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Using multi-criteria evaluation techniques of fuzzy analytic hierarchy process and fuzzy TOPSIS in locating waste sanitary landfill sites

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Abstract

Due to irregular and non-normative extension of cities, a lack of appropriate model for consumption and increasing growth of waste production, sanitary landfill is the most logical and economical method for municipal waste disposal. Due to the high sensitivity of the issue, detection of potential waste landfill sites requires comprehensive techniques. Therefore, this study aimed to select a suitable location for waste sanitary landfill of Shahriar by using multi-criteria evaluation techniques of fuzzy analytic hierarchy process and FTOPSIS (Fuzzy Technique for Order Preference by Similarity to Ideal Solution). First, the effective criteria for the selection of waste landfill were collected from the relevant organizations and they were analyzed and standardized by geographic information systems. Then, criteria weights were calculated by fuzzy analytic hierarchy process and after weights were applied in corresponding layers, layers were overlaid by fuzzy functions. Next, options were prioritized by FTOPSIS method. Thirty-one appropriate options were obtained by implementing above methods. Then prioritizing led to one option as the best site, which is located in the southwest of Shahriar. The results showed that selected options are located in a better site than the current landfill and this combined approach has a better performance than other methods because of considering the imprecise nature of phenomena.

Keywords: Analytic, Evaluation, Hierarchy, Technique

Introduction

Municipal solid wastes are one of the major problems of governments and urban planners around the world [1]. With growing urbanization and also the desire to live in cities, a greater amount of waste is produced and unfortunately this problem aggravates every day [2]. Disposal of municipal waste has been an issue in human societies for many years. First, the easiest and most practical way to resolve this problem was to disperse and bury wastes in wasteland outside the city boundaries, or burn them to prevent contamination. For a long time, this method was common as the most practical approach in many parts of the world, regardless of its adverse effects [3]. Most of these places lack the potential to take types of waste, especially toxic materials, so they create numerous environmental problems. Hence, since long ago, some city authorities have revised municipal solid wastes disposal under their management and have reviewed other methods. Sanitary waste disposal is considered as important as recycling by managers of many large cities in the world [4]. In sanitary waste disposal, waste is spread and compressed as a layer on the ground or inside natural and artificial cavities and is covered with a layer of soil or other materials. Although more than 60 years is passed from sanitary waste landfill plan while other solid waste processing and disposal methods have been developed, solid waste landfill engineering is still considered the most common methods of municipal, industrial and hazardous waste disposal. Solid waste landfill engineering has 3 stages as follows: landfill site selection, landfill preparation and landfill operations [5].

One of the most important stages of development and design of waste landfill projects is to select the optimal landfill. Landfills are strategic places defined as solid waste collection point where wastes are burned or compressed [6,7]. Selection of landfill is a complicated and time consuming process requiring the evaluation of many factors and features [8]. Several criteria are proposed for selecting an appropriate location for waste landfill, each of which has its peculiar limitations and conditions for proper site selection. In other words, each criterion is based on a scientific context such that site selection studies have gained multidimensional identity and interdisciplinary structure [9]. Basic parameters for site selection include suitability of the place in terms of geology, ecology, hydrogeology, hydrology, topography and climatic conditions. Other factors include transportation and social and economic factors [10]. Also, many features of the sanitary landfill selection process pertain to location, which has created incentives to use geographical methods and made it possible to combine multiple features by using geographic information systems (GIS) [11,12]. Hence, GIS can be used with fuzzy logic and analytic hierarchy process to find the best site for waste landfill and can prepare a powerful tool for problem solving and decision-making [13]. Fuzzy logic was developed by Professor A. Lotfi Zadeh at UC Berkeley, America for acting under uncertainty. This theory can mathematically form many concepts, variables and systems that are vague or imprecise and can provide the context for argument, control and decision-making under uncertainty [14]. Analytical hierarchy process (AHP) is a flexible, strong and simple method and is best applied under conditions that selection criteria are opposite. The multi-criteria evaluation method was first suggested by Thomas L. Saaty and has had numerous applications so far, particularly in regional planning [15]. Analytical hierarchy process is in fact one of the most comprehensive systems designed for multi-criteria decision-making. This process, which is based on paired comparisons, can include various options in decision-making and can analyze sensitivity on criteria and sub-criteria. One superior advantage of this method is calculating the rate of compatibility and incompatibility of decision [16]. The above-mentioned disadvantages can be resolved by combination of AHP and fuzzy logics, besides providing the advantages of both approaches as follows: providing an understandable structure between multi-criteria decision-making with a set of quantitative and qualitative data, the presence of hierarchal, independent and understandable structure, reducing incompatibility coefficient and producing forms with priority [17]. FAHP logic reflects human thoughts in using approximate and uncertain information for decision-making [18]. Researchers have integrated the fuzzy theory and AHP to improve uncertainty and others have combined AHP and other fuzzy methods such as TOPSIS to overcome problems [16]. Likewise, Hadiani et al. developed a model by using fuzzy logic to determine the value and weight of various criteria affecting landfill site selection in Zanjan and their results were largely satisfactory with ground control [19]. Rahnama et al. used ordered weighted averaging method and GIS to select the appropriate waste landfill in Mashhad [20]. Other studies have been conducted in and out of Iran by using AHP method, the weighted linear combination, fuzzy algorithms and GIS [14,21-23]. In this study, according to methods of previous studies, and also considering the nature of natural phenomena affecting waste landfill site selection, a comprehensive combination of available methods is used including fuzzy AHP, FTOPSIS and GIS for Shahriar waste landfill site selection. Software used for this purpose included ArcGIS 10.1, Expert Choice and Matlab. The study area is Shahriar, one of 12 cities of Tehran province, with 320 square kilometers. This city is located on the west of Tehran Province, with an average altitude of 160 meters above sea level and located at 50° 56' to 51° 53' E and 35° 33' to 35° 40' N. According to census conducted in 2006, estimated population of Shahriar was 574,740, of whom 446,057 people were living in urban areas and 128,683 people in rural areas. Figure (1) shows the location of the study area.

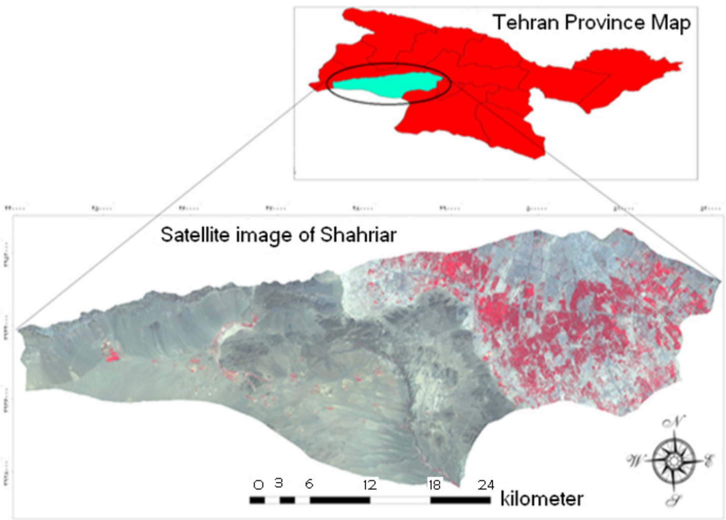

Figure 1 *The study area*

Method

Effective factors, criteria and limitations are required as map layers and should be processed and analyzed for site selection in GIS. In other words, various socioeconomic, cultural and environmental aspects in each region should be noted for selecting appropriate waste landfill site [3]:

Waste should be buried in an area which is not economically valuable.

The landfill should not be in areas of active fault movement or such a potential in future. Because the study area did not have a steep slope, this criterion was not applicable.

Landfill should not have a slope greater than 20 degrees and should be away from the city center and also important areas such as airport.

The landfill should have clay soil with greater thickness and low permeability, and the water table of groundwater should not be high and should have sufficient distance from surface waters. The area of landfill should meet the current and future needs. According to above discussions, this study was conducted in two stages, the first stage included: Data collection, Standardization, Weighting with FAHP method and Layers overlap by FUZZY OPERATOR. And in the second stage, options were prioritized by FTOPSIS (Figure 2).

Data collection: First, the parameters and criteria for appropriate sanitary landfill site selection were identified, examined and selected by reviewing standards of the Environmental Protection Agency, the Ministry of Interior and the international experiences. Criteria should have those features that adequately represent the nature of multi-criteria decision-making; in other words, they should be comprehensive, operational, degradable, non-repetitive and possibly at the minimum state [24]. The

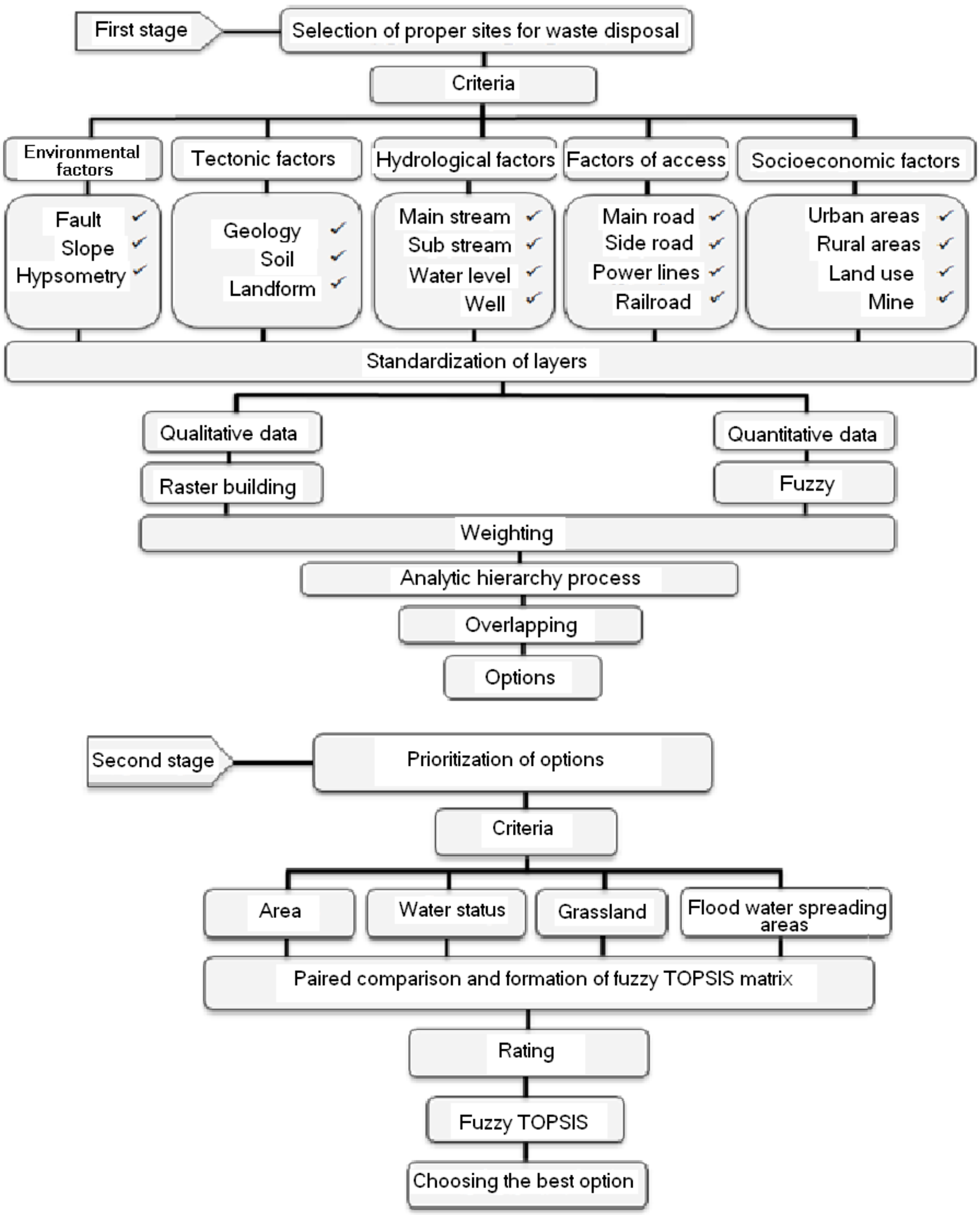

Figure 2 *Flowchart of locating waste sanitary landfill sites*

parameters are a subset of six main criteria including environmental factors, socioeconomic factors, accessibility factors, hydrological factors and tectonic factors (Table 1). Data required for site selection of sanitary waste landfill in Shahriar based on the selected criteria were provided from the Department of Natural Resources of Tehran province, and then information layers of all targeted criteria were extracted for site selection in GIS.

Standardization: After determining a set of criteria for evaluating options for decision-making, it is necessary that each criterion be stored as a map layer in the GIS database. The layers that represent evaluation criteria are referred to as criteria maps. The process of providing criteria maps is formed based on GIS functions including importing geospatial data, data storage, processing and data analysis and taking data output. A wide range of scales is used for measuring attributes. Accordingly, it is necessary that the values of different layers in the standard map be converted into comparable and proportional units [25]. Fuzzy method is used for standardization of quantitative variables. Fuzzification takes inputs and attributes a reasonable degree to each one by corresponding membership functions. Input variables should be in their own defined digital range (e.g., distance from the street from zero to 500) and outputs are the fuzzy membership degree from linguistic determining sets (between zero and one) [25]. For qualitative data (such as land use layer) each specific use was scored and then converted into a raster layer by experts' view in the range of zero to one.

Weighting by FAHP method: Criteria maps are not of the same importance in achieving the output. Therefore, it is necessary that criteria maps be scored or in other words be weighted. The aim of weighting criterion is that the importance of each criterion can be expressed relative to other criteria [25]. Fuzzy analytic hierarchy process allows decision makers to express their approximate or flexible primacies with fuzzy numbers [28]. Decision makers can express their view in general format as optimistic, pessimistic and average [29]. In 1996, extent analysis method was proposed by Chang with the following steps [30]. A hierarchical diagram and The definition of fuzzy numbers for performing paired comparisons to perform comparisons, the definition of fuzzy numbers and fuzzy scales are needed. A sample of these

Table 1 *Criteria, sub criteria and acceptable range of quantity data*

Criteria	Sub criteria	Type of data (quantity)	Limitation
environmental factors	Fault Slope Hypsometry	quantity quantity quality	150-300 meter 0-10% moderate
socioeconomic factors	Urban area Rural point Landuse Mine	quantity quantity quality quantity	2000-3000 meter 500-1000 meter Compatible use,s 150-300meter
accessibility factors	Primary road Secondary road Power line Rail road	quantity quantity quantity quantity	300-1000 meter 150-300 meter 200-400 meter 300-1000 meter
hydrological factors	Primary river Secondary river Water table well	quantity quantity quantity quantity	300-600 meter 200-400 meter 10-20 meter 300-400 meter
tectonic factors	Geology soil Landform	quality quality quality	Hard formations Fine texture Low height and plans
Environmental factors	Flood Spread area Range Water quality	quantity quality quality	300-600 meter Poor cover poor

Table 2 *Linguistic variables and their scales*

Certain number	Definition	Triangular fuzzy scale
1	Exactly equal	(1,1,1)
2	Equally important	(1/2,1,3/2)
3	Lesser importance	(1,3/2,2)
4	The importance of strong	(3/2,2,5/2)
5	The importance of a strong	(2,5/2,3)
6	Absolute importance	(5/2,3,7/2)

tables is given in the table below. Formation of paired comparison matrix using fuzzy numbers Paired comparison matrix ($\tilde{A}$) contains defined fuzzy numbers and is as follows.

$$\tilde{A} = \begin{bmatrix} 1 & \widetilde{a_{12}} & \dots & \widetilde{a_{1n}} \\ \widetilde{a_{21}} & 1 & \dots & \widetilde{a_{2n}} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{a_{n1}} & \widetilde{a_{n2}} & \dots & 1 \end{bmatrix}$$

Equation (1):

Si can be calculated by the following equation for each paired comparison matrix rows of Si which is a triangular fuzzy number.

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \times [\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}]^{-1}$$

Equation (2):

where i represents the row number, j represents the column number, and M^j_{gi} is triangular fuzzy numbers of paired comparison matrices.

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

Equation (4):

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

Equation (5):

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

Equation (3):

On above equations li and mi and ui, are the first to third components of fuzzy numbers, respectively.

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

$$= \left(\frac{\sum_{j=1}^{m} l_j}{\sum_{i=1}^{n} u_i}, \frac{\sum_{j=1}^{m} m_j}{\sum_{i=1}^{n} m_i}, \frac{\sum_{j=1}^{m} u_j}{\sum_{i=1}^{n} l_i}\right)$$

Equation (6):

Calculating the magnitude of Sis as compared to each other, in general the order of magnitude of Si to Sj is obtained from the following equation.

Equation (7):

$$V(S_i \geq S_j) = hgt(S_i \cap S_j) = \mu_{s_i}(d)$$

$$= \begin{cases} 1 & if\ m_i \geq m_j \\ 0 & if\ l_j \geq u_i \\ \dfrac{l_j - u_i}{(m_i - u_i) - (m_j - u_j)} & otherwise \end{cases}$$

Calculating the weight of criteria and options in the paired comparison matrices

To calculate the non-normalized weight of criterion, the magnitude of a triangular fuzzy number should be calculated with other triangular fuzzy numbers and finally the minimum of magnitude represents the non-normalized weight of criterion. For this purpose, the following equation is used.

Equation (8):

$d'(A_i)=\text{Min } V(S_i \geq S_k) \quad k=1,2,\dots,n, \quad k \neq i$

Calculating the final weight vector

The final weight vector is obtained from normalizing the criteria weight vector.

Equation (9):

$W=(d(A_1),d(A_2),\dots,d(A_n))^t$

Overlap: One of the most distinct and exclusive features of GIS is the integration of data for modeling, site selection and determining land suitability through evaluation of land; because, combining the criteria leads to selecting the best place to establish centers and optimal sites. Fuzzy logic is one of the different methods for combining criteria [14]. In this method different layers are combined by fuzzy operators such as PRODUCT, SUM, OR, AND GAMMA. The most important step of overlapping is selecting an appropriate operator, which depends on the nature of data and how they influence one another.

Prioritizing options using FTOPSIS: TOPSIS method was developed by Hwang and Yoon in 1981. In this method, the selected m is evaluated by parameter n. The basic logic of this model defines the ideal (positive) solution and negative ideal solution. The ideal (positive) solution is a solution that increases profitability criterion and reduces expense criterion. The optimal option is an option that has the minimum distance from the ideal solution and at the same time has the farthest distance from the negative solution. In other words, in TOPSIS method, options that have the greatest similarity to the ideal solution obtain a higher rank [31]. Giving relative importance to options is a feature of fuzzy method; while mathematical and deterministic values are used in deterministic methods. The definition of fuzzy set has been expressed in numerous papers [32-35].

Fuzzy TOPSIS: Fuzzy TOPSIS is different from TOPSIS method in that matrix elements or weights belonging to each parameter are expressed as fuzzy. The main logic of fuzzy decision-making techniques is the influence of uncertainty with human thoughts in decision-making. A literature review in this area suggests several ways to use TOPSIS technique as fuzzy [36]. Fuzzy TOPSIS employs TOPSIS method in a fuzzy environment through a fuzzy set. It has the following stages: Selecting linguistic values for each option considering criteria (selecting the importance of options), Constructing normalized weighting matrix., Obtaining positive and negative ideals., Calculating the distance of each option to positive and negative ideals., The degree of similarity to ideal solution and Prioritizing options in descending order (large to small) [37].

Results

Layers are standardized when they are prepared. In this study, the fuzzy method was used to standardize quantitative data. In selecting the function the type of increasing or decreasing criterion should be considered. For example, the distance from faults should be greater to make the site more appropriate for waste disposal, so an ascending function is used here. It should be considered that the sub-criteria of urban areas, rural areas and roads have increasing-decreasing distance due to economic and environmental reasons (Figure 3). The qualitative data were

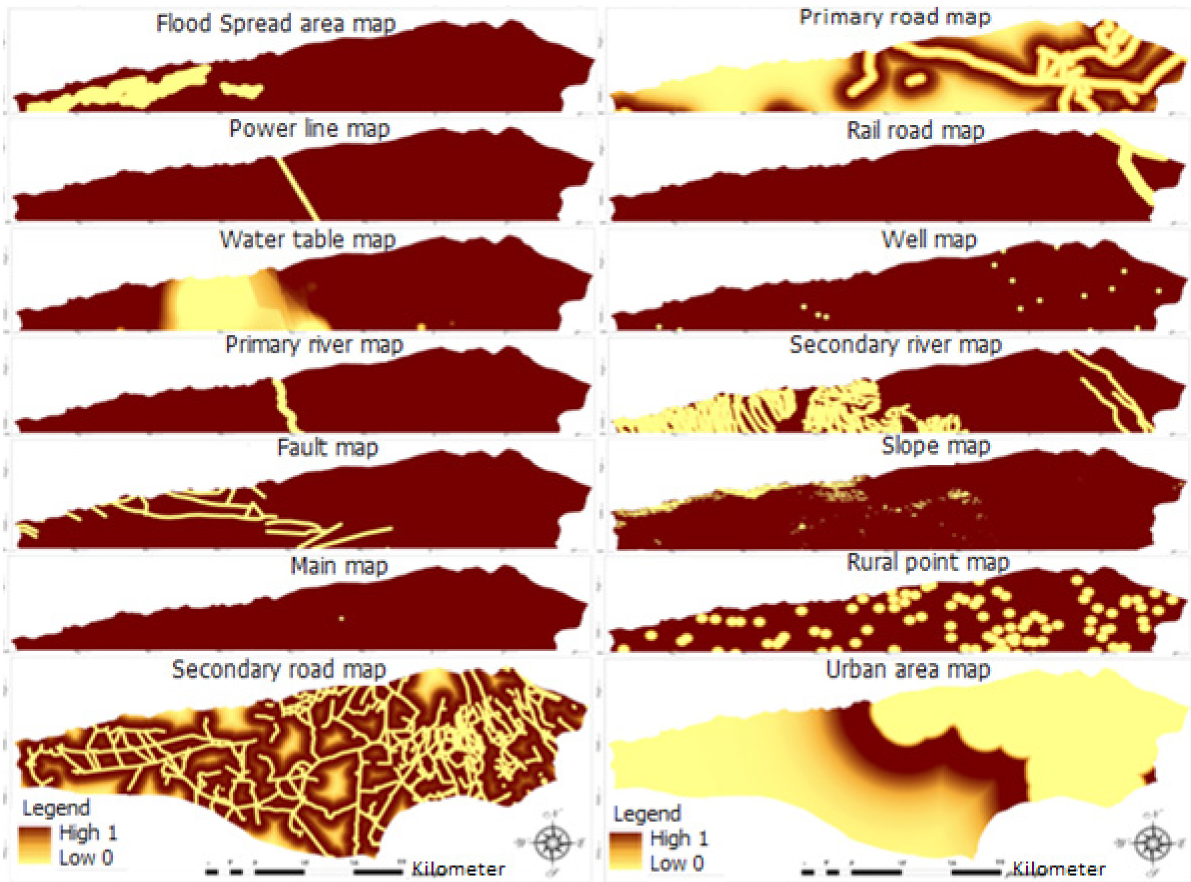

Figure 3 *Standardized criteria using fuzzy membership functions (in GIS)*

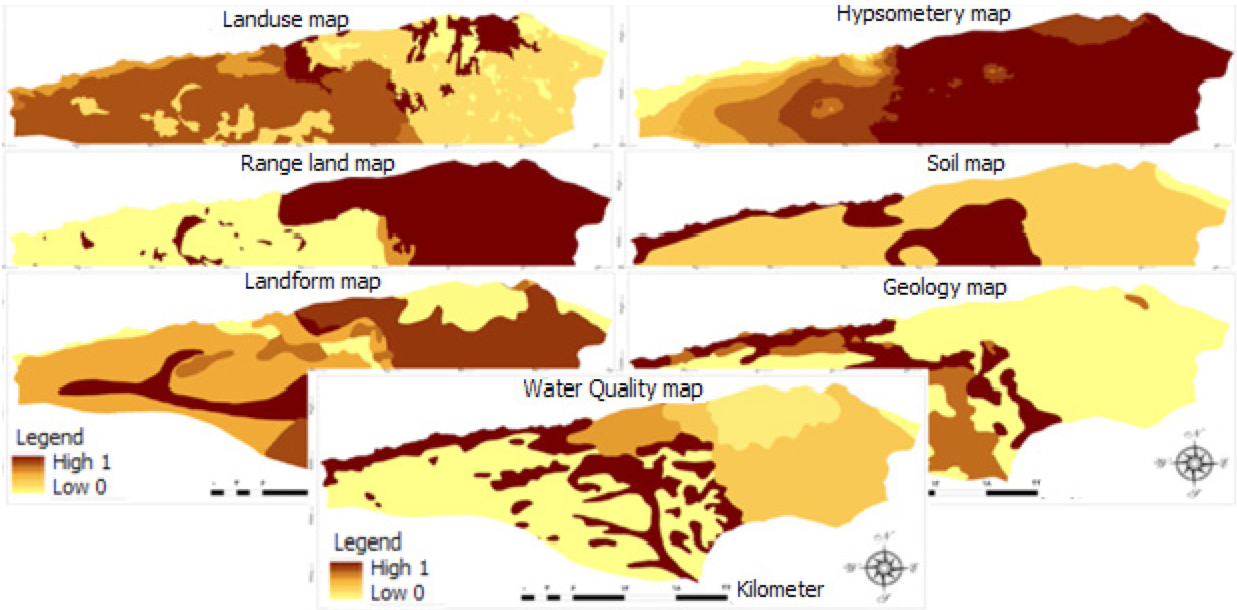

Figure 4 *Standardized criteria using raster functions (in GIS)*

converted into a raster layer with rating between zero and one (Figure 4).

When data are standardized, layers should be weighted as each criterion has a different effect on determination of the appropriate landfill site selection. In this method, first, fuzzy numbers and fuzzy scales used were determined and then paired matrices were generated by related criteria. Layers were compared by decision makers as pairwise by fuzzy numbers and entered into related tables as fuzzy numbers [20]. When paired comparison matrix was formed and completed, the weight of each criterion was determined by developmental analytical method. To this end, a software program in MATLAB environment was used and the weight of each criterion was determined by entering the data of the comparison tables which were fuzzy numbers (Table 3).

Table 3 *The final weight of layer*

Criteria	Weight	Criteria	Weight
Urban area	0.4258	Secondary river	0.1485
Rural point	0.2742	Water table	0.1598
Land use	0.1841	Well	0.3422
Mine	0.1159	Geology	0.4279
Primary road	0.379	Soil	0.4146
Secondary road	0.2232	Landform	0.1575
Power line	0.1598	Fault	0.1936
Rail road	0.2381	Slope	0.3865
Primary	0.3494	Hypsometry	0.4199

Each criterion map is multiplied by the weight from FAHP method to perform overlap with fuzzy method. Eventually, all maps are combined by fuzzy operators and the best options are selected; therefore, the resulting map shows areas suitable for waste landfill (Figure 5). The obtained sites in this map are classified as very good, good, moderate, poor and very poor.

When hierarchical fuzzy technique was used to achieve the priority weights of areas for each sub-criterion, fuzzy TOPSIS method was used for final prioritization of selected options (Figure 6). To this end, a software program in MATLAB environment was used, and the weights obtained for criteria in the second stage were calculated by FAHP method (Table 4) and TOPSIS stages were

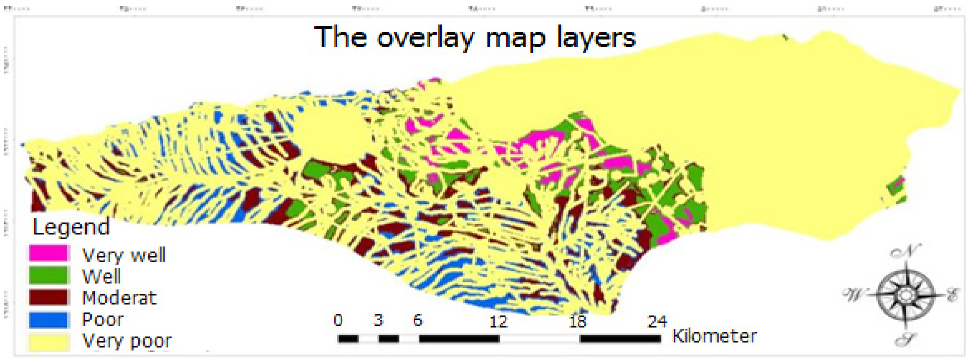

Figure 5 *Map of overlapped layers (in GIS)*

Table 4 *The calculated weight of each criterion using FAHP*

Area	Water Quality	Range	Flood Spread area	Criteria
0.182	0.2454	0.1937	0.379	Weight of FAHP

Table 5 *Prioritize options*

The similarity to the positive ideal solution (CC)	Options	Prioritize Options	The similarity to the (CC) positive ideal solution	Option	Prioritize Options
0.8944	10	17	0.8702	8	1
0.9023	26	18	0.8788	5	2
0.884	7	19	0.9113	3	3
0.8937	13	20	0.8291	18	4
0.8858	30	21	0.9247	17	5
0.8937	1	22	0.8469	27	6
0.8643	25	23	0.8755	28	7
0.8499	14	24	0.9455	20	8
0.8684	23	25	0.8516	22	9
0.8767	16	26	0.8716	11	10
0.8944	9	27	0.8858	21	11
0.8941	24	28	0.8772	19	12
0.8797	31	29	0.8714	29	13
0.8711	6	30	0.8674	2	14
0.8499	4	31	0.8672	12	15
			0.8537	15	16

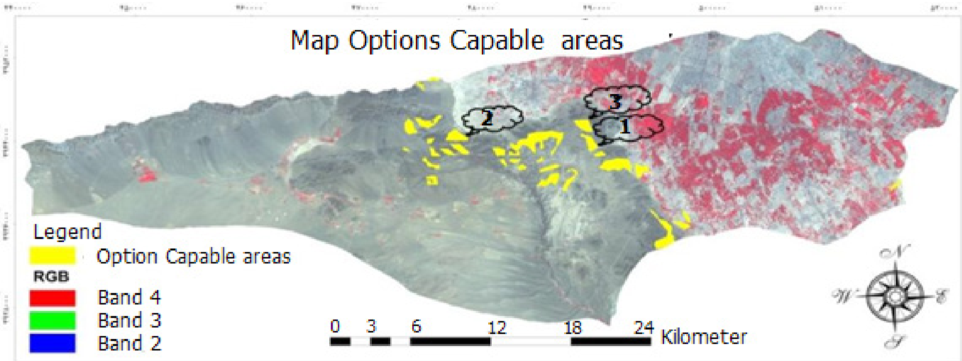

Figure 6 Map Option Capable areas and 3 top Option

implemented through equations 12-15. The results of this analysis are shown in Table 5.

Discussion

Taking active and preventive approaches in environmental planning is the most effective approach to avoid environmental consequences of human activities. Among active approaches, selecting a site for different projects including landfills will effectively prevent possible risks in waste landfills. Due to the high volume of data used to determine optimal location of landfills and the study results, it can be stated that GIS is a unique tool for evaluating operations due to its ability to use different functions, to change and manipulate data, to combine different information layers and to use satellite images and the results from interpretation of these images, so it might be impossible to conduct these studies accurately and fast without using GIS. Furthermore, the multi-criteria evaluation method employs combined information of several criteria to form an evaluation parameter and helps decision-makers to choose the correct option by providing the necessary conditions for considering various criteria. According to the results, the first priority was identified with the area of 107.49 acres as the proposed and final site for waste landfill of Shahriar. In terms of environmental factors, the proposed area is 150 m away from faults, with a slope of less than 6% and altitude of 1000-1200 meters. In terms of socio-economic factors, according to available standards, in the distance of 3-20 km away from urban areas, there is a distance more than 500 meters from rural areas, 150 meters away from mines and registered as a poor pasture. In terms of factors of access, the proposed area is 300-10000 meters away from main roads, 150-5000 meters away from subroads, more than 300 meters away from the railway and 200 meters away from power transmission lines. In terms of hydrological and tectonic factors, the area has a favorable condition regarding the required standards. A criterion that should be considered according to international and environmental standards in waste landfill site selection is windroses and land price, but they were not considered in this study due to the unavailability and restrictions. However, the absence of these layers did not affect the results, as the suggested area has poor pasture land use and is in the southwest of Shahriar and is not in the direction of main winds i.e. west direction. Therefore, the results show that the present study has better performance than previous studies because of using fuzzy-based methods in weighting and rating; as they consider continuous and imprecise nature of effective criteria and natural phenomena in weighting and rating. Among these studies, the study of Moeinaddini et al. in 2011 conducted on site selection for solid waste disposal in Alborz Province [38] and the study of Niknam and Hafezi Moghadas in 2010 on site selection for waste landfill in Golpayegan by using GIS can be noted [39]. Fuzzy-based methods were not used in rating in the first study and in weighting in the second study and continuous and imprecise nature of criteria and natural phenomena were not considered in site selection. Also Chitsazan et al. in 2013 investigated site selection for waste landfill in Ramhormoz [40]. The strengths of this study include the use of fuzzy-based methods for weighting criteria and considering an important criterion of wind direction. Finally, it is recommended that criteria of windrose and land price be considered for their impact on site selection for waste landfill.

Conclusion

Combined implementation of FAHP and fuzzy TOPSIS methods and their results in this study proved the validity of this conclusion, as shown above (Figure 8). The final results of layer overlap led to 31 options as appropriate areas for waste landfill. Most options were located in areas with poor pasture land use and away from agricultural and urban areas. Prioritization in the second stage determined option 8 located in southwest of Shahriar as the final option. Given that more than 800 tons of wastes are generated per day in Shahriar and there is only one active waste landfill in Akhtarabad for disposal and recycling of these wastes, the suggested landfill is located in a better location than the current landfill with regard to environmental criteria, economic feasibility and potential for development in future.

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Contributions

Study design: SA, PH, AT
Data collection and analysis: PH, AT, SF, RA
Manuscript preparation: SA, SF

Conflict of interest

"The authors declare that they have no competing interests."

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