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Solid waste disposal site selection using geospatial information technologies and fuzzy analytic hierarchy process (FAHP): a case study in Bandar Bushehr, Iran

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Abstract The Bandar Bushehr city is located on the northern coast of the Persian Gulf, which due to generated 170 tons per day per capita municipal and household solid waste, today there is a serious problem of landfill of municipal solid waste. The current waste disposal site is in the area, 4 km far from the Bandar Bushehr city. The site has been used without any environmental considerations and the unavailability of land is also a major tension in the study area. Therefore, the present study developed a methodological framework for locating suitable landfill candidate sites and selecting the best alternatives. Thus, 11 input map layers into 7 relevant alternatives were selected and relative weight was calculated using the fuzzy analytic hierarchy process. The alternatives of all criteria were rated from a 1–5 scale indicating lowest to highest suitability for landfill. The weighted linear combination was performed between different criteria for modeling suitable candidate sites. The minimum required landfill area for 10, 20, 50, and 100 years was selected. The results revealed that throughout the study area, initially, 8 candidate sites were identified based on geospatial analysis, but out of them, 7, 3, 1, and 3 sites for a period of 10, 20, 50, and 100 years, respectively, suitable sites can be accepted for a landfill site due to current land use, public acceptance, transportation, and local environmental issues, although these are also not completely satisfying the environmental concern. However, the landfill site is also essential; otherwise, it will appear as more adverse impact. Therefore, with little compromising with the environmental component, the engineered plan can be designed for the sanitary landfill specific sites that are recommended in this suitability analysis.

Introduction

The city is a complex space, with components that are all systematically in close contact with each other; so that the disruption of any of these components causes problems in the entire system. Urban waste is one of the components of the city, and failure to deal with it can affect the urban units' landscape. One of the most critical problems in human societies is the production of different types of waste in different quantity and quality that must be disposed. There has been a tremendous increase in the volume of generated solid waste worldwide. Piling up the waste material in a flat area and incineration is the first solution that comes into the mind. Problems of the unsanitary disposal of solid wastes such as smoke and smell, insidious

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organisms, combustion waste, contaminated surface water and groundwater have changed this idea and have forced the decision-makers to convert the solid waste dump area into the sanitary landfills. In this regard, the selection of a suitable landfill site for solid municipal wastes can, for many reasons, lead to the elimination of many environmental, economic and social concerns associated with the disposal of wastes. It should be noted that different methods of disposal depend on many factors and indicators. But without the use of a robust system as a sure-tier tool capable of utilizing and analyzing multiple layers of information, this problem cannot be solved. Geographic information system (GIS) is very suitable for this because of the ability to manage a large amount of data. Therefore, the use of GIS techniques not only provide the possibility of studying large areas, while taking into account all the parameters simultaneously but also saves time and money. One of the issues to be analyzed by the help of GIS, is the study of environmental pollution, climate change, directions of city expansion (urban sprawl), the landfill of domestic and industrial wastes, degradation of forests, etc. Combine multiple criteria analysis with GIS has been extensively used to facilitate and lower the cost of the landfill site-selection process (Demesouka et al., 2019; Kamdar et al., 2019; Yalcinkaya & Kirtiloglu, 2020).

Most of the previous studies perform an exclusion analysis to remove unsuitable areas, then estimate the weights of the preference factors relative to their influence using the AHP, finally performing a weighted overlay analysis in a GIS to generate the suitability map. The reclassification technique was generally applied for scaling the spatial membership degrees of each preference layer, such as distance to roads. Reclassification in raster data is done by assigning values to user-specified ranges. Reclassification of preference factors fits the classical set theory. In classical set theory, each object belongs to a particular set or not. Often real-world problems cannot be solved entirely by mathematical methods developed based on classical set theory. In fuzzy logic, on the other hand, each element of the set takes membership degrees between [0 1] and the same element can belong to multiple sets at the same time (Jing et al., 2020; Yalcinkaya & Kirtiloglu, 2020).

In the evaluation of siting an incineration facility with a suitable slope, for example, in classical set theory, the areas that are steeper than a certain slope (assuming a slope above 40% is not suitable) will be classified as not suitable or limited areas. Similarly, all areas with a slope less than the specified slope will be classified as the least suitable, relatively suitable, suitable, and the most suitable. The evaluation results are always Boolean (1 or 0, suitable/unsuitable). If the same example is to be evaluated with fuzzy logic, a membership function must first be defined according to the relationship between the slope and the study purpose. Suppose this relationship is defined as a decreasing linear function between 0 and 40%. As a result of the evaluation made with fuzzy logic, membership degrees decreasing from 1 to 5 will be defined for slope values between 0 and 40%. Partial membership to a set is possible with the degree of membership determined by fuzzy logic. Therefore, the model to be developed in this way will be more realistic and will provide a more accurate decision. In this study, spatial membership degrees of preference factors were calculated with fuzzy logic rather than the reclassification technique commonly used in previous studies.

Bushehr city is located in the west of Bushehr province, due to the per capita production of municipal and household solid wastes of 170 tons per day and land limitations due to being a peninsula and limited to the sea on three sides, nowadays it faces a serious problem of burying urban solid wastes. Is. The current waste disposal site is 4 km away from Bushehr. This site is currently being used without any environmental considerations. Therefore, this study aims to develop an integrative modelling approach for siting waste management facilities and its application for an incineration plant in Bandar Bushehr, Iran. Our approach combines GIS and fuzzy AHP techniques and includes a pre-screening process for the exclusion of unsuitable areas, and preference analysis by MCDA. The land suitability map for an incineration plant was generated considering legislative requirements and economic, environmental and technical aspects. Such a methodology is needed in Iran to help decision-makers for sustainable planning of municipal solid waste (MSW) management facilities.

Material and methods

Geographical description of the study area

Population growth has accelerated the dynamics of the urbanization process in Bandar Bushehr city. As such, suitable solid waste sites must match with rapid urbanization process. Selection of a standard landfill is important for environmental protection in these areas; however, it is a challenging activity, especially when waste dumping is dominant. The city has a sea border and commercial ports as one of the entry and exit points for goods and services, it can play an important role in the development of trade relations at the national and regional levels. Due to its special geographical situation (water bodies surrounding the city, lack of proper land for landfill), bordering the Persian Gulf, running along the coastal region and commercial port, and benefiting from large oil and gas resources, Bandar Bushehr city is of great economic and strategic importance, and it is known as a centre for Iran Energy, this has led to a more sensitive investigation into the city's landfill for a number of reasons. The city's population approximately

265,377 in 2020 (PBO 2020). The city is bounded by the Persian Gulf on its south and west. Bandar Bushehr city has a hot and humid climate, with an annual average temperature of 24 °C and annual precipitation of 217 mm. The prevailing wind is northwestern (Danesh et al., 2019). Figure 1 presents the study area map.

Data collection

In order to identify suitability level of the area and successfully analyze the entire region, Information, including the most recent Landsat satellite images, DEM, and expert views were collected from various sources. Website data were used as basic data to prepare the information layer of criteria and options, for example, Landsat images were used with vegetation index Normalized Difference Vegetation Index (NDVI) and Modified Normalized Difference Water Index (MNDWI) to prepare a land use/cover map. The Digital topography sheet was used to prepare the DEM area DEM was used for prepare the slope map. Except for views from experts, including geologists, hydrologists, environmentalists, policymakers,
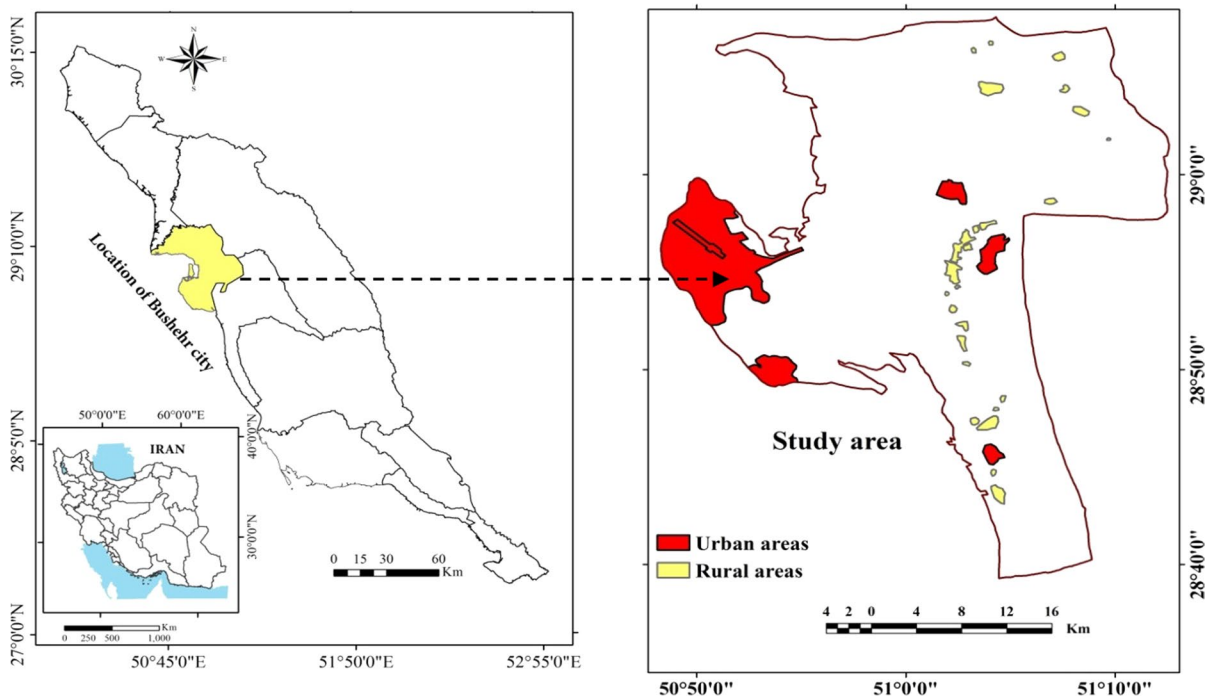

Fig. 1 Location of Bandar Bushehr city in Bushehr province of Iran: Landsat 8 OLI RGB

pollution control personnel, city planners, and waste management practitioners whose ratings sourced the weight and value for each criterion, additional information was obtained from a ground survey while recording the geographical coordinates of the particular sites using the GPS, other data sources are as shown in Table 1.

Research methodology

The selection of appropriate criteria is the main task for any kind of suitability analysis. The criteria selection differs with study objectives and geographical locations. As far as the present study is concerned, multiple criteria should require to consider, because landfill is a practice where the disposal of waste materials takes place and the surrounding environmental components and public health are truly impacted due to unscientific disposal and management. Criteria for suitability analysis of landfill site selection at global scales have differed in the previous studies. Through

the detailed literature survey (Danesh et al., 2019; Jamshidi-Zanjani & Rezaei, 2017; Kamdar et al., 2019; Pavani et al., 2019), experts' views, and the regulations of pollution control board (CJJ17-2004, GB 16,889) on landfill site selection in Iran (IRI, 2020), 11 relevant and site-specific criteria were selected in the present study to identify the suitable site of a landfill in Bandar Bushehr, Iran. To normalize and reduce the calculation complexity, these 11 criteria were combined into eleven categories by putting four criteria in each category (Table 2).

The flowchart of the research methodology (Fig. 2) illustrates the study procedures from data sources to the study goal which was evaluating and mapping all criteria for assessment in order to produce the final site suitability and zonation map. In this diagram, the seven selected criteria are shown along with the visualization of the GIS use and a multi-criteria fuzzy analytic hierarchy process (FAHP). In this method, all values of map layers are arranged in the range between zero and one. The process of standardization in a fuzzy method is

Table 1 Data types, sources, and resulting maps for the analyzed criteria

Criteria	Data type	Data source	Produced thematic map
Land use	Landsat-8 images	Landsat of the USGS: http://earth explorer.usgs.gov/	Land use map
	Topographic map	National Cartographic Center of Iran (NCC): https://www.ncc.gov.ir/en/	
	Regional master plan	Planning and Budget Organization (PBO): https://www.mpob.ir/	
Geological factor	Geological information	Geological survey & Mineral exploration of Iran (GSME); https://www.gsi.ir/	Regional Geological map Faults map extraction
Soil type	Soil data	Soil & water research institute http://www.swri.ir/fa-IR/ Iran national cartographic center	Soil type map
Hydrological factor	Surface water cover Satellite images	1: 25,000 digital map National Cartographic Center of Iran (NCC): https://www.ncc.gov.ir/en/	Surface water cover map
Position of wells	Point map	Global position system (GPS)	Distance of ground water map
Elevation	Digital elevation model (DEM)	National Cartographic Center of Iran (NCC): https://www.ncc.gov.ir/en/	Elevation map
Road network	Satellite images A topographic and regional master plan map	Landsat of the USGS: http://earth explorer.usgs.gov/ National Cartographic Center of Iran (NCC): https://www.ncc.gov.ir/en/	Road network map
Weather data	Statistical yearbook of the Bushehr Meteorology Organization, (BMO)	https://www.bushehrmet.ir/SC.php?type=static&id=13	Precipitation map and predominant wind direction

Table 2 Criteria selected and decision-making approaches applied for landfill site suitability at global scale

S.N	Study area	Criteria considered for landfill site suitability evaluation	Technique applied	Authors
1	Lemnos Island, Aegean Sea, Greece	Water permeability, dis to water sources, surface water, sensitive ecosystems, land cover, urban areas, cultural areas, land uses, visibility criteria, morphology, wind orientation	Simple Additive Weighing (SAW) and Analytic Hierarchy Process (AHP)	Kontos et al. (2005)
2	Thrace region, Greece	Aquifers vulnerability, seismic hazard assessment, soils permeability, slopes, elevation, soil texture, protected areas, surface water, pluviometry, temperature, land use, residential areas, transportation network, waste consumption source, road network	Multi-criteria spatial decision support systems (MCSDSS) based AHP and TOPSIS	Demesouka et al. (2013)
3	Istanbul, Turkey	Haul distance, restriction sites, land use, soil structure, geological condition, hydrology, surface water, local climate, wind direction, transportation lines, proximity to building materials, land prices	Fuzzy AHP and fuzzy TOPSIS	Beskese et al. (2015)
4	Al-Musayiab Qadhaa, Babylon, Iraq	Groundwater depth, rivers, soil types, agriculture land, land use, elevation, slope, gas pipelines, oil pipelines, power lines, roads, railways, urban centers, villages, archeological sites	Combined analytic hierarchy process (AHP) and simple additive weighting (SAW)	Chabuk et al. (2017)
5	Abuja, Nigeria	Built-up area, road network, water body, slope, geology, soil	Simple Additive Weighing (SAW) and Fuzzy set theory	Aderoju et al. (2020)
6	Abuja, Nigeria	Built-up area, road network, water body, slope, geology, soil	Simple Additive Weighing (SAW) and Fuzzy set theory	Aderoju et al. (2020)
7	Ahvaz, Iran	Land use., distance from rivers, fault, flood areas, protected and sensitive areas, distance from residential areas, distance from airport, distance from industrial areas, archeological sites, road and transportation links, slope	Fuzzy-AHP approach combined with GIS	Chabok et al. (2020)
8	Izmir, Turkey	Proximity to roads, Proximity to transfer stations, Proximity to transformers, Proximity to power line, MSW availability, elevation, slope, surface area	Fuzzy logic approach-AHP	Yalcinkaya and Kirtiloglu (2020)

Table 2 (continued)

S.N	Study area	Criteria considered for landfill site suitability evaluation	Technique applied	Authors
9	Rajshahi, Bangladesh	Land value, slope, elevation, distance from roads, distance from railway, soil, ground water depth, distance from settlements, distance from protected area, land use, distance from airfields, aspect, distance from river and canal, distance from water body	Fuzzy analytic hierarchy process (F-AHP) approach	Islam et al. (2020)
10	Antalya, Burdur and Isparta, Turkey	Land use, slope, elevation, soil depth, geology, aspect, precipitation, distance from protected areas, distance from fault, distance from roads, distance from rivers, distance from airports, distance from wells, distance from industrial, distance from historical and cultural sites	GIS and multi-criteria analysis (MCA)	Dereli and Tercan (2020)

implemented through the formatting of values into a practical membership set. In this case, the highest value, i.e. 1, belongs to the maximum membership rate and the lowest value, i.e. 0, belongs to the minimum membership rate. In the fuzzy standardization method, membership functions are usually used to format values (Vavatsikos et al., 2019). Membership function specifies the fuzzy nature of a fuzzy set, and in fact, a function that shows the membership rate of different elements to a set is called a membership function. Membership functions have three incremental, decreasing and combined incremental-decreasing modes. It should be noted that in the Fuzzy Analytic Hierarchy Process (FAHP), the weighting is based on the experiences and knowledge of individuals. This method consists of seven steps: the hierarchical charting, the definition of fuzzy numbers in order to perform paired comparisons, the formation of a pairwise matrix using fuzzy numbers, calculating the triangular fuzzy number for each of the rows of the paired comparison matrix, calculating the magnitude of the triangular fuzzy number relative to each other, calculating the weight of criteria and options in the paired comparison matrices and calculating the final weight vector (Karasan et al., 2018). Then, Each criterion was analyzed as an independent layer to produce the intermediate thematic maps. Together, they were superimposed using the layering technique and reclassified to produce the final landfill suitability and zonation map, using site suitability index. The use of the weighted overlay analysis (WOA) allowed the inclusion of various features of the study area and aided in the analysis by the use of ArcGIS software.

Criteria selection for suitable landfill site

In Table 2, the reference of the important criteria in the selection of the burial place is given based on previous studies. In this study, the selected criteria are based on the instructions of the Environmental Protection Organization of Iran, because these criteria are general, based on an overview of the studies presented in Table 2, the importance of effectiveness was weighted according to local experts, and was considered in this research (Table 3).
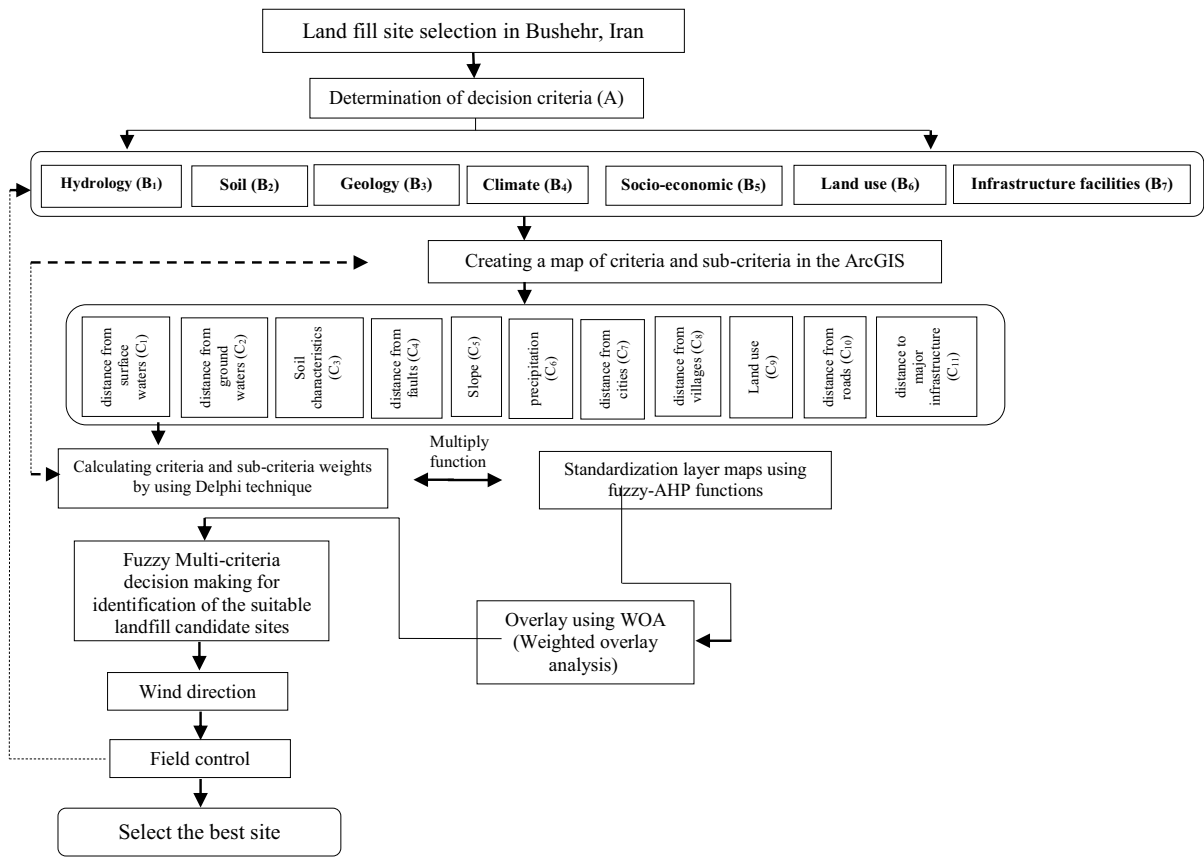
Fig. 2 Flow chart of methodology applied to suitability analysis for municipal landfill site selection

Weight calculation using fuzzy analytic hierarchy process (FAHP)

The Iran of environmental hazardous waste control board has set up predefined criteria and specific distance for setting the suitable location of the landfill site. Hence, the study is required to select multiple alternatives and criteria. The effects of the factors to be evaluated during the site selection process may be different. From the consider environmental protection, different component nearness to landfill site has a vulnerability and each factor or criteria is not equally vulnerable to risk due to landfill. Thus, criteria-based comparison and weight should be calculated. As far as multi-criteria analysis is concerned, there are various techniques for weighting selected criteria or factors like weighted sum model (WSM), weighted product model (WPM), weighted aggregated sum product assessment (WASPAS), technique for order preference by similarity to ideal

solution (TOPSIS), analytic hierarchy process (AHP), Best–worst method (BWM), entropy method, evaluation based on distance from average solution (EDAS), fuzzy analytic hierarchy process (FAHP), fuzzy TOPSIS, etc. (Kontos et al., 2005; Önüt and Soner 2008; Tavares et al., 2011; Demesouka et al., 2013; Beskese et al., 2015; Khan & Samadder, 2015; Rezaei, 2015; Chabuk et al., 2017; Guler and Yomralioglu 2017). Among these used techniques, AHP and fuzzy gained wide popularity (Chabok et al., 2020; Islam et al., 2020; Özkan et al., 2020; Şener & Şener, 2020; Unal et al., 2020). The analytic hierarchy process was introduced by Saaty (1980) which is considered as the best technique for tackling complex MCDM (multi-criteria decision-making) problems in real situations. Literature has proved that AHP is very useful for decision-making and suitability analysis (Kamdar et al., 2019; Şener et al., 2006; Wang et al., 2009). But practically, the uses of a crisp numeric value in AHP are often inadequate, because human judgment

Table 3 Criteria and and sub-criteria options and suitability rate (CJJ17-2004, GB 16,889; IRI, 2020)

Criteria and and sub-criteria	Suitability rate				
	[a] Most suitable (5)	Suitable [b] (4)	[c] Relatively suitable (3)	Least suitable [d] (2)	Limited areas [e] (1)
Land use	scattered rangeland-halophyte	uncultivated land	agricultural land	salty land	built-up land, shrimp farms
Hydrology					
Distance from surface waters (m)	> 3000	2000–3000	1000–2000	300–1000	< 300
Distance from ground waters (m)	> 1000	700–1000	500–700	300–500	< 300
Soil					
Soil characteristics	Deep soil with very heavy texture	Deep soil with heavy texture	Deep soil with medium to heavy texture	Soil with gravel, sandy and light texture	Shallow deep with gravel texture
Climate					
Precipitation (mm)	< 144	144–148	148–152	152–156	> 156
Wind	Direction				
Geology					
Distance to faults (m)	> 700	500–700	300–500	100–300	< 100
slope (%)	< 5	5–10	10–20	20–40	> 40
Socio-economic					
Distance from cities (m)	5000–7000	3000–5000	> 7000	1000–3000	< 1000
Distance from villages (m)	> 3000	2000–3000	1000–2000	500–1000	< 500
Infrastructure facilities					
Distance from roads (m)	1000–1500	> 1500	750–1000	500–750	< 500
Distance to restricted sites (m)	> 700	500–700	300–500	100–300	< 100

[a] Is very suitable with the least possible time and investment to develop a solid municipal landfill site

[b] Are suitable for areas requiring investment and medium time to develop solid municipal landfill

[c] Areas that are somewhat suitable and require preparation operations before the beginning of solid municipal wastes' landfill

[d] Unsuitable areas. These areas are not economical for landfill of solid urban wastes, and the cost and time for preparation of these areas is high

[e] Metropolitan areas, buildings lands are areas that are not capable of landfill of solid urban wastes. These areas are eliminated in the assessment

may be biased and vague. However, to overcome such a shortage of AHP, Van Laarhoven and Pedrycz proposed fuzzy AHP in 1983, which is the combination of AHP and Fuzzy set theory. A fuzzy set is the most preferred theory in multicriteria decision-making (Yalcinkaya & Kirtiloglu, 2020). A fuzzy set is an extended form of ordinary set theory that was introduced by Zadeh in 1965 for dealing with business, vagueness, and uncertainty in the data set (Beskese

et al., 2015). Looking toward this advantage, fuzzy AHP (FAHP) was used in the present study for the deriving weight of selected criteria. However, fuzzy in AHP deals with ambiguous and uncertainty information (Ballı and Korukoğlu 2009). Literature shows that there are different procedures to derive weight using fuzzy AHP (Bozbura et al., 2007). Among these, the geometric mean method proposed by Chang (1996) are the most popular and widely used.

In the present study, the extent analysis method introduced was applied with triangular fuzzy numbers (TFNs) to calculate the fuzzy weight.

Fuzzy extent analysis

The fuzzy set theory incorporated with original AHP to deal vagueness of human judgment in the decision-making process. The study used the Delphi technique to collect 30 experts' opinions, which were finally processed to give weight to each criterion. The technique is considered an interactive method of collecting the fundamental data by allowing interaction between researchers and experts in the field through multiple rounds of questionnaires and/ or focus group discussion to obtain expert views on the subject matter (Chabok et al., 2020). In each round, responses were aggregated and weighted using an analytical hierarchy process (AHP) (Lizot et al., 2020), from which outcomes were shared with the same group for another session/ round of questions/discussion. The same procedures were followed for all criteria until a consensus was reached. Chang (1996) introduced a new approach that includes the use of triangular fuzzy numbers (TFNs) for pairwise comparison scale of fuzzy-AHP and the use of the degree analysis method for synthetic degree values of pairwise comparisons (Table 4).

Table 5 shows the pairwise comparison scale used for the fuzzy-AHP method (Taibi & Atmani, 2017).

Firstly, the pairwise comparison matrices were prepared for the seven main criteria (Table 6). The pairwise comparison matrices were created for land use criteria, soil criteria, hydrological criteria, geology criteria, socio-economic criteria, climatic criteria, and criteria relating to infrastructure criteria separately and are presented in Tables 7. Moreover, pairwise comparison matrices were created for each sub-criterion. The weighting results of the criteria

Table 5 Triangular fuzzy numbers pairwise comparisons

Triangular fuzzy numbers (TFNs)	Linguistic variables
(1, 1, 1)	Exactly equal
(3/2, 1, 1/2)	Equal important
(2, 3/2, 1)	Weak important
(5/2, 2, 3/2)	Strong important
(3, 5/2, 2)	Demonstrated important
(7/2, 3, 5/2)	Absolute important

Table 4 Options' membership functions in a FAHP method (Tan et al., 2014)

Sub-criteria	Control points (threshold values)			Membership function	Shape of membership function
	a	b	c		
Land use	–	–	–	Discrete	–
Distance from surface waters	300	–	3000	Monotonically increasing	Linear
Distance from ground waters	300	–	1000	Monotonically increasing	Linear
Soil	–	–	–	Discrete	–
Precipitation	141	–	161	Monotonically decreasing	Linear
Distance to faults	100	–	700	Monotonically increasing	Linear
Slope	0	–	40	Monotonically decreasing	Linear
Distance from cities	–	7000	–	Monotonically increasing–decreasing	Raster Calculator
Distance from the villages	–	3000	–	Monotonically increasing–decreasing	Raster Calculator
Distance from roads	–	1500	–	Monotonically increasing–decreasing	Raster calculator
Distance to restricted sites	300	–	1500	Monotonically increasing	Linear

Table 6 Comparison matrix and weights of using main criteria

	Land use	Soil	Hydrology	Geology	Socio-economic	Infrastructure facilities	Climate	Weight
Land use	(2/3, 1/2, 2/5)	(1, 2/3, 1/2)	(2, 1, 2/3)	(3/2, 1, 1/2)	(2/3, 1/2, 2/5)	(1, 1, 1)	(2, 1, 2/3)	0.2345
Soil	(2, 1, 2/3)	(2, 3/2, 1)	(3/2, 1, 1/2)	(5/2, 2, 3/2)	(1, 1, 1)	(5/2, 2, 3/2)	(2, 3/2, 1)	0.141
Hydrology	(1, 1, 1)	(5/2, 2, 3/2)	(2, 3/2, 1)	(3, 5/2, 2)	(3/2, 1, 1/2)	(5/2, 2, 3/2)	(3, 5/2, 2)	0.1424
Geology	(1, 2/3, 1/2)	(3/2, 1, 1/2)	(1, 1, 1)	(2, 3/2, 1)	(2, 1, 2/3)	(3/2, 1, 1/2)	(2, 3/2, 1)	0.0721
Socio-economic	(1/2, 2/5, 1/3)	(2, 1, 2/3)	(1, 2/3, 1/2)	(2, 3/2, 1)	(1, 2/3, 1/2)	(3/2, 1, 1/2)	(1, 1, 1)	0.1975
Infrastructure facilities	(1/2, 2/5, 1/3)	(2/3, 1/2, 2/5)	(1, 2/3, 1/2)	(1, 1, 1)	(2/3, 1/2, 2/5)	(2, 1, 2/3)	(1, 2/3, 1/2)	0.1114
Climate	(2/3, 1/2, 2/5)	(1, 1, 1)	(2, 1, 2/3)	(5/2, 2, 3/2)	(1, 2/3, 1/2)	(2, 3/2, 1)	(3/2, 1, 1/2)	0.1011

in Table 5 show that among criteria, weight-related land use criteria (0.2345), socio-economic criteria (0.1975), and hydrologic criteria with weight (0.1424) were the most effective and most important criteria, respectively, in locating a disposal site for the waste landfill in the research area. The results of the study Danesh et al. (2019) showed the importance and significant weight of environmental criteria in

Table 7 Comparison fuzzy membership matrix of main and sub-criteria

Fuzzy membership	Soil criteria	Land use criteria
0.1	Shallow deep with gravel texture	Built-up land, Shrimp farms
0.3	Soil with gravel, sandy and light texture	Salty land
0.5	Deep soil with medium to heavy texture	Agricultural land
0.7	Deep soil with heavy texture	Uncultivated land
0.9	Deep soil with very heavy texture	Scattered rangeland- halophyte

Hydrology main criteria

	Distance from surface waters	Distance from ground waters	Weight
Distance from surface waters	(1, 1, 1)	(5/2, 2, 3/2)	0.6644
Distance from ground waters	(2/3, 1/2, 2/5)	(1, 1, 1)	0.3356

Geology main criteria

	Distance to faults	Slope	Weight
Distance to faults	(1, 1, 1)	(2, 3/2, 1)	0.7196
Slope	(1, 2/3, 1/2)	(1, 1, 1)	0.2804

Socio-economic main criteria

	Distance from cities	Distance from villages	Weight
Distance from cities	(1, 1, 1)	(5/2, 2, 3/2)	0.6644
Distance from villages	(2/3, 1/2, 2/5)	(1, 1, 1)	0.3356

Infrastructure facilities criteria

	Distance from roads	Distance to restricted sites	Weight
Infrastructure facilities criteria***Distance from roads	(1, 1, 1)	(2, 3/2, 1)	0.7196
Distance to restricted sites	(1, 2/3, 1/2)	(1, 1, 1)	0.2804

prioritizing the proposed areas for disposal of waste. Kamdar et al. (2019) in selecting the location of landfills in Songkhla urban municipalities have considered land use criteria as the highest weighted factor. A general overview of the results of the above studies shows that despite different results from the impact of different factors in different regions, land use 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.

Weighted overlay analysis (WOA)

The weighted overlay is the most applied approach for overlay analysis to solve multi-criteria problems in ArcGIS application. Where multiple factors are chosen to develop certain conclusion, weighted overlay offers the best result such as site selection and suitability models. Weighted overlay technique can be used in selecting a suitable site for a landfill (Islam et al., 2020; Şener & Şener, 2020; Yalcinkaya & Kirtiloglu, 2020).

In the present study, seven criteria relating to landfill site selection were chosen. The weight of each criterion was calculated using fuzzy AHP. Raster layer of each criterion was assigned with a weight based on their role in the site selection of landfill and reclassified them into a common scale ranging from 1 to 5. Looking towards the criteria selected in the present study, the weighted overlay was done twice. First of all, the overlay was performed each of the main criteria category, i.e., land use criteria, soil criteria, hydrological criteria, geology criteria, socio-economic criteria, climatic criteria, and criteria relating to infrastructure. Finally, the suitability of landfill site selection was performed by overlaying the suitability result of these output raster layers. For suitable landfill site selection, the weighted overlay can be expressed as:

$$S = \sum_{i}^{n} W_i C_i, \tag{1}$$

where S is the site suitability index for each layer, W_i is the weight of the ith criteria layer, C_i is the sub-criteria score of the ith criteria layer, and n is the number of suitability layers. The five suitability classes (the most suitable, suitable, relatively suitable, the least suitable and limited areas) were determined using the equal interval ArcGIS raster data classification method. This classification method divides the data range into equal sub-ranges and provides a more accurate and understandable legend (Aderoju et al., 2020; Al-Anbari et al., 2018; Şener & Şener, 2020).

Assessment of the accuracy of the site selection map

A proper method to evaluate the accuracy of a site selection map is to use a receiver operator characteristic (ROC) curve. In a ROC curve, the greater the deviation from the baseline, the higher the accuracy of the site selection map. In addition to examining the curve's trend, the area under the curve (AUC) is determined by counting the number of field sample points that are correctly located at the location site and the sample points that are not properly located at the location site. The ground truth sample points were selected by stratified random sampling method. In the ROC curve, the accuracy of the location map is determined by evaluating field points that are correctly located at the location site (TP), the number of ground truth sample points that are not correctly located on the location site (TN), the number of ground truth sample points that are incorrectly located on the location site (FP), and the number of ground truth sample points that are not incorrectly located on the location site (FN). To draw the ROC curve, the y-axis, which contains "sensitivity" (Eq. 2), and the x-axis, which represents "1-specificity " (Eq. 3), must be calculated for each value of the desired class threshold.

$$\text{Sensitivity} = \frac{TP}{TP + FN}, \tag{2}$$

$$\text{Specificity} = \frac{TN}{TN + FP}, 1 - \text{Specificity} = 1 - \frac{TN}{TN + FP} \tag{3}$$

The "precision" and "accuracy" of the location map was determined from Eqs. 4 and 5, respectively.

$$\text{Precision} = \frac{TP}{TP + FP} \tag{4}$$

$$\text{Accuracy} = \frac{TP + TN}{n} \tag{5}$$

The area under the curve (AUC) was used to determine the accuracy of the site selection model. A value of AUC of 1 is considered perfect and value of

AUC equal to 0.5 is considered as random guessing (Khatami et al., 2017; Quesada-Ruiz et al., 2019).

Results and discussion

Description of criteria

Due to the different social, cultural, technical, environmental, geographical structures, and regulations and criteria introduced by environmental protection organizations in each countries, the factors related to landfill site selection are variable. In addition, the amount and manner of waste collection in different areas is different, which leads to the determination of landfills for each area by different methods. In the present study, the eleven criteria namely land use, distance from cities, distance from the villages, distance from surface waters, distance from the groundwater, soil characteristics, distance to faults, slope, precipitation, distance to restricted sites and distance from roads, and waste production area were taken into account in determining appropriate landfill sites in the Bandar Bushehr city. These criteria were classified into seven main groups: land use, socio-economic, hydrology, soil characteristics, geological, climate, infrastructure facilities. The reasons for the selection of each criteria are discussed below.

Land use criteria

Remote-sensing image with the clear-sky condition was downloaded (from https://landsat.usgs.gov). The Landsat-8 Operational Land Images acquired in 2018, was used in this research. The remote sensing (RS) data were processed with the following steps. First, a geometric correction was made for the RS data using the polynomial method based on ground control points. To unify the data resolution, all the data were resampled to 30×30 m. After radiation correction and atmospheric correction, the False Color Composite (FCC) was used for diagnosing feature. These operations were conducted on ERDAS Imagine 9.3 Software (Rawat and Kumar, 2015). Five typical categories of land use; (i) built-up land, shrimp farms (ii) uncultivated land (iii) scattered rangeland- halophyte (iv) agricultural land (v) salty land. The water bodies inside the study area were extracted using

the Modified Normalized Difference Water Index (MNDWI) (Geo et al. 2019):

$$MNDWI = \frac{Green - MIR_1}{Green + MIR_1} \tag{6}$$

where Green and MIR_1 refer to the green band and a middle infrared band of the RS image, respectively. Next, a manual threshold for separating all of the bodies of water from other areas was determined. This method was modified based on the MNDWI method. The results contained more information and eliminated the terrain influence (Geo et al. 2019). The area covered with vegetation was extracted using the Normalized Difference Vegetation Index (NDVI) method after masking out water areas (Huete et al., 2002).

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \tag{7}$$

where NIR and RED refer to a near-infrared band and a red band of the RS image, respectively. The threshold (0.255) was determined after a thorough visual interpretation of the study area. To work out the land use classification, supervised classification method with maximum likelihood algorithm was applied in the ERDAS Imagine 9.3 Software. Then, to standardize this layer, the values between zero and one were assigned to each of the classes and the land use map of the fuzzy process was prepared in five classes (Fig. 3).

Hydrological criteria

Maps of rivers and grade-3 and above waterways were prepared using 1: 25,000 digital map sheets and spatial analysis functions in the GIS system. Given the fact that the more distance from the surface water resources, the more suitable site for landfill, Euclidean distance was first calculated using the distance function. Then increasing linear membership function was used to phase out this layer, and number 0 was assigned to a distance of 300 m and less, and no. 1 was assigned to a distance of 3000 m or more and the map of the distance from the surface waters were prepared in five classes using the fuzzy process (Fig. 3).

The location of wells in the region was determined using a field survey by GPS. It should be noted that the greater the distance from groundwater resources, the more suitable site for landfill. Therefore,
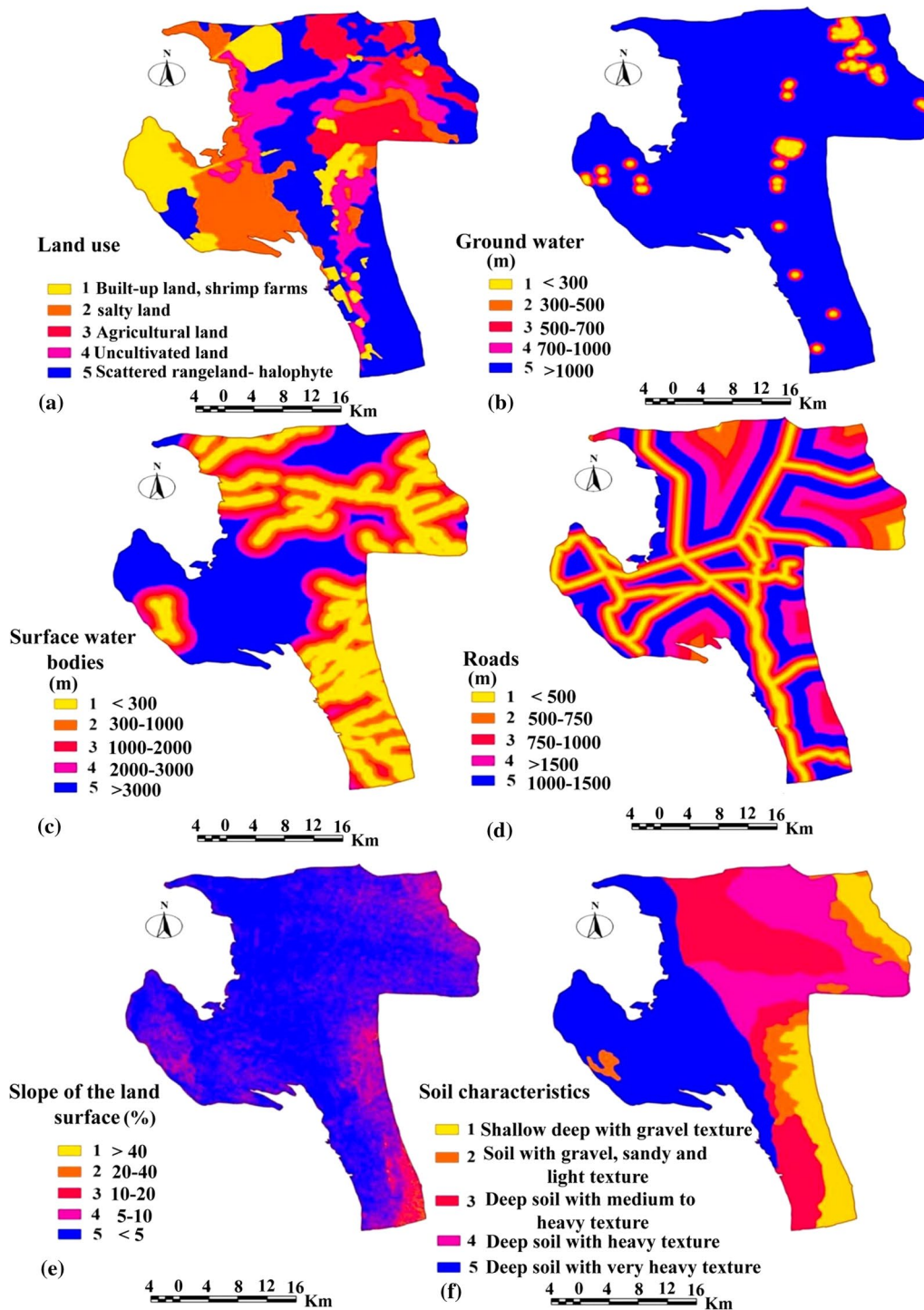
Fig. 3 The spatial distribution of land use suitability index (**a**), ground water suitability index (**b**), surface water bodies suitability index (**c**), roads suitability index (**d**), slope of the land surface suitability index (**e**), soil suitability index (**f**). Descriptions of values: 1: limited areas; 2: the least suitable; 3: r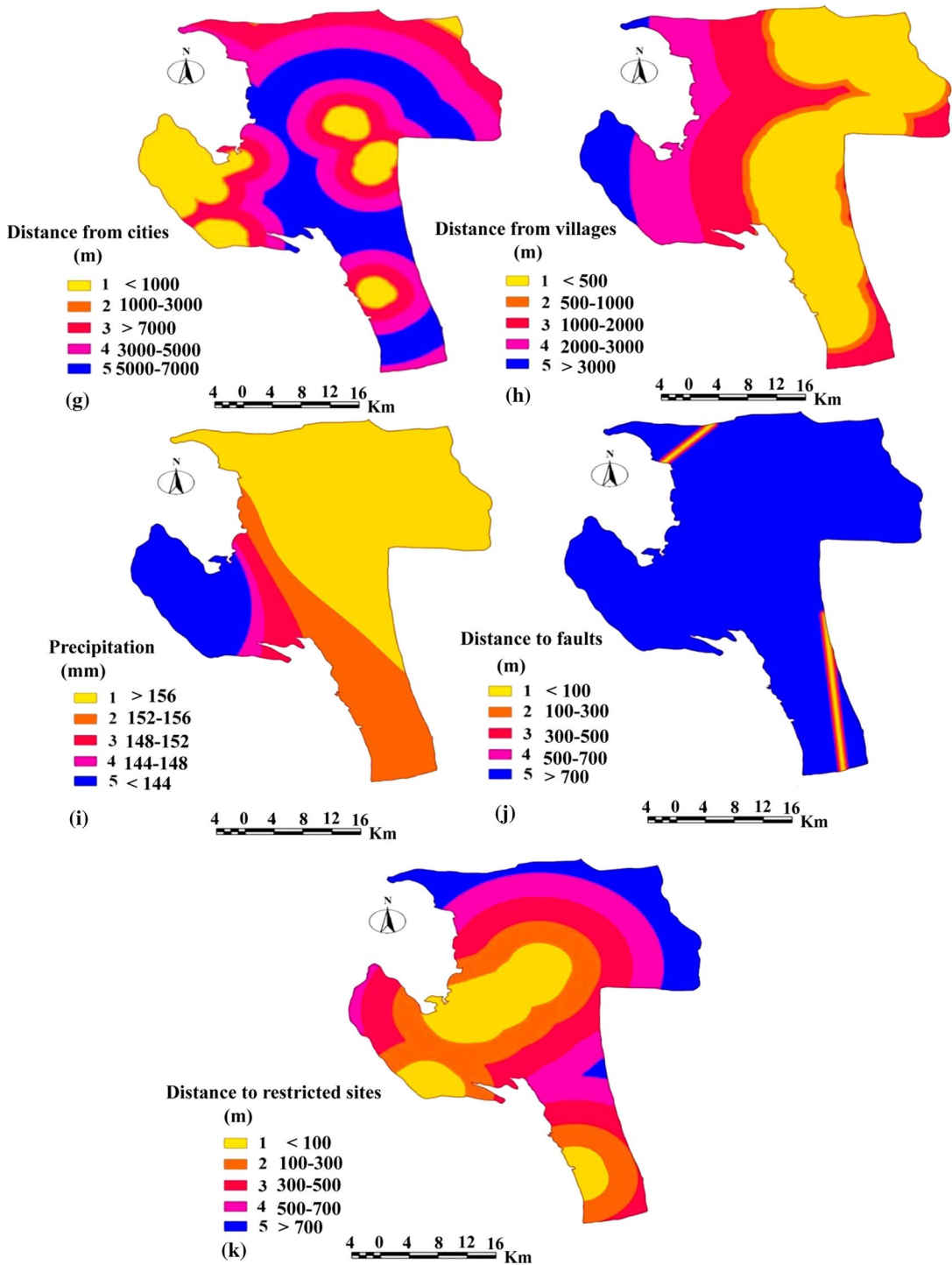elatively suitable; 4: suitable; 5: the most suitable. The spatial distribution of cities suitability index (**g**), villages suitability index (**h**), precipitation suitability index (**i**), faults suitability index (**j**), major infrastructure suitability index (**k**). Descriptions of values: 1: limited areas; 2: the least suitable; 3: relatively suitable; 4: suitable; 5: the most suitable

Distance from cities (m)
1 < 1000
2 1000-3000
3 > 7000
4 3000-5000
5 5000-7000

(g)

Distance from villages (m)
1 < 500
2 500-1000
3 1000-2000
4 2000-3000
5 > 3000

(h)

Precipitation (mm)
1 > 156
2 152-156
3 148-152
4 144-148
5 < 144

(i)

Distance to faults (m)
1 < 100
2 100-300
3 300-500
4 500-700
5 > 700

(j)

Distance to restricted sites (m)
1 < 100
2 100-300
3 300-500
4 500-700
5 > 700

(k)

Fig. 3 (continued)

Euclidean distance was calculated using distance function, and then the increasing linear membership function was used to phase out this layer, and number 0 was assigned to a distance of 300 m and less, and no. 1 was assigned to a distance of 3000 m or more and the map of the distance from the underground waters were prepared in five classes using the fuzzy process (Fig. 3).

Soil criteria

The soil map of the region was prepared using the maps of Iran National Cartographic Center. Soils of the region are classified into five classes. Then, to phase out this layer, the values between 0 and 1 were assigned to each of the classes and the soil map of the fuzzy process was prepared in five classes (Fig. 3).

Climate criteria

In climatic criteria, rainfall was considered for spatial evaluation in landfill site selection. The rainfall map was prepared using the data collected from the local weather report, meteorological station Bandar Bushehr. The average rainfall of the two stations for a statistical period of ten years from 2010 to 2020 was collected (IRI, 2020). These data were converted into geo-database and spatial rainfall map was prepared using the widely used IDW (inverse distance weighted) method in a GIS environment. The proper location for landfill is the areas with the least rainfall, decreasing linear membership function was used to phase out this layer. The minimum and maximum rainfall were considered, and number 1 was assigned to the minimum rainfall and number 0 was assigned to the maximum rainfall. Then precipitation map of the fuzzy process was prepared in five classes (Fig. 3).

In order to determine the predominant wind direction, first, the raw meteorological data format of the ten-year period (2010–2020) of the Bandar Bushehr synoptic station (Statistical yearbook of the Bushehr Meteorology Organization, BMO, 2020) was converted to the usable format of the WRPLOT software by a program written in the Excel environment. Then, in the environment of this software, the wind direction for the ten-year statistical average was drawn.

Geology criteria

The faults map of the region was prepared using the Geology Organization data. The greater distance from the faults, the more suitable the site for landfill, Euclidean distance was first calculated using distance function, and then the increasing linear membership function was used to phase out this layer. Number 0 was assigned to the distance of 100 m and less, and number 1 was assigned to the distance of 700 m and more, and the map of the distance from the fault was prepared in five classes using the fuzzy process (Fig. 3).

The slope of the land surface was calculated on the pixel basis using the digital elevation model (DEM). The greater the topographic slope of the area, the more improper site for landfill, the decreasing linear membership function was used to phase out this layer. Number 1 was assigned to zero slope, and number 0 was assigned to 40% slope and more. The slope map was prepared in five classes using the fuzzy process (Fig. 3).

Criteria related to infrastructure

The residential map was prepared using the land use map. Demographic areas are important in two directions: landfills should not be located near demographic areas, and an area of concern should be considered for them; because these areas are the source of waste products, they are important in terms of economy and transportation costs. Due to the increased transportation costs with moving away from demographic areas, and the distance from demographic areas has its own problems, Euclidean distance was calculated for each layer (urban and rural areas) using the distance function; and then, the increasing–decreasing linear membership function (using the Raster calculator function) was used to phase out these layers. The median limit was 7000 m for urban areas and 3000 m for rural areas, and the map of the distance from the demographic regions was prepared in five classes using the fuzzy process (Fig. 3).

The main road maps (highways) were prepared using 1: 25,000 digital sheet maps and spatial analysis functions in ArcGIS. Given the fact that with increased distance from the roads, the cost of transportation is increased and with decreased distance from the roads, the visual beauty of the environment

is damaged, Euclidean distance was first calculated using the distance function and then the increasing–decreasing linear membership function (using the Raster Calculator function) was used to phase out this layer. The intermediate boundary was considered to be 1500 m and the distance map of the main paths was prepared in five classes using the fuzzy process (Fig. 3).

Socio-economic criteria

The demographic areas are important component in terms of socio-economic criteria from two perspectives; landfills should not be located near demographic areas, and an area of concern should be considered for them; because these areas are the source of waste products, they are important in terms of economy and transportation costs. Due to the increased transportation costs with moving away from demographic areas, and the distance from demographic areas has its own problems (Rızvanoğlu et al., 2019). The present study assessed two related criteria including the distance from urban and rural residential areas in the study area to find a suitable location for the municipal landfill site. polygon shape files were created using place layer in Google earth professional version. These identified polygons were exported into GIS environment. The Euclidean distance analysis was carried out layers with measured safe distances from the each urban and rural polygons layer using the distance function; and the increasing–decreasing linear membership function was used to fuzzy out these layers. The median limit was 7000 m for urban areas and 3000 m for rural areas, and the map of the distance from the demographic regions was prepared and the output of the analysis resulted to raster maps with radial distances in five classes using the fuzzy process (Fig. 3).

Identification of suitable areas for landfill

The criteria of land use, which is one of the main criteria in the landfill site selection in this research, in which land ownership is considered, for example, agricultural lands, built-up land and shrimp farms which are personal ownership, are not suitable for the landfill. Therefore, all the selected sites are located in scattered rangeland- halophyte and uncultivated lands, which are under the government ownership.

The results of land use classes showed that the dominant type of lands was scattered rangeland- halophyte lands (38,200 ha, 37.75%), uncultivated land (15,200 ha, 15.02%), agricultural lands (13,300 ha, 13.14%), salty lands (20,000 ha, 19.76%) and built-up land, shrimp farms (14,500 ha, 14.33%), respectively. Areas with limitations for landfill (cities, buildings, shrimp farms) cover 14,500 ha (14.33%) of the region. The results of land suitability class for waste landfill and their desirable amounts are presented in Table 8. Areas of the most suitable of environmental criteria are located in scattered rangeland- halophyte lands which include 38,200 ha (37.75%) of the region. About 11,783 ha (11.65%) were classified as limited soils because of shallow deep with gravel texture. Lands located at very low levels of surface and underground water resources (<300 m) are 29.77% and 1.34% of the area, respectively, which are not suitable for landfill. The two sub-criteria of geological; distance to faults and slope by allocating 1.19% and 0.05%, of the area, respectively, do not limit the suitability of areas for landfill (Table 8). The level of precipitation in more than 56.48% of the region is more than 156 mm. Due to its proximity to the sea and the low slope and high-level groundwater, these areas are not suitable for landfill. In the socio-economic criteria, due to the multitude of rural areas, 47.41% of the region was unsuitable for landfill. In infrastructure facility criteria, due to the low number of industrial centres and main roads, there were 18.6% and 14.8% of areas are not suitable for the landfill, respectively.

The best site characteristic

Suitable areas were classified after the integration of weighted fuzzy layers of different criteria such as land use, hydrology, soil, climate, geology, socio-economy and infrastructure; and then, the map of suitable sites for the municipal landfill was obtained. The final suitability results were divided into five discrete categories: best landfill areas, good landfill areas, and unsuitable landfill areas. According to landfill size requirements, the best landfill sites are shown in Fig. 4. 3140 ha of the lands are classified as the most suitable and 31,160 ha as unsuitable (Table 9).

The present study reveals that 8 considerable sites were found for municipal sanitary landfill.

The wind direction is one of the most important criteria in landfill site selection, for this purpose,

Table 8 The area of land in suitability class

Criteria	Most suitable		Suitable		Relatively suitable		Least suitable		Limited areas	
Sub-criteria	ha	%	ha	%	ha	%	ha	%	ha	%
Land use	38,200	37.75	15,200	15.02	13,300	13.14	20,000	19.76	14,500	14.33
Hydrology										
distance from surface waters	33,200	32.84	9200	9.1	11,700	11.57	16,900	72.16	30,100	29.77
distance from ground waters	92,530	93.06	1980	1.99	1850	1.86	1740	1.75	1330	1.34
Soil										
soil characteristic	35,796	35.39	21,138	20.9	25,274	24.99	7151	7.07	11,783	11.65
Climate										
precipitation	15,400	15.23	2200	2.18	4600	4.55	21,800	21.56	57,100	56.48
Geology										
distance to faults	97,500	96.44	700	0.69	700	0.69	1000	0.99	1200	1.19
slope	70,600	70.14	26,800	26.63	2600	2.58	600	0.60	50	0.05
Socio-economic										
distance from cities	29,590	29.17	30,460	30.02	22,140	21.82	2380	2.35	16,880	16.64
distance from villages	5950	5.88	15,369	15.19	24,867	24.59	7010	6.93	47,950	47.41
Infrastructure facilities										
distance from roads	28,800	28.49	22,900	22.65	16,800	16.62	17,600	17.41	15,000	14.84
distance to restricted sites	13,600	13.45	18,500	18.3	23,660	23.4	26,540	26.25	18,800	18.6

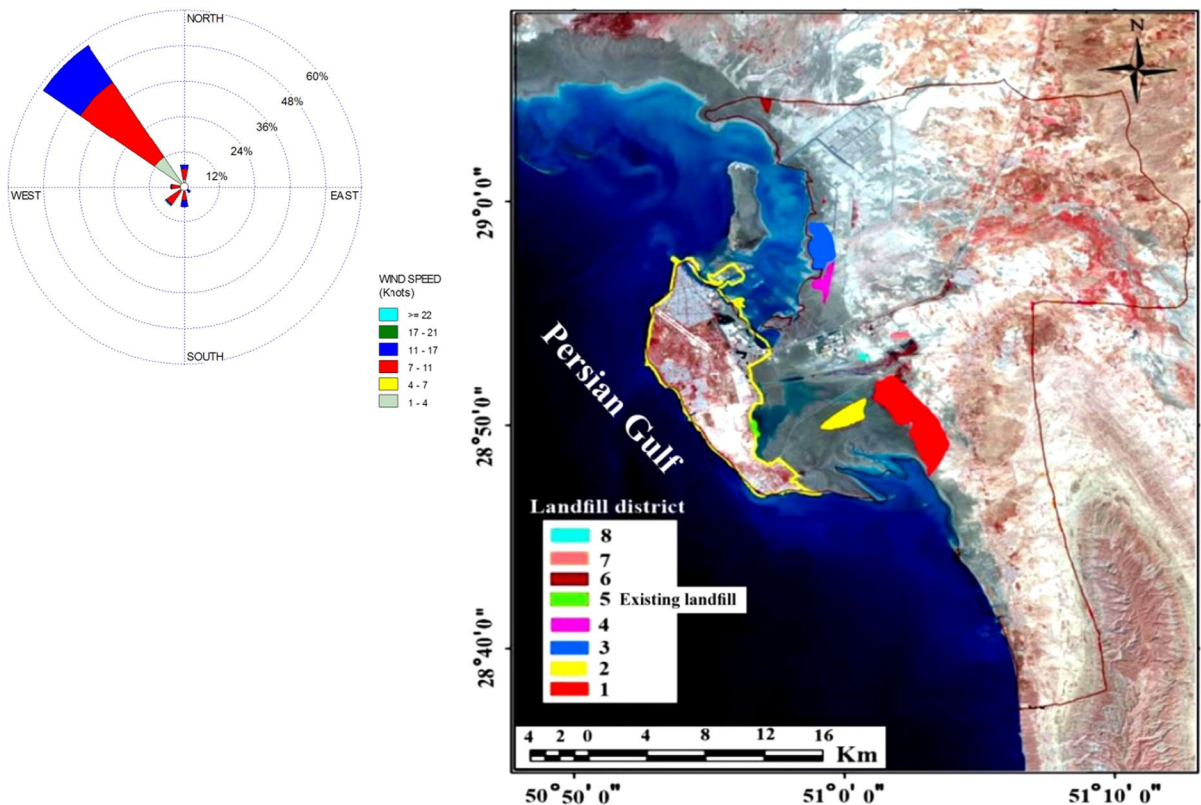**Fig. 4** Final suitable candidate sites for municipal landfill in Bandar Bushehr city, and the predominant wind direction is northwest

Table 9 The area of land in capability class

Region capability classification	Area (hectare)	Area (%)
Unsuitable	31,160	30.8
Least suitable	22,690	22.4
Relatively suitable	25,400	25.1
suitable	18,780	18.6
Most suitable	3140	3.1

the data of the Bandar Bushehr synoptic station was examined, based on which the predominant wind was in the northwest direction, which is not towards the city (Fig. 4). Therefore, the city is not affected by the adverse effects of the unsuitable site. But after field investigation for knowing current land use, public views, and authority's decision, the maximum of these sites cannot be accepted as a suitable municipal landfill. In Fig. 4, suitability sites show that 8 sites were found for the suitable municipal landfill with an area ranging from 1804 to 26 ha, but out of these 8 sites cannot be accepted for a landfill due to transportation issues, current land use, public acceptance, and local environmental issues. The existing solid waste landfill facility is located in the east of Bandar Bushehr city center. According to the analysis, the area where the solid waste landfill facility currently operates is located in the site 5 suitable sites (Fig. 4). This site is restricted for use as a landfill site in terms of criteria such as land use, and proximity to residential areas. Two candidate landfill sites (1 and 2) are proposed in the study. The landfill suitability map shows that the candidate site 1 and 2 is located east of Bandar Bushehr city. these areas aren't far from waste production areas and there will not be serious transportation costs. These areas are highly suitable areas for landfilling, they are proposed as landfill sites because of availability, and location in a wasteland and at a convenient distance from the urban area, where the bulk of the waste generated also belongs to these areas, and Also having a suitable area due to the growth of urban population in this area.

The accuracy of the site selection map

In selecting the best site for municipal solid waste landfill, evaluating the reliability of the method is important. The results of verifying the map produced from the ROC showed that the area under the curve (AUC) in 8 landfill site selection is above 0.5, which indicates the accuracy of the prediction of the landfill map (Table 10).

Minimum size land area required for landfill

The minimum required area of the landfill was determined by considering four factors such as rate of population growth, annual waste production, the density of compacted waste materials and an average height of the landfill were taken into consideration. Considering the fact that in parallel with the growth of population, the amount of generated wastes increases, the population growth rate can be considered the same as the rate of generation of

Table 10 The results of the accuracy of landfill sites' suitability by ROC curve indices and their components

Index	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
TP	117	28	28	16	11	11	7	5
FP	30	8	8	5	3	3	2	1
FN	10	6	4	4	3	2	1	1
TN	143	38	30	15	13	14	10	8
Specificity	0.83	0.83	0.79	0.75	0.81	0.82	0.83	0.89
Sensitivity	0.92	0.82	0.88	0.80	0.79	0.85	0.88	0.83
Precision	0.80	0.78	0.78	0.76	0.79	0.79	0.78	0.83
Accuracy	0.87	0.83	0.83	0.78	0.80	0.83	0.85	0.87
1-Specificity	0.17	0.17	0.21	0.25	0.19	0.18	0.17	0.11
Area Under the Curve (AUC)	0.78	0.80	0.64	0.67	0.75	0.66	0.70	0.81

Table 11 Number of classes and the percentages of the total study area

District	Areas (ha)	Best landfill areas			
		A < 27 ha	27 ha < A < 57 ha	57 ha < A < 189 ha	A > 189 ha
Operation age (year)		10	20	50	100
1	1804				Suitable
2	558				Suitable
3	440				Suitable
4	189			Suitable	
5	50		Suitable		
6	36		Suitable		
7	35		Suitable		
8	26	Unsuitable			
Total	3140	1	3		
Percentages	100	0.83	3.87	6.02	89.28

solid waste. The population of Bandar Bushehr city in 2011 was 195,222 people. According to the Iranian Statistic Center of 2020, Bandar Bushehr has a population of 223,504 people (PBO 2020). Based on Eq. 8, the growth rate during this 5 year period was determined to be 1.11.

$$P_0 = P_t(1 + r)^t \qquad (8)$$

where P_0 is the population at time 0, P_t is the population at time t and r is the rate of growth. According to Bandar Bushehr municipality statistics, the average daily waste production is about 170 tons (PBO 2020). After a simple calculation, the total weight of the waste produced (Q) is 62,050 tons over the one year period. The weight of solid wastes in the period of 10, 20, 50 and 100 years (t), $wight_t$, was calculated by Eq. 9 with annual solid wastes (Q), and growth rate (r).

$$Wight_t = Q_{ton/year} \times \frac{(1 + r) \times (t - 1)}{r} \qquad (9)$$

V_{20} is the volume of solid wastes per cubic meters in the period of 10, 20, 50 and 100 years (t) and $Wight_t$, the weight of annual solid waste in each period, was determined by Eq. 10.

$$V_t = \frac{Wight_t}{0.5} \qquad (10)$$

After calculating the landfill capacity using the Eq. 20, considering that the percentage of total landfill capacity should be allocated to covering soil, and the fact that 20–25% of the landfill capacity will be allocated to the covering soil, the required volume for landfill site (V) was determined by Eq. 11.

$$V_{(m^3)} = V_t \times 1.2 \qquad (11)$$

where, V the required volume for the solid waste landfill site. If the height of landfill site (H) is considered to be an average of 10 m (Wang et al., 2009), the minimum area required for each period can be calculated by Eq. 12.

$$A_{(m^2)} = \frac{V}{H} \qquad (12)$$

The areas in different classes in each district are presented in Table 11. The best landfill areas for the next 20 years, only account for 3.87%. Furthermore, most of the candidate areas are in districts 5, 6, and 7. For example, there are three candidates best landfill sites for those which can be used for 20 years.

The present study offered scientific bases for the study area using multi-criteria-based suitability analysis. The suitable areas for the selection of municipal landfill candidate sites were delineated using the best and common method, i.e., weighted overlay analysis (WOA). GIS has the competence To store, manage, analyze, and display spatial information with combined a spatial information. In this study, the fuzzy analytic hierarchy process (FAHP) as multi-criteria evaluation technique was used for calculating weight and overlay analysis for the potential landfill candidates. The applied technique has the opportunity for adjusting the degree of influence and weight-based

level of risk in the decision analysis which offers potential suitability map. This technique was applied to specify areas under potentiality and level of environmental risk that pose upon sitting municipal landfill. Thus, more relevant and interconnected criteria from each aspect were taken as geo-environmental factors which govern landfill siting in term of environmental safety, local aesthetic value, public awareness, and health. This site suitability model offers a chance to planners and developers to rethink about sitting either new or back-up municipal landfill sites.

The present research emphasized the significance of GIS-based techniques in selecting and locating such suitable sites for landfill. This study involved the analysis of enormous spatial and a spatial input data and retrieved output in terms of the degree of suitability for landfill candidates. This study also suggests establishing and applying such techniques for suitability analysis not only for sitting municipal landfill or solving waste management issues but in every field where complex decision support system is required for selecting best alternative for application and interest.

Conclusions

The increasing generation of municipal solid waste in the Bandar Bushehr is one of the greatest challenges faced by governmental authorities. The development of our model is motivated by the desire to mitigate the impact of landfill sites on the land use, socio-economic, hydrology, soil characteristics, geological, climate and distance to major infrastructure systems, and proposition reference for landfill site selection in the future. We have integrated GIS and a multi-criteria evaluation technique, fuzzy analytic hierarchy process (FAHP), in the assignment of site suitability for landfills. In this study, the effective criteria in the selection of suitable landfill sites and taking into account population growth and the development of the city to consider. The model proposed in this study is a combination of two methods of Fuzzy and Analytic Hierarchical Process (Fuzzy-AHP) using the calculated weights in Delphi technique which enables the decision-maker to locate the suitable location according to the importance of the criteria. Having

a structure with understandable multi-criteria decision making with a set of quantitative and qualitative data, and the existence of an orderly and independent structure reduce the incompatibility coefficient and can provide the most flexibility in judgment and the most realistic and best relation between criteria and options.

Intermediate suitability maps were produced for all criteria, which were combined to create the final composite suitability map. Different values for each criterion determined by experts with fuzzy models were standardized. A classification scheme was applied for criteria. A weight was assigned as objective as possible by applying fuzzy techniques. In the final aggregation process, the criteria from the Fuzzy- AHP logics overlay and the minimum required landfill area for 10, 20, 50 and 100 years was selected. This case study illustrates the process of identifying a few optimal sites. All candidate sites based on the 7 criteria were aggregated based on their weights and screened by sizes. The best landfill areas were given, and they can be taken as the optimal landfill candidate sites. The better landfill areas can be taken as back-up landfill candidate sites.

This evaluation is based on the criteria provided by Iran's Environmental Protection Organization, which is the decision authority for allocating a place to landfill site selection, for a period of 10, 20, 50, and 100 years. Therefore, according to the criteria provided by the Environmental Protection Organization of Iran, this evaluation and location have been done for the region. Definitely, in the future, due to policy changes, more advanced methods such as waste incinerators, etc. may be included in the agenda of this organization.

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