. The selection of the final site, however, requires further analysis. Using the attributes of these data sets and the fuzzy numbers, we have carried out evaluations of these landfill sites by Chang's fuzzy-AHP method and the developed program. Using the fuzzy theory and developed program, cases 3, 4, 1 and 2 were selected as best sites, respectively. It is observed that case 3 is the most preferred site. Thus, based on various numerical experiments, the evaluation of different fuzzy classifiers, fuzzy-AHP method and the program developed herein, it is reasonable to advocate the use of the Chang's fuzzy-AHP method for sites ranking. Chang's fuzzy-AHP method is easy to use and understand and eliminates the difficulties resulting from ranking of fuzzy numbers. Due to space limitation, data is not presented in this study. Based on the results obtained in our study as well as the comparison carried out, it can be conclude that this program is a useful tool for optimal landfills siting.

Thus, we recommend that the rating program developed in this study be used as site classifier to identify appropriate sites. Our study shows that this instrument has the potential to assist planners, decision makers and other agents involved in the process of selecting suitable sites for municipal landfills since it decreases the computation time and identifies the appropriate sites, facilitating the analysis and implementation of action plans. From the landfill siting point of view, the proposed method is a generalized model, which can be applied to a great variety of practical problems encountered in the landfill site selection.

Conclusion

Landfill site selection is one of the most important problems in waste management. Therefore, after identification of candidate sites, these sites should be ranked. For this purpose, two MADM methods are used and a program is also developed that can rank the candidate sites. The program is set based on fuzzy set theory and application of linguistic terms. Fuzzy calculation method of the program is Chang's fuzzy-AHP method which one of the most suitable methods for ranking alternatives. In this program, linguistic terms are applied that lead to simplicity of the program application, and this is the basic advantage of this program. Regarding the multiplicity of siting attributes, using this program minimizes possibility of errors outbreak in decision-making and ranking process, and consequently results in speediness of landfill site selection process. Although the fuzzy-AHP approach in this study is suitable for location selection, there is a limitation that evaluation attributes in this study are considered independent. In the real world, selection attributes are not independent and there are dependencies between them that should be considered. For this reason, analytic network process is suggested to be used in the program.

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