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Compilation of a model for hazardous waste disposal site selection using GIS-based multi-purpose decision-making models

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Abstract Nowadays, given the high production volume of industrial and dangerous materials and their impacts on the human society and environment, disposal of waste materials in the environment and finding the best disposal site for industrial and hazardous wastes, as the most significant managerial measure, have become one of the most important and complex decisions in urban management. In order to find a disposal site, analysis of spatial data, laws, and large socioeconomic and environmental criteria is required. Multi-criteria analysis techniques coupled with GIS capabilities can be a good solution for this. Due to numerous industrial units, especially refineries in Bushehr province, it is essential to find a management solution for hazardous wastes of this province. The main objective of this study is to find an optimal location which has the lowest environmental risk and economically favorable. For this purpose, ecological and socioeconomic criteria were identified and normalized by fuzzy method. The weight of the parameters was determined by analytical network process method combined with the weighted linear combination method. In the capability of the area to locate the hazardous waste disposal, the results showed that the highest weight belonged to ecological criteria (61.34%) and land use (0.27), respectively. Also, 6.13% of the province areas are identified with high potentials for disposal of hazardous wastes. The results of this study showed the importance and significant weight of environmental criteria in prioritizing the proposed areas for disposal of this type of waste. Efficiency of the employed models, integrated with GIS and MCDM, was also proven.

Keywords Petrochemical units · WLC · ANP · Ecological criteria · Bushehr province · Hazardous waste disposal

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Introduction

In recent years, population growth and urban and technological development have led to change in lifestyles, industrialization of cities, and production and accumulation of large volumes of hazardous wastes (Afzali et al. 2014; Khan and Samadder 2014; Babalola and Busu

2011). According to United States Environmental Protection Agency, hazardous wastes are wastes that are dangerous to human health and the environment due to their specific characteristics (USEPA 2016).

Severity of environmental pollution caused by hazardous wastes is reduced by proper disposal or proper recycling of these materials, which is the most important stage in the management and control of these industrial materials, aimed at protecting the environment and managing resources; this has attracted special attention (Gorsevski et al. 2012; Nouri et al. 2011; Hatami-Marbini et al. 2013; Soroudi et al. 2018; Berisa and Birhanu 2015; Nishanth et al. 2010). Improper planning and management of hazardous wastes can lead to pollution of surface and underground water sources, soil and air pollution, and emissions of greenhouse gases such as CO_2, methane (Hatami-Marbini et al. 2013; Nishanth et al. 2010). Finding a proper site for hazardous waste disposal is a complex and challenging process because first, it affects public health, quality of human life, and natural ecosystems and second, there are many factors involved. Therefore, locating a disposal site requires a multi-criteria approach that combines natural, physical, social, political, and esthetic aspects so as to identify, analyze, evaluate, and select the site among different alternatives (Hanine et al. 2016; De Feo and De Gisi 2014).

Multi-criteria decision-making (MCDM) method can integrate expert's opinion with real information. These methods evaluate different criteria and cover all possible and contradictory objectives and results of analysis.

Analytical network process (ANP) is a MCDM method proposed by Thomas L. Saaty (1996) to improve AHP method based on super matrix technique (Eldrandaly 2013). This method can be used to solve complex problems with non-hierarchical structure (Khan and Faisal 2008). Among its several advantages is the possibility of considering interconnection of different levels of a decision relative to each other as well as internal connection of decision criteria at one level.

Most of the management and design problems in real world require a GIS-based MCDM method (Soroudi et al. 2018; Afzali et al. 2014; Eldrandaly 2013). A combination of GIS features and MCDM technique provides an inclusive approach for MCDM analysis which has been widely used by researchers around the world for optimizing waste disposal; these include AHP, Fuzzy AHP, ANP, PROMETHEE, Fuzzy TOPSIS, OWA, WLC, etc. (Hanine et al. 2016; Eskandari et al. 2012). These researchers, as MCDM advocates, show the importance of using GIS.

As a powerful tool, GIS is capable of managing large volumes of data from different resources, simulating, and managing social, economic, political, and environmental constraints together with several other hydrological, hydrogeological, physiographic, and environmental parameters. By taking all the parameters into account, it can save time and money and build up a digital data bank for long-term monitoring of a research site (Eskandari et al. 2015; Moeinaddini et al. 2010; Mat et al. 2017; Gbanie et al. 2013).

Many researchers have used GIS as well as AHP, WLC (weighted linear combination), and SAW (Eskandari et al. 2012; Tavares et al. 2011; Berisa and Birhanu 2015; Hashemi et al. 2016; De Feo and De Gisi 2014; Gorsevski et al. 2012; Hanine et al. 2016; Demesouka et al. 2013; Shahabi et al. 2014), or some other methods such as TOPSIS, PROMETHEE, and Electre (Arıkan et al. 2017; Hatami-Marbini et al. 2013; Aydi et al. 2013).

In India (Khan and Faisal 2008), Spain (Banar et al. 2007; Aragonés-Beltrán et al. 2010), Turkey (Babalola and Busu 2011), and Malaysia, ANP is commonly used to properly locate a site for solid waste disposal, and it is known as a useful MCDM with favorable outcomes helpful to researchers. Isalou et al. (2013) used fuzzy logic integrated with ANP to locate a site for Qom waste disposal and concluded that this method gives a better result than other methods, such as AHP, Fuzzy, and ANP alone. Iran has experienced significant growth in oil extraction, exploitation, and refining with production of chemical pollutants from petrochemical, oil and gas industries, and refinery, to sensitive biological resources and human societies. The main objective of this study is to find the best site for disposal of hazardous wastes in Bushehr, one of the largest industrial centers (for chemical pollutants) of Iran by emphasizing on effective environmental criteria and using WLC and ANP methods so as to leave the lowest unwanted and adverse economic and environmental effects.

Materials and methods

Study area

Bushehr province, in southwest of Iran, with a population of 1032,949 people and an area equal to

23,072 km^2, lies as a narrow strip between the Persian Gulf and foothills of Zagros Mountain and in the geographical position between 27° 16′ to 30° 17′ northern latitudes and 50° 06′ to 52° 57′ east (Fig. 1).

This province having sea borders and commercial ports as one of the bases of input and output of goods and services can play an important role in developing commercial relations at the national and regional levels. Due to its special geographical situation, bordering the Persian Gulf, running along the coastal region and commercial ports, and benefiting from large oil and gas resources, existence of petrochemical refineries and complexes, as well as strategic import/export position, Bushehr province is of great economic and strategic importance, and it is known as a center for Iran Energy. Thus, it is regarded as the industrial center of Iran in terms of exploration and extraction of oil and petroleum products, and consequently, production of hazardous waste in the country. Despite the fact that large volume of hazardous industrial wastes is produced in this province, there is no disposal site for these wastes.

Methodology

Siting a disposal site is a difficult, complicated, and prolonged process because several criteria and parameters have to be accurately combined and analyzed; each of which is important and has limitations (Kontos et al. 2005).

Computable and measurable criteria are the basis of decision-making, and they can be divided into two categories: factors and constraints. For both categories, layers of information and maps are prepared (Mahini and Gholamalifard 2006; Afzali et al. 2014). For this purpose, first, the target criteria were identified using library studies, domestic and foreign researches, and rules and regulations of Iranian Department Of Environment (IDOE 2001) and United States Environmental Protection Agency (USEPA 2016). For initial screening by Delphi method, 51 parameters were considered. Then, the parameters were arranged as a questionnaire, and 20 experts (waste and environment specialists, academicians, and stakeholders, administrative, and legal authorities) fully familiar with the study area were surveyed (Nouri et al. 2011; Hatzichristos and Giaoutzi 2006). The questionnaire was designed in a way that it enabled the experts to rate the importance of each of the listed parameters with a point from 0 to 5. They could also add a new criterion if needed. Parameters that obtained at least half of the total point were included in the site selection analysis. At the end, only 24 criteria were selected for the siting analysis.

The selected criteria were divided into two main groups: ecological criteria including physiography (slope and elevation), climate (evaporation, rainfall and dominant wind direction), geology and soil science (geology, distance from fault, soil depth, soil texture, and erosion intensity), and hydrology and hydrogeology (distance from river, distance from the springs and wells, underground waters, water table, distance from the coastline, distance from flood plains, and water quality) and socioeconomic criteria including land use, distance from roads, distance from residential areas, distance from airports, distance from historical and cultural sites, distance from petrochemical industries, and distances from protected areas. Both categories are shown in Table 1 (Sharifi et al. 2009; Berisa and Birhanu 2015; Cheng and Thompson 2016; Demesouka et al. 2013; Gorsevski et al. 2012; Khan and Samadder 2014; Mahini and Gholamalifard 2006; Tavares et al. 2011; Babalola and Busu 2011). EC, SAR, and PH values were used to obtain water-quality layer.

Data obtained in relation to the abovementioned criteria was converted to a digital format using the same reference landing system (UTM, WGS 1984, Zone 39 N), with similar scale and cell size (30 × 30), in GIS platform. Therefore, in order to identify the location of a site with potential for hazardous industrial waste disposal, a database of target criteria (factors and constraints) was established in the province (Soroudi et al. 2018). In the next step, all criteria were quantified and normalized based on fuzzy logic and membership functions. Fuzzy logic has been widely used in identifying potential sites (Hashemi et al. 2016). In this method, higher membership values show greater desirability and lower membership values show lower desirability for the considered purpose (Isalou et al. 2013). In order to fuzzify the operating maps, it is necessary to determine threshold values of the criteria as well as the type and shape of the membership function. Different types of membership functions used in this study are discrete functions, uniform enhancers, and uniform reducers. The method used to convert the standardized maps to fuzzy layer is linear scale conversion method in which minimum and maximum values are used as scaling points as indicated in Eq. 1 (Eastman 2006):

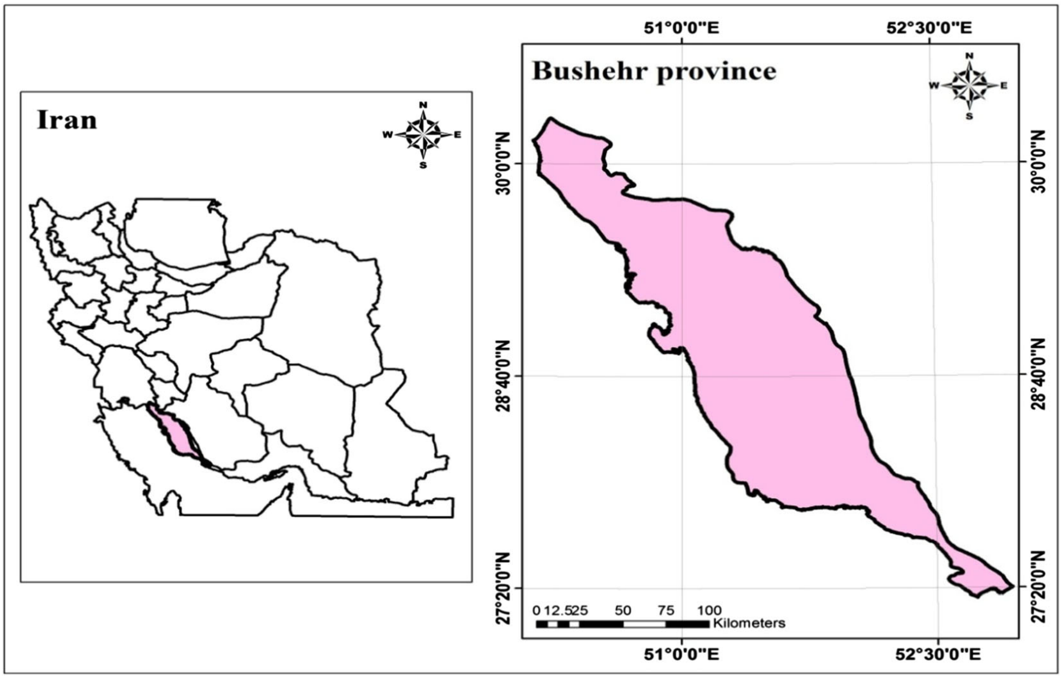

Fig. 1 Location of Bushehr province in Iran

$$X_i = \frac{R_i - R_{\min}}{R_{\max} - R_{\min}} * \text{Standardized range} \quad (1)$$

where, X_i represents the cell value after standardization, R_i is the cell value before standardization, $R_{\min}$ is the minimum factor value, $R_{\max}$ is the maximum factor value, and Standardized range represents the range of changes in standardization.

In case of discrete factors such as land use, because of inconsistency between numbers or descriptive states, fuzzy values for each category were first determined using Eq. 1, and after defining a fuzzy field in a table related to the factor's map, fuzzy numbers were transferred to the field. Constraints are criteria that limit decision-making options and remove some of the considered location. The basis for decision-making on the locations is natural causes or regulated standards and rules. Fuzzy logic is not applicable for limitation criteria, but to standardize the maps of constraints, Boolean logic (0, 1) is used. Accordingly, the study area is divided into two classes: proper (1) and improper areas (0). The maps of constraints are obtained by implementing Boolean logic (Eq. 2) (Younes et al. 2015; Gbanie et al. 2013).

$$S = \Pi_{j=1}^{n} x_j \quad (2)$$

S Boolean suitability index (0, 1)

x_j suitability index for each constraining criterion (0 or 1)

n total number of binary attribute map (number of constraining criteria)

In order to weigh the factors in this study, ANP method was used. This method allows examining interdependencies and feedback of decision analysis parameters (criteria and/or alternatives) from decision-making networks. In fact, ANP is a more precise model of complex configuration of network elements' impact on other elements within the decision-making network, which is shown with a super matrix (Demesouka et al. 2013; Aragonés-Beltrán et al. 2010; Afzali et al. 2014).

Calculation of weight and priority of the alternatives by ANP method is carried out according to the following steps.

In this research, to determine relative weight and coefficient of importance of each parameter based on ANP model, their impact on locating a disposal site for hazardous waste disposal is scored using a numerical scale ranging from 1 to 9 (Saaty 1996) where 1 shows the least impact and 9 shows the greatest impact. Final weights of the parameters are calculated by ANP model and Super Decision software (Banar et al. 2007). The relationship between clusters and within clusters

Table 1 Shapes and types of membership functions of the effective indices and ANP Weight of criteria

Index	Shape of membership function	Final utility
Slope (%)	Discrete	0–5% equal to 1; 5–25% between 1 and 0; more than 25% equal to 0
Elevation (m)	Discrete	0–250 m equal to 1; 250–1000 m between 1 and 0; more than 1000 m equal to 0
Soil texture	Discrete	Soil with very heavy, heavy to very heavy texture is 1; Soil with heavy texture is 0.8; Soils with medium to heavy texture is 0.6; Soils with medium texture is 0.4; Soils with medium texture to heavy gravel, medium texture with heavy round gravel is 0.2; Soil with gravel, gravel to stone, soft gravel, sandy and soft texture is 0
Soil depth	Discrete	Very deep equal to 1; deep equal to 0.8; relatively deep equal to 0.6; shallow equal to 0.4; very shallow equal to 0.2
Land use	Discrete	Barren lands equal to 1; poor range equal to 0.8; moderate range, dry farm, and mix (aquiculture and dry farm) equal to 0.4; aquiculture, thicket and arboretum equal to 0.2; other lands equal to 0
Geology	Discrete	Marl, shale, and clay stone are equal to 1; Schist, clay tow, evaporation rocks, fine grained rocks are 0.8; Schist, clay-tuff, evaporate rocks, and fine-grained clay deposits are equal to 0.8; Igneous rocks with low fracture transformation are equal to 0.6; mass ganglier is equal to 0.4; Siltstone and sandstone are equal to 0.2; Sandstone, lime, dolomite, salt domes, slope deposits, coniferous, flood plains are equal to 0
Erosion	Discrete	Extremely low, very low equal to 1; Low equal to 0.8; low to moderate equal to 0.6; moderate equal to 0.4; moderate to high equal to 0.2; high equal to 0
Aspect (based on wind directions)	Discrete	F equal to 1; E & NE equal to 0.8; SE equal to 0.7; S equal to 0.6; N & W equal to 0.4; SW & NE equal to 0.2
Evaporation (mm)	Discrete	More than 3400 mm equal to 1; 2500–3400 mm equal to 0 and 1; 0–2500 mm equal to 0
Rain (mm)	Discrete	0–100 mm equal to 1; 100–200 mm between 1 and 0; more than 200 mm equal to 0
Water table (m)	Monotonically increasing (linear)	More than 40 m equal to 1; 10–40 m between 0 and 1; 0–10 m equal to 0
Distance from protected areas (m)	Monotonically increasing (linear)	More than 2500 m equal to 1; 1000–2500 m between 0 and 1; 0–1000 m equal to 0
Distance from fault (m)	Monotonically increasing (linear)	More than 15,000 m equal to 1; 1000–15,000 m between 0 and 1; 0–1000 m equal to 0
Distance from roads (m)	Monotonically increasing (linear)	More than 3000 m equal to 1; 300–3000 m between 0 and 1; 0–300 m equal to 0
Distance from rivers (m)	Monotonically increasing (linear)	More than 2500 m equal to 1; 300–2500 m between 0 and 1; 0–300 m equal to 0
Distance from airports (m)	Monotonically increasing (linear)	More than 10,000 m equal to 1; 8000–10,000 m between 0 and 1; 0–8000 m equal to 0
Distance from coastline (m)	Monotonically increasing (linear)	More than 2500 m equal to 1; 1000–2500 m between 0 and 1; 0–1000 m equal to 0
Distance from residential areas (m)	Monotonically increasing (linear)	More than 15,000 m equal to 1; 2000–15,000 m between 0 and 1; 0–2000 m equal to 0
Distance from aquifers (m)	Monotonically increasing (linear)	More than 2500 m equal to 1; 1000–2500 m between 0 and 1; 0–1000 m equal to 0
Distance from flood plains (m)	Monotonically increasing (linear)	More than 2500 m equal to 1; 1000–2500 m between 0 and 1; 0–1000 m equal to 0
Distance from wells and springs (m)	Monotonically increasing (linear)	More than 1000 m equal to 1; 500–1000 m between 0 and 1; 0–500 m equal to 0
Distance from industrial areas (m)	Monotonically decreasing (linear)	0–10,000 m equal to 1; 10,000–15,000 m between 1 and 0; more than 15,000 m equal to 0
Distance from historical and cultural sites (m)	Monotonically increasing (linear) –	More than 4500 m equal to 1; 1500–4500 m between 0 and 1; 0–1500 m equal to 0

Table 1 (continued)

Index	Shape of membership function	Final utility
Water quality (EC, PH, SAR)		PH: 6.5–9 equal to 0; less than 6.5 and more than 9 equal to 1 EC: More than 2250 m equal to 1; 1250–2250 m between 0 and 1; 0–1250 m equal to 0 SAR: More than 3 equal to 1; 0–3 equal to 0

elements is evaluated using a pairwise comparison matrix. It should be noted that, in all comparative matrices, the rate or consistency ratio (CR) should be acceptable (CR < 0.1), which is obtained using the largest eigenvector value (λ_{max}) (Eq. 3) and consistency index (CI) of pairwise comparison matrix. In Eq. 4, random index (RI) is a parameter derived from Saaty and Vargas (2006) table.

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n-1} \tag{3}$$

$$\mathrm{CR} = \frac{CI}{RI} \tag{4}$$

Assume a ANP model with N cluster and (C_1,C_2, … …C_n) subcategories, where nth element belongs to ith cluster. First, a pairwise comparison matrix has to be created by pairwise comparison of the criteria. Thus, when two clusters are selected (C_i and C_j), all elements of C_i are compared with the first element of C_j. Then, all the obtained comparison matrices, which include all elements of C_i, cluster and start with the first element of C_j and create a comparison matrix as Eq. 5:

$$\mathrm{D} = \begin{matrix} i_1 \\ i_2 \\ . \\ . \\ . \\ . \\ i_{ni} \end{matrix} \begin{bmatrix} i_1 & i_2 & \ldots i_{ni} \\ a_{11} & a_{12} & \ldots a_{1n} \\ . & . & . \\ . & . & . \\ . & . & . \\ . & . & . \\ a_{ni,1} & a_{ni,2} & \ldots a_{2n} \end{bmatrix} \tag{5}$$

Eigenvector technique is one of the best methods for weighing all elements of the subgroups. Weight of each element is determined by Eq. 6:

$$W_i = \frac{1}{\lambda_{max}} \sum_{i=1}^{n} a_{ij} w_{ji=1,2,3,\ldots\ldots n} \tag{6}$$

Where, λ_{max} is the largest eigenvector value and a_{ij} are the elements of pairwise comparison matrix. The above eigenvector matrix includes relative weights of all C_i weights that are compared with the first element of C_j and rearranged as Eq. 7:

$$\begin{bmatrix} w_{i1}^{j1} \\ w_{i2}^{j1} \\ : \\ : \\ w_{ini}^{j1} \end{bmatrix} \tag{7}$$

To obtain their eigenvector, all C_i elements are compared with all C_j elements in the matrix below. Accordingly, if n_i represents the number of elements in C_i and w_{ik}^{j1} is the weight of kth element from ith subcategory, as compared to the first element of jth subcategory, then judgment matrix of the ith subcategory elements relative to elements of jth subcategory can be obtained from Eq. 8. In all cases, eigenvectors should be normalized; that is, the sum of the elements of each one should be equal to 1.

$$w_{ik}^{j1} = \begin{bmatrix} w_{i1}^{j1} & w_{i1}^{j2} & \ldots & w_{i1}^{jnj} \\ w_{i2}^{j1} & w_{i2}^{j2} & \ldots & w_{i2}^{jnj} \\ : & : & & : \\ : & : & & : \\ w_{ini}^{j1} & w_{ini}^{j2} & \ldots & w_{ini}^{jnj} \end{bmatrix} \tag{8}$$

The above matrix is generated for all the clusters so as to obtain a weightless super matrix as in Eq. 9:

$$w_{ik}^{j1} = \begin{bmatrix} W_{11} & W_{12} & \ldots W_{1N} \\ W_{21} & W_{22} & \ldots W_{1N} \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ W_{N1} & W_{N1} & \ldots W_{NN} \end{bmatrix} \quad (9)$$

The final weighted super matrix (W_C) is obtained by calculating C_i clusters' weight by comparing its elements with each other and with effective clusters and multiplying them by the weight of each of the clusters' element of the weightless supermatrix. The final Eisenhower matrix for each element of each subcategory is calculated using Saaty (1996) chain, and Markov transition probability matrix is calculated by finding the limit in Eq. 10:

$$W_C = \lim_{1 \to \infty} w^{2k+1} \quad (10)$$

Thus, prioritization of options is possible by comparing and sorting the final values of W_C matrix in each column (Afzali et al. 2014; Isalou et al. 2013).

In the final stage, a combination of map of the parameters and obtained weights by WLC method with Eq. 11 generated a map to identify areas with potentials for locating a hazardous waste disposal site (Mahini and Gholamalifard 2006; Syed Ismail 2017)

$$S = \sum_{i=1}^{N} W_i C_i \Pi C_j \quad (11)$$

S Suitability score for hazardous disposal site
W_i Weight of factor i
C_i Fuzzy value of i
C_j Rating (score) for the constraint criteria of j
Π Product

Results and discussion

In the present study, information layers were first introduced to GIS and the maps were weighed using ANP method. Then, the obtained results for each criterion layer are shown in Table 1. In this table, in order to locate a hazardous waste disposal site in the study area using threshold values defined for each criterion and fuzzy membership functions, a degree of acceptability was determined. For constraint maps, Boolean logic was used to identify sites that are by no means suitable for waste disposal. Fuzzified maps of decision criteria are shown in Figs. 2, 3, 4, 5, 6, and 7. Generally, fuzzy logic scale varies between 0 and 1, that is, depending on the level under which each criterion is considered, each area has a membership value that reflects its quality. Thus, each area or pixel that has a higher membership value and is closer to 1 in fuzzy scale would be more desirable.

After standardizing the maps, in stage of integrating and overlapping the considered layers, a single map of the located disposal sites was obtained to locate a proper site for waste disposal using WLC combination method. Based on the obtained weight, the effect of each map on disposal location was determined. The weight determined by this method shows that ecological criteria, with 61.34% of the total weight, play a greater role in the process of locating a disposal site for hazardous waste in this province, while socioeconomic criteria, with 38.66% of total weight, are less effective in this process. Among the parameters used, land use and evaporation had the highest (0.2736) and lowest (0.0017) weights, respectively.

Figure 8 shows zoning of areas with potential for locating a disposal site for hazardous waste disposal in the studied area, classified into five levels: extreme capability, high capability, moderate capability, low capability, and unsuitable. Zoning results in Table 2 indicate that 139,353.48 ha (6.13%) of the studies area are identified with extreme capability and 352,620 ha are identified with high capability. However, because of ecological and socioeconomic conditions, 402,042.87 ha (17.7%) of the province are identified as unsuitable for locating a waste disposal site.

Unsystematic disposing of hazardous wastes or locating disposal site in inappropriate sites may bring about irreparable consequences to the environment and human health. Given the importance of this issue, in line with development of industry and technology, it is necessary to develop and implement programs to control such contaminations. Hazardous wastes management program is very important. In most countries, sanitary landfills are the most common ways of waste disposal. Locating a site for waste disposal is a very complicated spatial and decision-making problem because so many factors are involved in this process.

With emphasis on petrochemical industry, as the most concentrated industry in Bushehr province, this research was conducted based on environmental and socioeconomic criteria and constraints so as to locate a

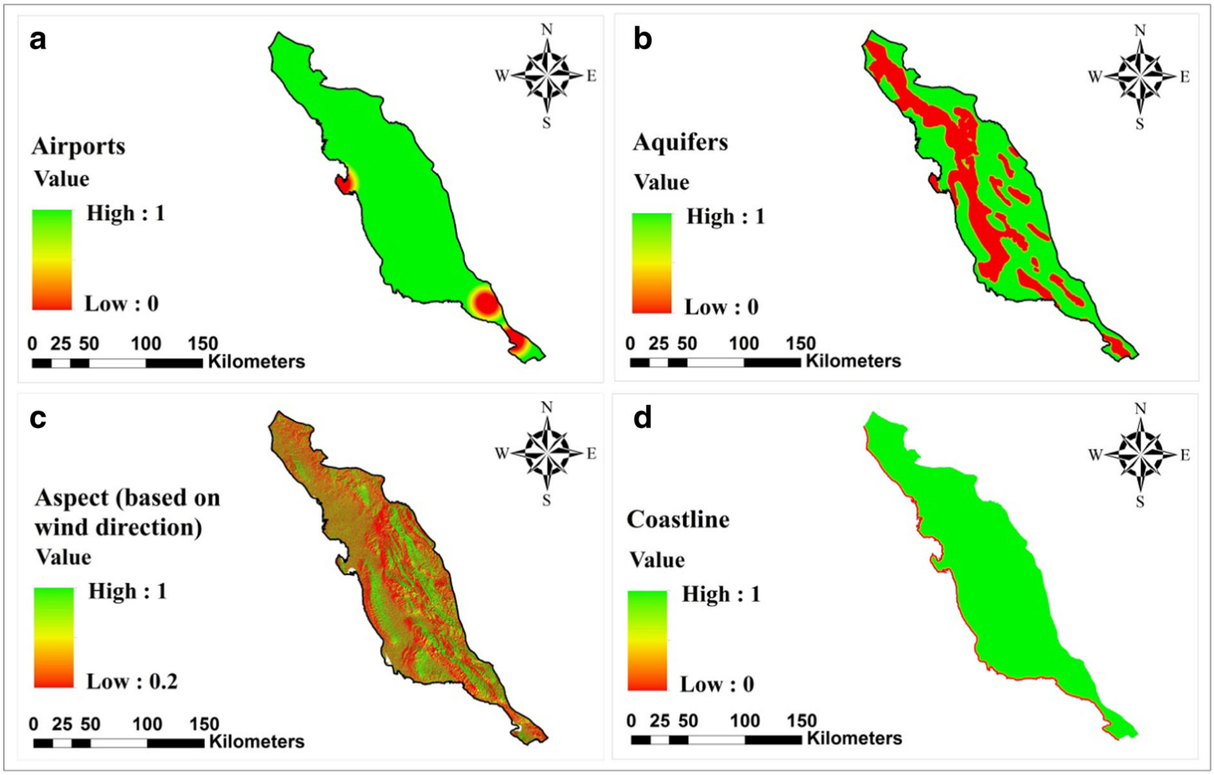

Fig. 2 Maps of distance from airports (**a**), distance from aquifers (**b**), wind direction (**c**), and distance from coastline (**d**)

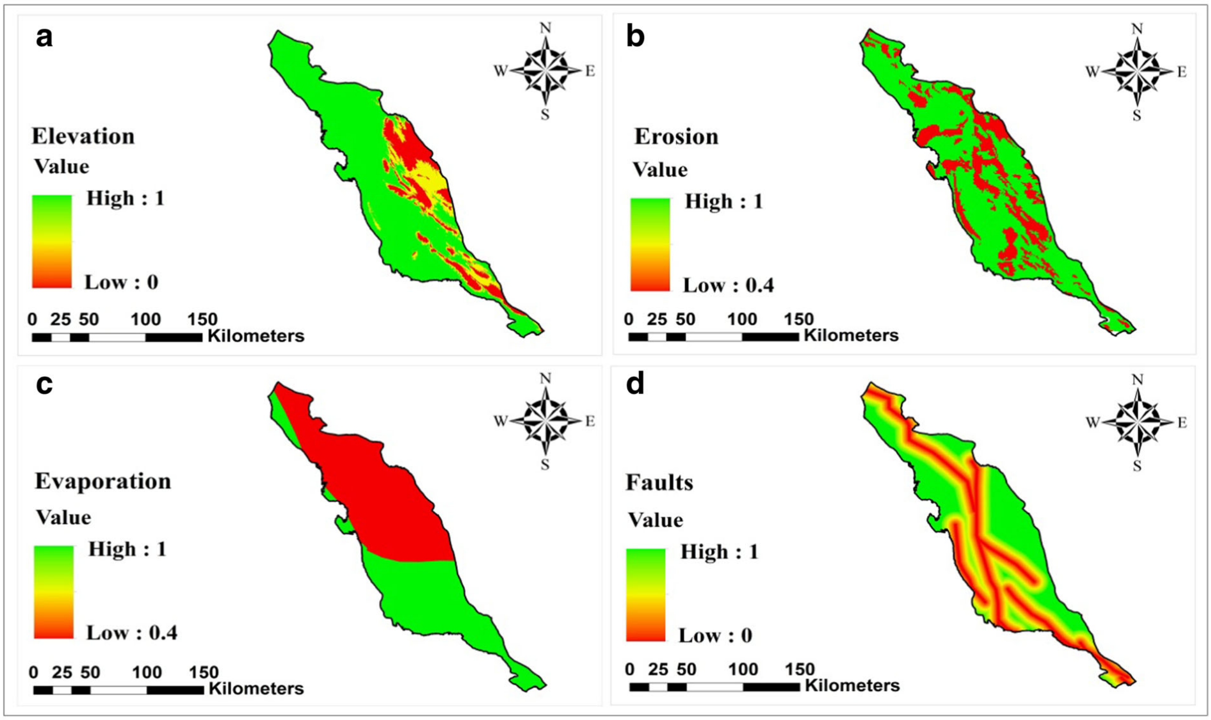

Fig. 3 Maps of elevation (**a**), erosion (**b**), evaporation (**c**), and distance from faults (**d**)

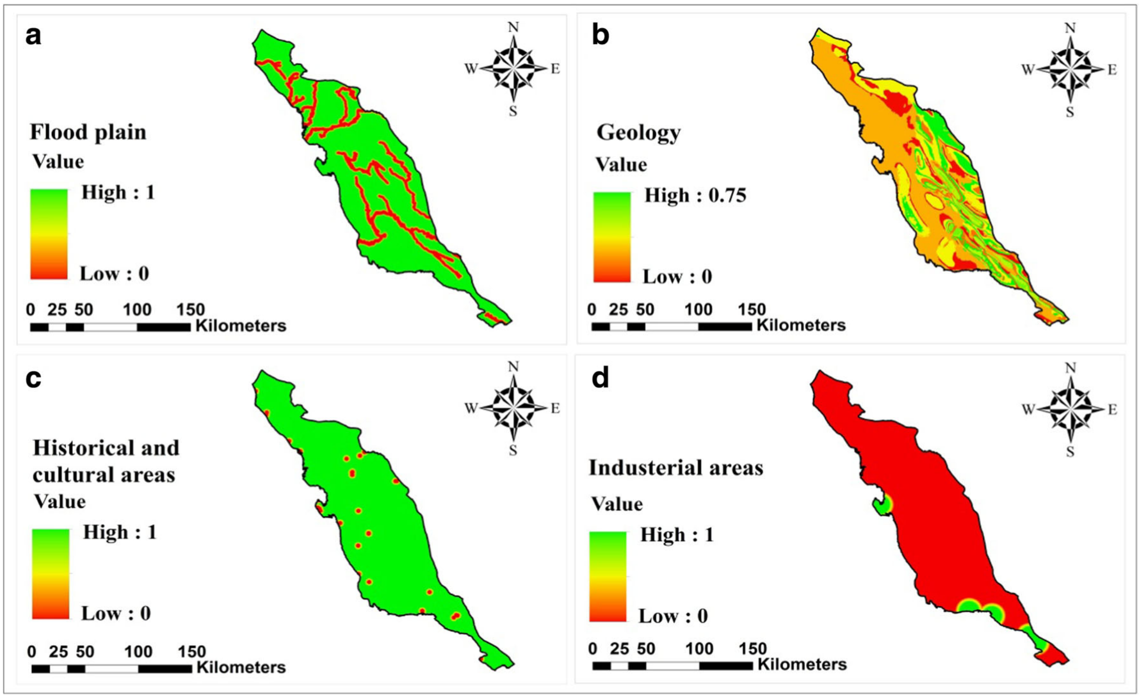

Fig. 4 Maps of distance from flood plain (**a**), geology (**b**), distance from historical and cultural areas (**c**), and distance from industrial areas (**d**)

disposal site for hazardous industrial wastes. Since it is important to focus on environmental factors in locating a disposal site for hazardous waste because they have adverse effects on their surroundings and substrates

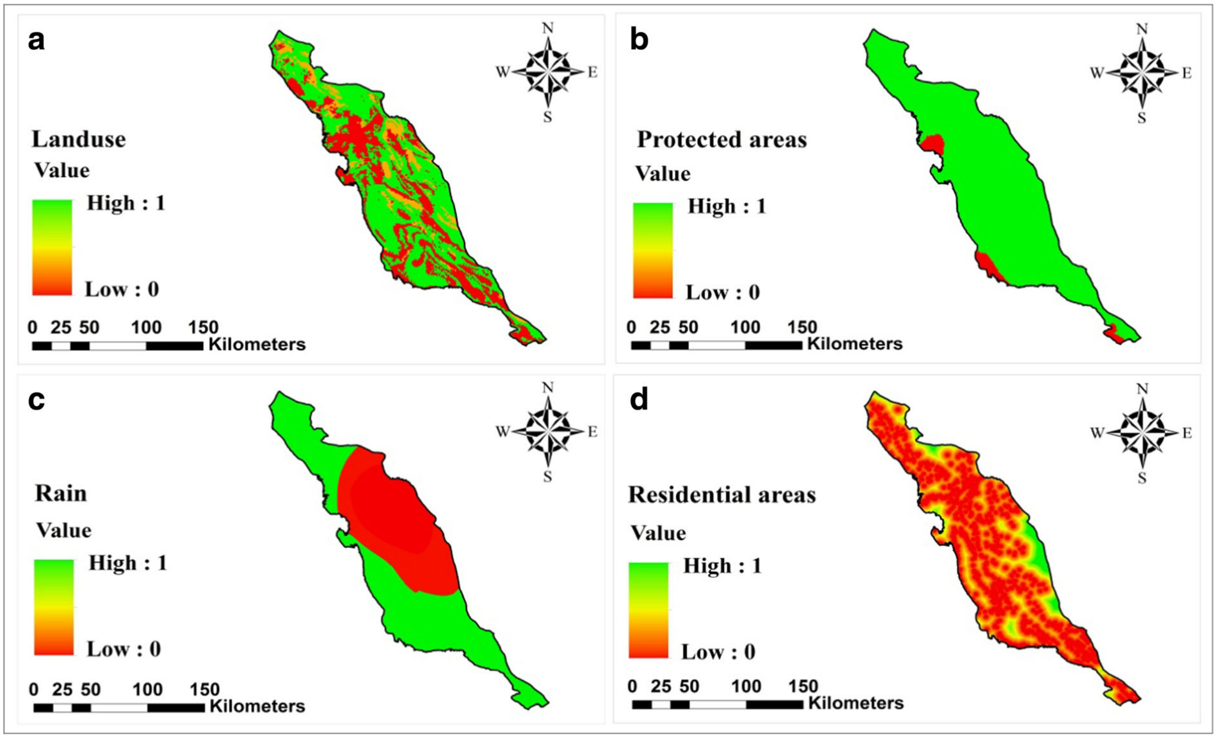

Fig. 5 Maps of land use (**a**), distance from protected areas (**b**), rain (**c**), and distance from residential areas (**d**)

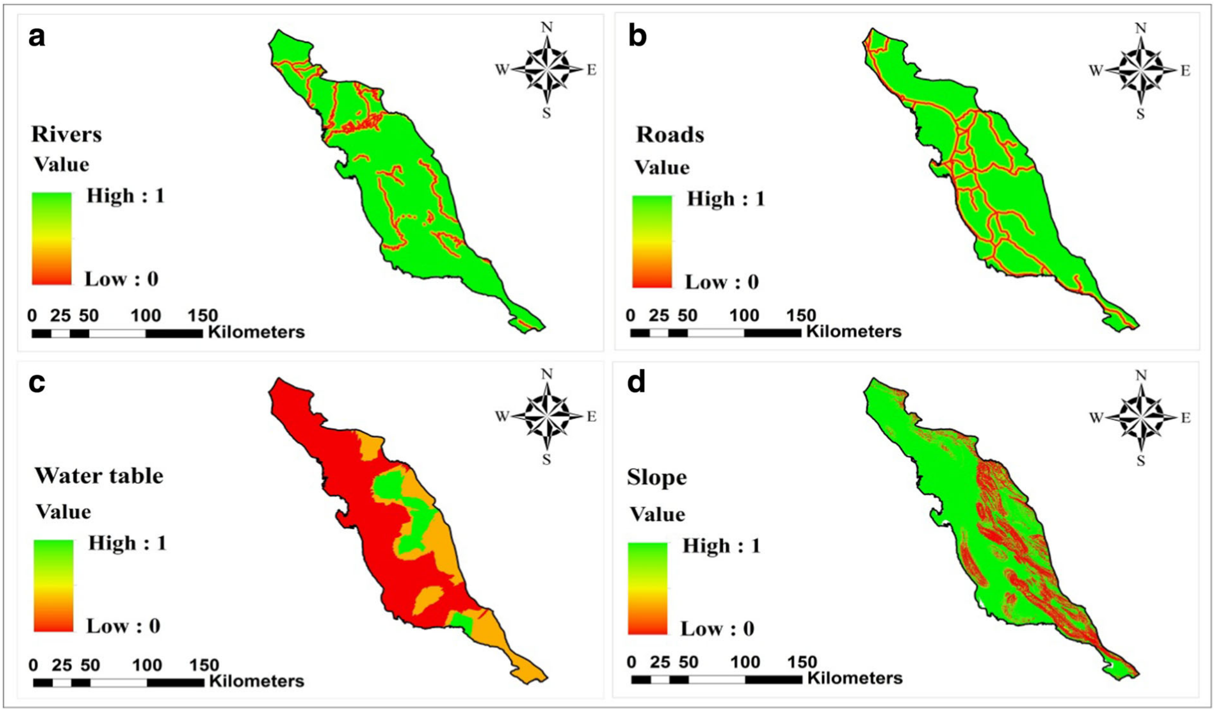

Fig. 6 Maps of distance from rivers (**a**), distance from roads (**b**), distance from water table (**c**), and slope (**d**)

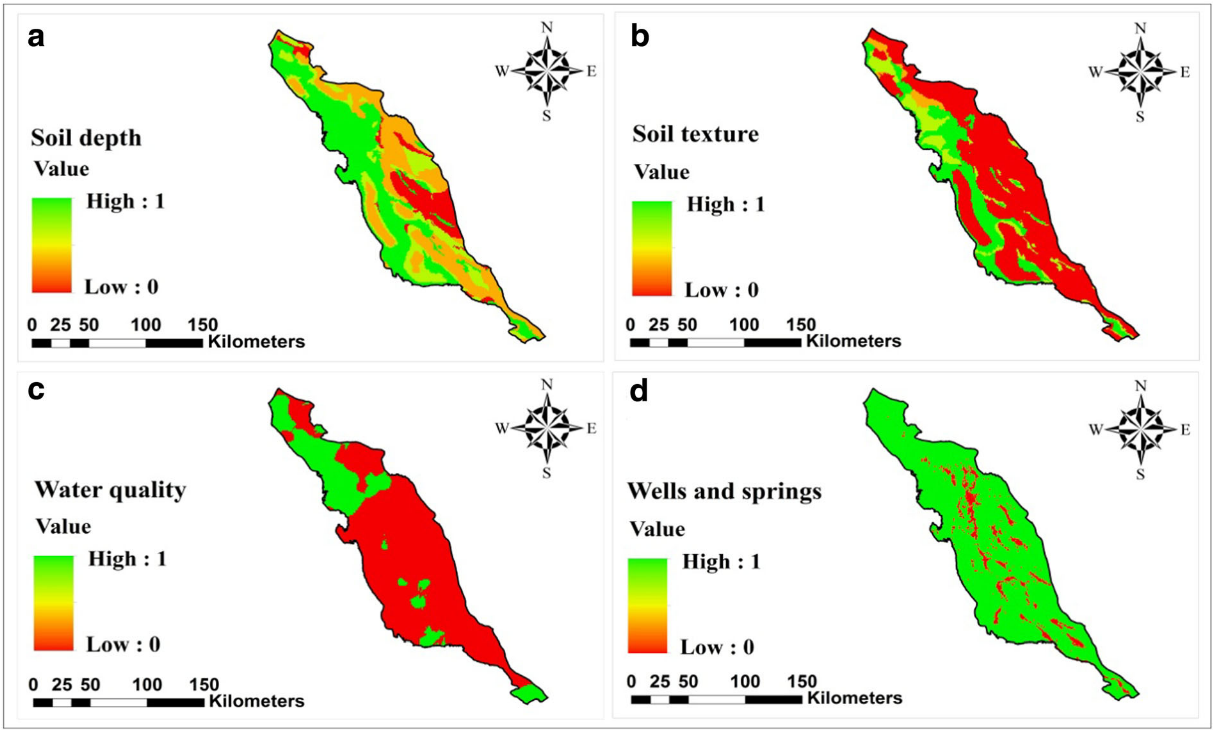

Fig. 7 Maps of soil depth (**a**), soil texture (**b**), water quality (**c**), and distance from wells and springs (**d**)

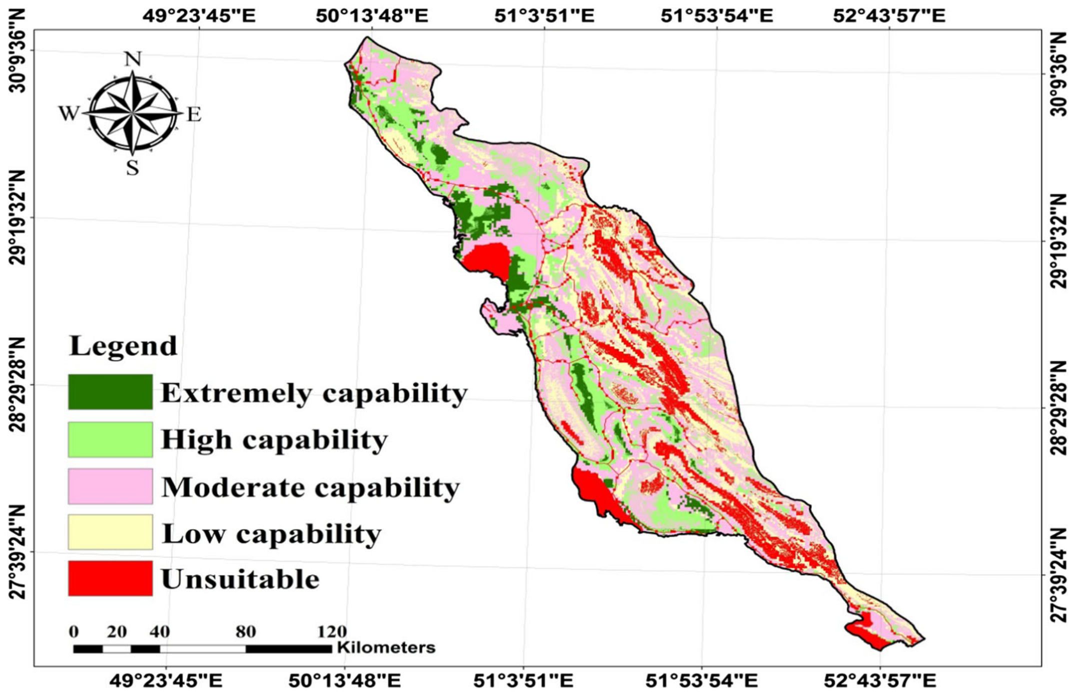

Fig. 8 Map of areas with capability for selection of hazard waste site in Bushehr province

(Sharifi et al. 2009; Berisa and Birhanu 2015), this research focused on ecological parameters as well as economic and social factors. Considering the role of many factors in the process of locating waste disposal sites, spatial nature of the target area and input information of decision-making system, this issue is considered as a multi-criteria issue and GIS technique is used for its utility in managing large amounts of spatial data (Eskandari et al. 2012).

In general, the results of this study showed that among ecological factors, weight-related soil criteria (0.2329), physiographic criteria (0.17444), and hydrologic criteria with weight (0.0797) were the most effective and most important criteria, respectively, and also among the indices, land use indices (0.2736), slope (0.1526), soil depth (0.1426), and soil texture (0.0903) were the most important factors, respectively, in locating a disposal site for hazardous waste in the research area. Many studies in this field have similar results with this study, and the more relevant criteria and indicators obtained in this study have also been shown in their results.

Table 2 The area of land in capability class

Region capability classification	Area (hectare)	Area (%)
Extremely capability	139,353.48	6.13
High capability	352,620	15.52
Moderate capability	881,000	38.79
Low capability	496,183.95	21.84
Unsuitable	402,042.87	17.70

Sayhani Porshokooh et al. (2011) in selecting the location of landfills in Hajiabad urban municipalities have considered soil permeability and land use criteria as the most important. For Mirabadi and Abdi (2017), the hydrological and land use criteria have the highest importance in locating disposal site in the city of Bukan. In the study of Babalola and Busu (2011), soil, land use, and groundwater had the highest weight, respectively, in Damaturu, Malaysia. To create a new model for construction of a landfill site in Malaysia, Younes et al. (2015) used a hybrid model (MRSS-ANP) and reported land topology and distance from surface waters as the most important factors. Isalou et al. (2013) introduced topographic (slope and elevation) criteria as the most effective factors in Khahak, Iran.

A general overview of the results of the above studies shows that despite different results from the impact of different factors in different regions, environmental factors are very important in locating the waste disposal site, because the disposal site may have adverse and mutual biophysical and ecological impacts on the surrounding environment which is proved in the current study area with 61.34% of the total weight.

According to the obtained results, 6.13% of the study area is identified with extreme capability. This area can be considered as target area for locating a disposal site for hazardous waste.

The results of this study showed that modeling a location finding method by integrating GIS with MCDM (ANP and WLC) technique is a practical and straightforward way, and the research findings revealed ANP utility, as expected. Nowadays, GIS-based methodology and its progression process simply helps decision makers in solving site design problems with features such as storing, retrieving, and analyzing spatial information (Khan and Samadder 2014; Mat et al. 2017; Babalola and Busu 2011; Cheng and Thompson 2016). WLC is a method that empowers decision makers by weighing all factors, and its potential is proven in several studies (Mahini and Gholamalifard 2006; Berisa and Birhanu 2015; Moeinaddini et al. 2010; Gbanie et al. 2013; Syed Ismail 2017).

ANP can be used to solve complex problems with non-hierarchical structure and supports feedback in decision-making systems. Among its several advantages is flexibility in deconstructing a complex decision-making, by considering interaction between different levels of decision relative to each other as well as internal connection of decision criteria at one level, which is practically ignored in other decision-making methods. Therefore, it is an ideal method for modeling and creating interactions and interdependencies among indices that have attracted the attention of most researchers and managers (Isalou et al. 2013; Khan and Faisal 2008; Eldrandaly 2013; Demesouka et al. 2013).

Khan and Faisal (2008) used ANP with 5 criteria and 13 sub-criteria to identify a proper disposal site for solid wastes in India and put it among perfect solutions in solving complex problems. To solve the problem of locating a disposal site for solid wastes in Valencia (Spain), Aragonés-Beltrán et al. (2010) compared ANP and AHP with 21 criteria and reported ANP as a useful tool with acceptable results which helps professionals in MCDM approach. Younes et al. (2015) reported that, with the ability to control interactions and feedbacks, and thus justify and judge decisions, ANP is widely used in many decision-makings. In the study on locating disposal sites in Eskesehir (Turkey), Banar et al. (2007) compared ANP and AHP and obtained different results.

Considering the importance of locating sites for hazardous waste disposal as well as factors affecting it, ANP method can be an effective step in decision-making which helps managers and planners to take into account all affecting factors and their interactions.

Conclusion

Investigations and studies on locating disposal sites for hazardous waste, based on environmental characteristics such as groundwater and aquifer characteristics and hydrological and geological characteristics of the area, as a suitable planning and management tool, make it possible to prevent contamination of soil and groundwater resources by blocking contaminants' release and dissemination. Bushehr province, due to its specific geographical conditions, proximity to Persian Gulf, dryness of climate with the prospect of climate change, and lack of healthy water resources, is currently among critical and vulnerable areas. Because of numerous industrial units, including refineries and petrochemical complexes, chemical contamination of these wastes can reduce the quality of drinking water and give rise to health and environmental problems, incurred water treatment costs, destruction and contamination of high quality soils of the province, causing loss of economic value, destruction and extinction of rare and genetically and pharmaceutically important herbs, immigration or extinction of wildlife, destruction of historical monuments in the province, and damage to esthetic, recreational, and tourism status of the province. Considering the presence of Iran refineries in Bushehr province, and extremely urgent need to protect water resources of the province, in order to solve the problem of locating a site for hazardous waste disposal in industrial Bushehr province, WLC integration method was used to prepare a zoning map and ANP was used to determine relative weights of the criteria. Based on the results of this study, 6.13% of the total area has a very high capability and 15.52% has high capability. This is due to the fact that more than 75% of the province (78.33%) was found to be inappropriate due to ecological conditions and socio-economic context for selecting the disposal sites for these wastes. Finally, it can be said that the WLC method used in this study is a multi-criteria evaluation method that allows simultaneous review ecological, economic, and social criteria and due to ease of implementation and simplicity, its flexibility, and overlapping capabilities with geographic information systems, it has the ability to locate hazardous waste disposal sites. Also, the WLC method uses weighting to factor in more important factors (with greater weight) in the problem of site selection and provide more favorable results, and the final map of this method provides suitable locations for site selection.

Compliance with ethical standards

Declarations The authors declare that they have no conflict of interest.

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