A COMPARATIVE EVALUATION OF MUNICIPAL SOLID WASTE LANDFILL SITES IN NORTHERN IRAN

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Abstract. Not only in developing countries has remained land-filling the most customarily used method despite the increased attention to development of the Municipal Solid Waste (MSW) management. There is a worldwide need to find the right management of MSW and this research is developing an strategy for landfill sites in Iran. We first determine the characteristics of the ten landfill sites in western part of Mazandaran province, northern Iran, using seven different landfill site sitting approaches. After reviewing each waste deposit site, considering all the criteria in each one of the seven methods applied in the present study, the incoherence in suitability was apparent in first phase. The second phase was to address the locally preferred criteria for landfill site evaluation**.** The aims of the present research were to show the unsuitability of the current landfill sites in western part of Mazandaran province and therefore, addressing locally preferred criteria for landfill site evaluation in northern Iran, commonly referred to as the Caspian Landfill Criteria (CLC), using which the most suitable areas for landfill sites were formerly chosen. The most principal parts in the CLC model were the importance of the weights of the criteria and the preferred weights of them. This model with eighteen effective and native criteria provides the suitable evaluation technique for municipal landfill sites. The final aim of this project was to apply the obtained results to illustrate the lack of suitable regions for MSW landfill sites in studied area.
Keywords: *Evaluation method, Caspian Landfill Criteria, Iran, GIS, AHP*

Introduction

During the last decade improvements about how to manage the solid waste in the cities was developed. Landfills have been a quick and efficient solution but still there are many improvements to be done (Adamcová et al., 2016; Cassinari et al., 2016; Chen et al., 2015; Wong et al., 2016a, 2016b). Solid waste management is a challenging issue (Guerrero et al., 2013) as waste disposal in developing countries is one of the significant environmental challenges (Baun and Christensen, 2004; Sharholy et al., 2008). Waste generation has grown rapidly over the recent years in Iran. It has been shown that new capabilities and capacities are required to address the crisis of growing waste production in Iran, as well as new disposal centres. The location of a disposal centre is an important factor, which should be considered in construction of any new centre (Shahabi, 2008). Although, the municipal solid waste (MSW) management has been developed worldwide, it is still in a critical status in Iran (Abdoli, 2005; Yazdani et al., 2013). In most Iranian cities, landfills are not used. About less than 50% of the municipal solid waste disposal methods in Iranian cities is still confined to pile-up or other unsafe methods of disposal (Rahim et al., 2005). Open dumping is a common method of waste

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disposal in most Iranian cities (Yazdani et al., 2015a). Numerous problems are seen in the landfill sites in Iran including those in Mazandaran province. Open-air waste burning, open-pit dumping and unsafe disposal considerations are common procedures in this province which can result in irreparable damages in the environment and also on society health (Yazdani et al., 2013 and 2015a; Calvo et al., 2005; Calvo et al., 2007; Diaz et al., 2005). Some land degradations caused by landfills have been previously reported, for instance, the impacts of landfills on soil quality. It has been shown that the leachate from landfills causes the soil degradation (Hernandez et al., 1998; Raman and Narayanan, 2008; Shaylor et al., 2009). The important environmental problems affiliated with open dumps are the infiltration and ground water pollution and the subsequent contamination of the land (Kale et al., 2010; Fatta et al., 1999). The leachate from municipal solid waste (MSW) landfills is a chemical compound. Therefore, small amounts of leachate can pollute soil which can contaminate a large amount of groundwater (Nema et al., 2009; Dimitriou et al., 2008; Mor et al., 2006). For example, leachate changes the nitrate level of soil. Nitrates are easily transported with water and therefore it pollutes surface and subsurface waters (Novara et al., 2013). Uncontrolled waste incineration resulted from the degradation process is one of the other important issues in the open dumping sites (Yazdani et al., 2015b). In the present studied area, uncontrolled waste incineration is the common process in most of the 10-landfill sites. Some studies have reported the negative impacts of the fire, resulted from waste incineration, on soil quality by affecting the chemical and microbiological properties of the soil (Martínez-Murillo et al., 2016; Pereira et al., 2016) In natural ecosystems, such as existing landfill sites in the studied area, restoration of the degraded soil is achieved by returning the microbiota activity and plant community recovery. Soil development is dependent on the erosion severity, total nitrogen and pH (Yazdani et al., 2015b), since these parameters in soil texture is determined the soil typicality (Pallavicini et al., 2014).

Therefore, the attempt of the present study was to understand the quality of existent landfill sites. During the last decades multiple methods have been applied to develop more suitable municipal solid waste landfill sites. Some relevant studies have integrated GIS with MCDA (Multi Criterai Decision Making) on landfill site sitting in several procedures, some of which are mentioned below.

Alanbari et al. (2014) and Sureshkumar et al. (2017) have used Multi Criteria Decision Analysis and GIS for municipal solid waste landfill site sitting. Elahi et al. (2014) have applied Multi Criteria Decision Analysis after preparing the data and evaluating the criteria according to the geographic situation of the studied area and have overlaid the map layers with the relevant criterion in ArcGIS. This recent study finally presented 3 places in Tafresh city for municipal landfill site sitting.

Moeinaddini et al. (2010) have used spatial cluster analysis (SCA) method and weighted linear combination (WLC) to choose the proper options for MSW landfill site in Karaj city. The most preferred site was then identified by Analytical Hierarchy Process (AHP). This study has indicated that WLC was useful for identification of the criteria and AHP was useful for prioritization.

In another research carried out by Eskandari et al. (2012) a methodology based on socio-cultural and economical-ecological aspects using multi criteria evaluation integrated with GIS has been suggested to choose a proper MSW landfill site in Marvdasht city. Delgado et al. (2008) have presented three spatial analysis models (overlay analysis, Boolean logic, binary evidence) for MSW landfill site sitting.

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Furthermore, available MSW landfills are evaluated by some procedures, such as Monavari 95-2 (Monavari and Shariat, 2000; Farzaneh, 2003; Ghanbari et al., 2011), Oleckno method (Salimi et al., 2013; Monavari and Arbab, 2005), Drastic (Wang, 2007), USEPA method (Christensen, 1992) and regional and locally screening (Davami et al., 2014; Aliowsati et al., 2013).

Human beings critically influence their environment, therefore, disorder in any element of a municipal system may cause a deficiency in the entire system (Meshkini et al., 2007). Although, various waste disposal approaches have significantly been developed worldwide, land-filling as yet is the most popularly applied procedure in third world countries (Yazdani et al., 2015b; Sumathi et al., 2008). In Iran, MSW land-filling is expanded day by day because of the rapid urban population growth and the changes in consumption patterns (Davami et al., 2014; Eskandari et al., 2012).

The aims of the present research were to show the unsuitability of the current landfill sites in studied area and therefore, addressing the locally preferred criteria for landfill site evaluation in the northern Iran, commonly referred to as the Caspian Landfill Criteria (CLC), using which the most suitable areas for landfill sites were formerly chosen. The final aim of this project was to apply the obtained results to illustrate the lack of suitable regions for MSW landfill.

The landfill sites are serious issues in the western part of Mazandaran due to the geographic conditions, including the proximity of forests and the sea, high groundwater levels and high tourists in holiday seasons, this region is in a more sensitive condition than the other parts of Mazandaran province (Yazdani et al., 2013). After the evaluation of landfill sites and showing the indications of land degradation, it is essential to restore these lands. Numerous researches have been carried out on land recovery after degradation using different methods which can be used in the future. For instance, there has been a report on restoration of mine dunes with fungi species (de Suza et al., 2011). Furthermore, in another study, limestone quarries has been resorted using three approaches; tree and shrub planting, no herb layer and hyseed (Gillardeli et al., 2013). (Pallavicini et al., 2014) have emphasised that environmental factors are very important for soil quality and development. It has also been shown that to forestation on degraded land (Haigh et al., 2013). Moreover, further researches have been carried out on forest restoration as well (Quinonero et al., 2016; Davies et al., 2010). Few studies have been conducted in Iran in the land restoration field (Sadeghi et al., 2015; Fallahzadeh et al., 2015). As to the sustainable municipal solid waste management, a wise plan in the western part of Mazandaran province should be prepared and performed.

Materials and methods

Study area

The studied area (8761.5 km^2) is located in the western part of Mazandaran, Iran, which is situated in the southern coast of the Caspian Sea in northern edge of Iran. In a region consisting about 36.88 percent of the total area of this province about 20.87 percent of the population of Mazandaran province is concentrated (Iranian Statistic Centre, 2010). The 610120 inhabitants of this area generate about 181040 tons of waste per year. The elevation of the studied area varies from 27 meters below sea level to almost 4800 meters above sea level because of locating between the Alborz mountain range and the Caspian Sea. There are three distinct geomorphologic conditions with different weather conditions in the studies area;

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coastal plains and foothills with temperate and humid weather and mountains with cold weather (Mazandaran Governor, 2014).

In Iran, similarly to the other developing countries, landfilling has continued as customarily used procedure despite the increased attention to develop the MSW management (Yazdani et al., 2013; Eskandari et al., 2012; Sumathi et al., 2008). Landfilling sanitary municipal solid waste, just like any other engineering project, requires basic information and planning. The landfill in every area has important effects on environment.

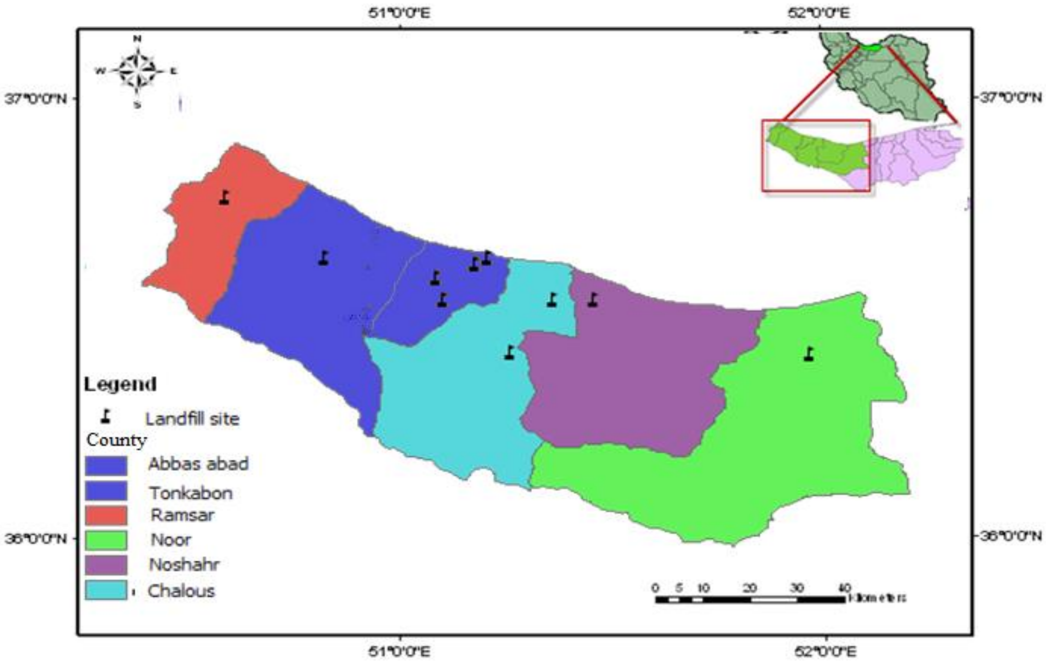

Figure 1. *Landfill sites in the study area*

Evaluation of the landfill sites using seven standards

The preliminary phase in the environmental impact assessment of landfill site is to know the sensitive parameters. Various methods have been introduced in literatures describing how to select a landfill site (Koshik et al., 2014; Alanbari et al., 2014; Elahi et al., 2014; Salimi et al., 2013; Eskandari et al., 2012; Moeinaddini et al., 2010; Shahabi et al., 2008; Sumathi et al., 2008; Hatzichristos and Giaoutzi, 2006; Heydarzadeh, 2001). The present study applied these methods to evaluate current municipal landfill sites situated in the studied area. In this study, 10 municipal waste landfills (Ramsar, Tonekabon, Abbas Abad, Kelardasht, Salmanshahr, Kelar Abad, Chalous, Marzan Abad, Noshahr, Noor) in 12 municipal districts were initially evaluated using the approved standards based upon the guidelines of British Columbia (BC), Environmental Protection Agency (EPA), Oleckno method, MPCA (Minnesota Pollution Control Agency), Regional Screening, Management and Programming Organization of Iran (MPO) and Iran Department of Environment (DOE). Each method and its criteria are mentioned and compared with each other in *Table 1*, however, the Oleckno index determination is mentioned separately in *Table 2*. In the Oleckno method, the annual average rainfall, soil type and soil depth are the three important

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factors which are considered to determine the rank of each landfill site. For this purpose the following equation was used (Monavari and Arbab, 2005; Salimi et al., 2013):

Oleckno Index Method Score = rainfall (mm/year) + soil type + ground water table (m)

Table 1. *Comparing the seven methods and their criteria*

Criteria methods	Distance to fault	Soil	Groundwater sources of drinking water	Distance to airports	Flood plain, flood basin	Land use
British Colombia			The distance between the discharged MSW and the nearest residence, water supply well, water supply intake, is to be a minimum of 300 meters.	The distance between an airport utilized by commercial aircraft and a landfill containing food wastes which may attract birds is to be a minimum of 8.0 kilometers.	Landfills proposed for locations within the 200 years floodplain and the associated floodway are not to be sited without adequate protection to prevent washouts.	The distance between the discharged MSW and public park is to be a minimum of 300 meters.
DOE			In areas where the water level is high ,it should be a2-meter-deep layer(made of silt and clay)and maximum permeability millionths of a centimeter per second must be provided	Minimum of 8 kilometers		Landfills should not be in conflict with Populated areas or other land uses distance to farmland 500metres, distance to the major cultural, archaeological and historical sites must be suitable
MPO	Minimum distance of 300 meters		Minimum distance of400 meters from the municipal water wells	Minimum of 3 kilometers		
MPCA **(Determinative criteria)**				Do not cumulate birds in sensitive area around airport	Distance from area with 100 years retention period flood	
EPA	The distance from faults must be at least 60 meters	Distance to areas with unstable soil		Distance within 3048 meters of runway airports turbojet aircraft, the distance of 1524 m from the runway airports piston aircraft	Distance from area with 100 retention period flood	

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Regional screening	The distance from faults must be at least 61 meters	The areas with shortage supply of heavy clay and fine grained soil for using coating layers are not suitable for municipal solid waste landfill sitting.	Regions with high underground water levels are not compatible for MSW sites, if the hydraulic trap method is used. At least 300 meters distance from water wells	At least 3 km distance from the airport.		At least distance of 150 m from, commercial, educational and residential centers and at least 80 m from industrial applications. The agricultural land use can be suitable for solid waste landfill sites

Continue ***Table 1.***

Criteria	Surface water (lake, river, lagoon)	Geology	Distance to residential areas	Distance to road	Preserve and bird habitat
BC	The distance between the discharged MSW and the nearest surface water is to be a minimum of 100 meters.	Landfills are not to be located within 100 meters of an unstable area	The distance between the discharged MSW and the nearest residence, hotel, restaurant, food processing facility, school, church or public park is to be a minimum of 300 meters.		The buffer zone between the discharged MSW and the property boundary should be at least 50 meters of which the 15 meters closest to the property boundary must be reserved for natural or landscaped screening (berms or vegetative screens)
DOE	Landfills should not be located in the wetlands and unique habitats Minimum distance of 2000 meters to surface waters	Not to be Placed on faults, underground mines, subsidence and collapse of cavities	Distance of 10-15 kilometers from the city	Distance of 3-5 kilometers to main road	
MPO	Wetlands should not be selected as the burial place ,landfills must be away from lakes ponds more than300meters.Minimum distance of 100 meters to rivers			Minimum distance of 300 meters	

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MPCA	Minimum 305 meters distance from any lake or pool, Minimum92meters distance from any river or channel, Avoiding from wetlands	Distance from area with limestone caves			
EPA	Landfills should not be located in the wetlands	Distance to high seismic areas, (displacement of rocks and karst areas)			
Regional screening	The MSW landfill sites should not be sited near the surface water (minimum distance of 61 m should be observed).	The regions with slide risk potential and sensitive clays are not suitable for landfill sites. The regions with high sensitive soils such as limestone and fragile soils are not suitable for landfill sites. The MSW landfill site should not be sited in the ravines		A proper distance from the main road should be considered. (Less than one kilometer is ideal)(economic)	

Table 2. *The indices of rank determining in Oleckno method*

The annual average rainfall (mm/year)	**Less than 250 (mm/year)**	**255-760 (mm/year)**	**765-1780 (mm/year)**	
Score	21	7	6	
Soil type	Clay silt or clay and sand	Silt and soft sand	Mud	Gravel and cobble
	12	5	4	0
Soil depth(m)	1.5 - 3	3 - 6	6 - 9	9 <
Score	3	7	9	9
Oleckno rank	Good	Acceptable	Unacceptable	
Score	24 - 42	21-23	>20	

The present study consisted of two phases; first phase included determining the characteristics of the 10 landfill sites by reviewing the library data, previously published literatures and using the ArcGIS software maps (version 10.2). The second phase is to address the locally preferred criteria for landfill site evaluation in the northern Iran for Caspian Landfill Criteria (CLC) model.

Most of the information was obtained from the Mazandaran Management and Planning Office of the Governor with a scale of 1:100000. The hydrology and hydrogeology maps (surface and groundwater maps) with a scale of 1:250000 were

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obtained from the Geographic Information Centre of the Mazandaran Regional Water Organization. By locating the GPS coordinates of the available landfill sites in field view and entering them as latitude and longitude in the GIS software database the landfill site map layer was prepared. The gathered data were then converted into a point data. Thematic maps, characterizing the affecting factors, were generated for landfill sites evaluation (Yazdani et al., 2013). The map layers of the evaluation criteria in the study area are shown in *Fig. 2*. The steps of the first phase of the present research are illustrated in *Fig. 3*. All the mentioned steps are considered in each of the seven evaluation methods for total research area.

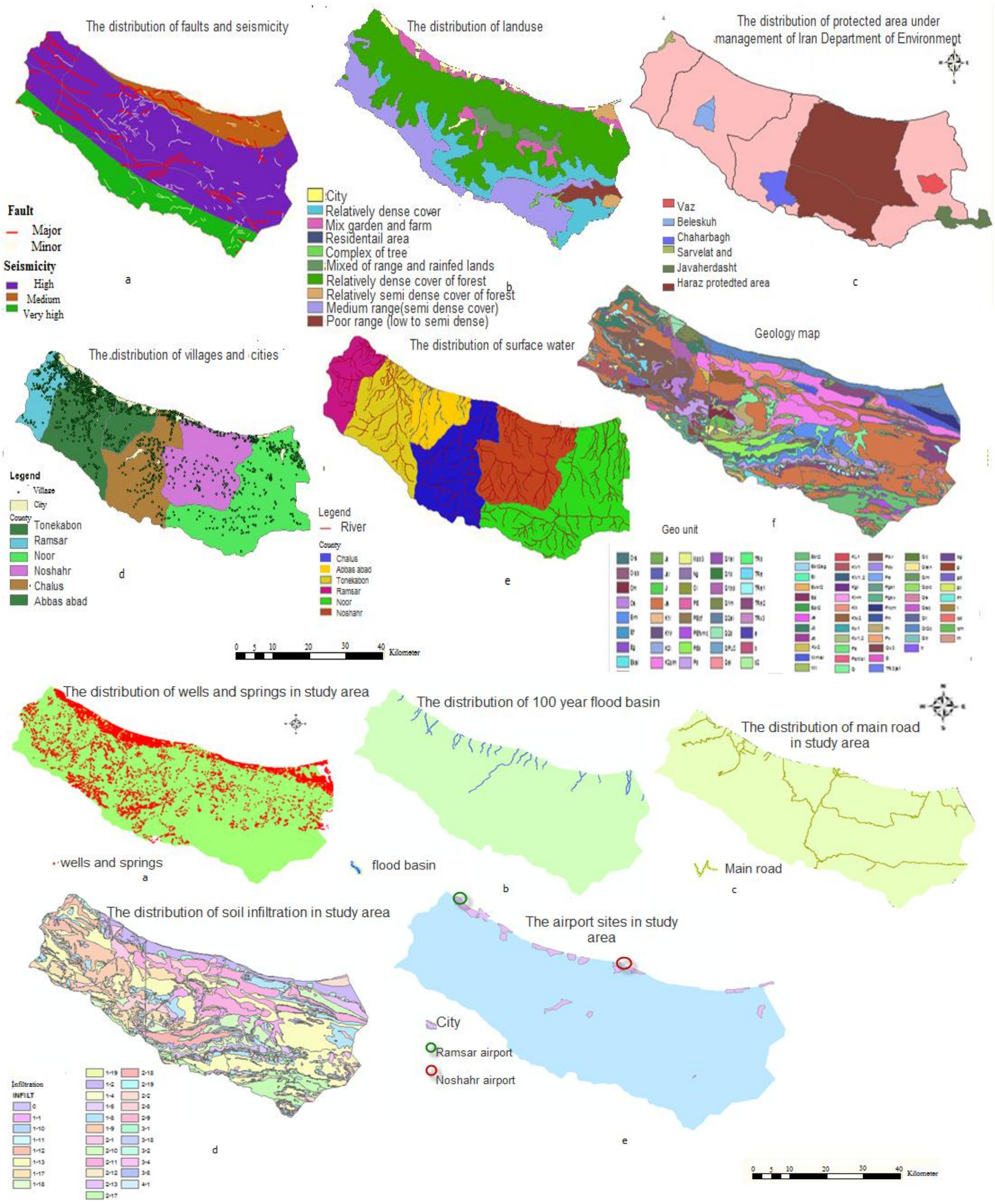

***Figure 2.** Criteria maps in the study area*

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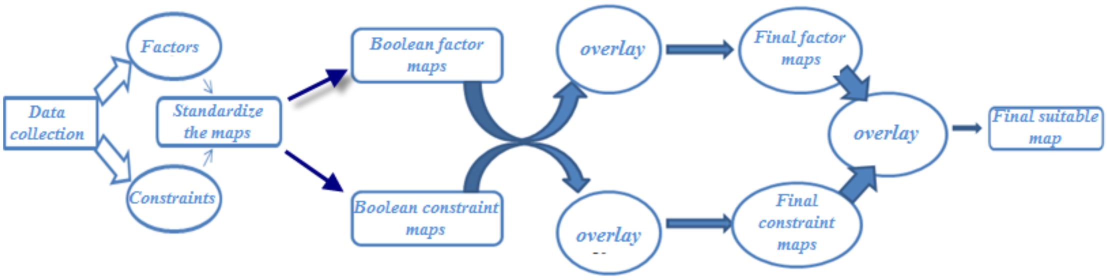

Figure 3. *The research steps in first phase (Yazdani et al., 2015a)*

There were two types of map in first phase of the study; factors (such as faults map and landuse), constraints (such as distance to spring, distance to road, distance to rivers and distance to protected areas). Since there are some regulations applying these seven methods to evaluate landfill sites, Boolean logic was used to standardize the constraint and factor of the map layers. Therefore, all the areas that are impermissible for landfill site sitting according to the 7 guidelines and their principals (constraints) as well as whole areas that fall inside the restricted area (buffers) which landfill site development is prohibited in ArcGIS software with the reclassified module were determined. In map layers the value of the restricted area (unsuitable area) was 0 and that of the other area was 1 (suitable area) (Yazdani et al., 2015a). Different criteria map layers were prepared according to the extant standards which are mentioned in *Table 1*. Buffer maps using the buffer option in ArcGIS were prepared for various criteria. The areas falling inside the buffer areas are unsuitable for municipal solid waste landfill site sitting.

The GIS-based constraint mapping technique was then used to evaluate the suitability of each existing landfill site in studied area considering all the mentioned criteria in each method. The results are shown in *Table 3*.

The overlaying of Boolean factor maps is shown in *Fig. 4* and *Fig. 5* shows the overlaying of Boolean constraint maps in Iran Department of Environment (DOE) method. The final suitable map according to DOE method is shown in *Fig. 6*.

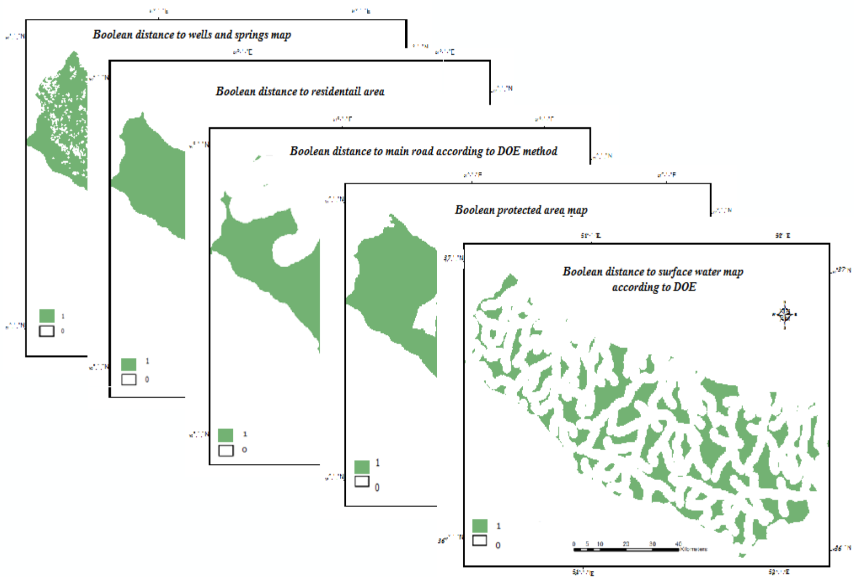

Figure 4. *Overlay of Boolean constraint maps to achieve the final suitable map in DOE method*

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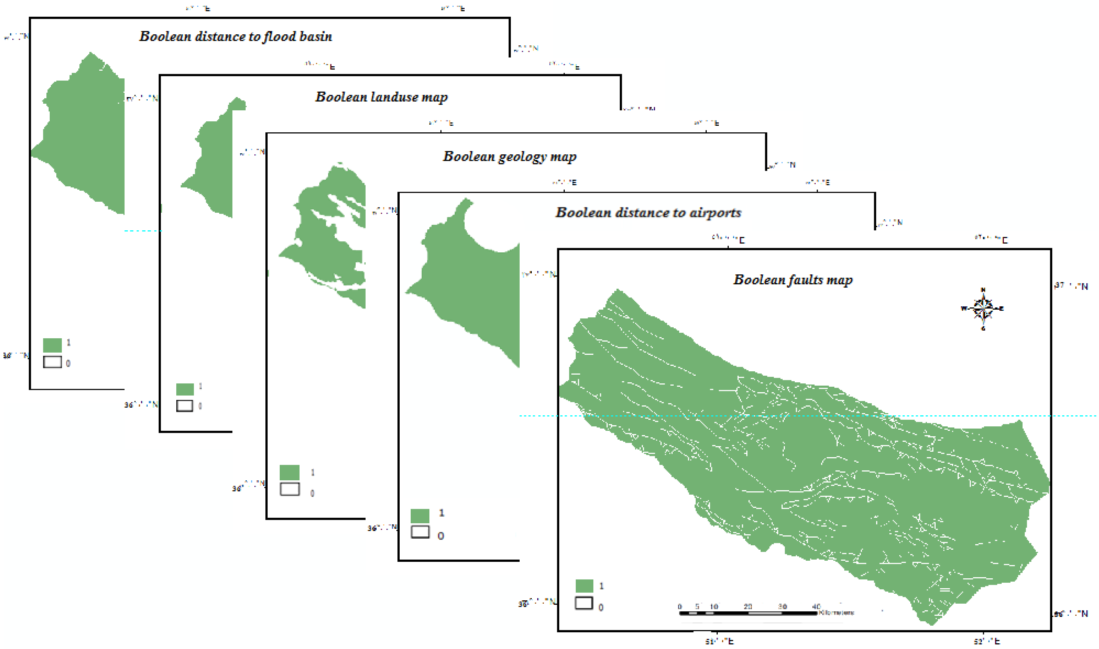

Figure 5. *Overlay of Boolean factor maps to achieve the final suitable map in DOE method*

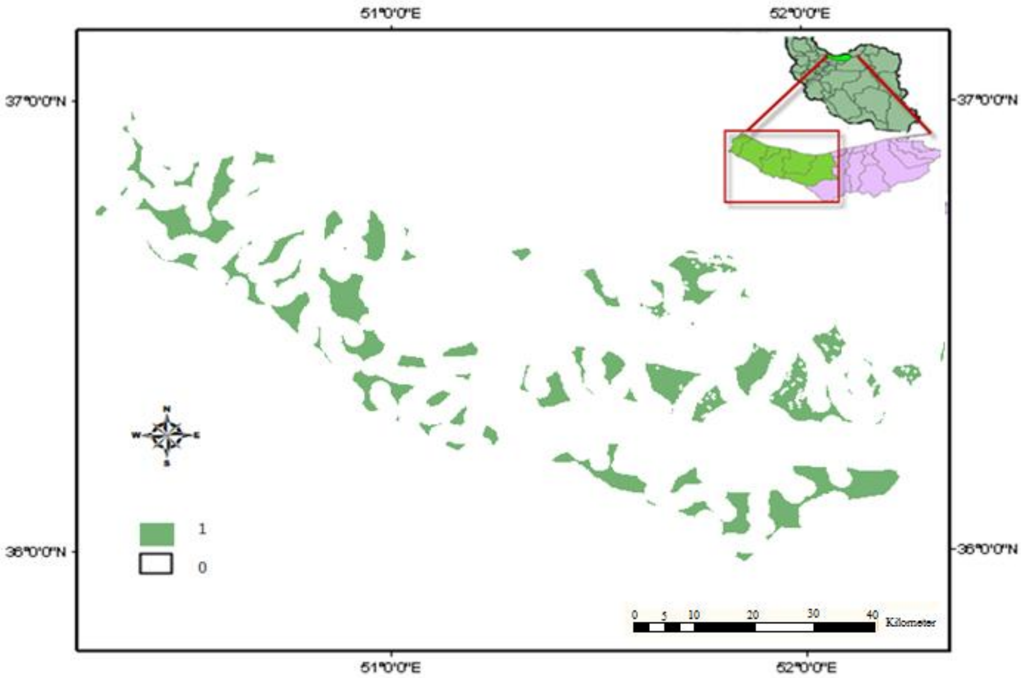

Figure 6. *Final suitable map according to DOE method after overlaying Boolean constraint maps and Boolean factor maps*

Evaluation criteria for Caspian Landfill Criteria (CLC) model

The second phase of the study consisted of four main stages to select and evaluate landfill site based on the Caspian Landfill Criteria (CLC) model; choosing evaluation criteria using Delphi method, standardizing map layers with Boolean logic and fuzzy

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functions, application of Analytical Hierarchy Process (AHP) method to identify the importance of the selected criteria and finally combining the information gathered from various criteria to combine a single evaluation index with Multi Criteria Evaluation (MCE).

Table 3. *The suitability of landfill sites with 7 methods in first phase*

Landfill site name	Regional screening suitability	BC suitability	EPA suitability	MPO suitability	DOE suitability	MPCA suitability	Oleckno suitability
Ramsar	Unsuitable	Suitable	Unsuitable	Unsuitable	Unsuitable	Suitable	Suitable
Tonekabon	Unsuitable	Suitable	Unsuitable	Unsuitable	Unsuitable	Suitable	Suitable
Abbas abad	Unsuitable	Suitable	Unsuitable	Unsuitable	Unsuitable	Suitable	Suitable
Kelardasht	Unsuitable	Suitable	Unsuitable	Unsuitable	Unsuitable	Suitable	Suitable
Salmanshahr	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Suitable
Kelar abad	Unsuitable	Unsuitable	Suitable	Unsuitable	Unsuitable	Suitable	Unsuitable
Chalous	Unsuitable	Suitable	Unsuitable	Unsuitable	Unsuitable	Suitable	Suitable
Marzan abad	Unsuitable	Suitable	Unsuitable	Suitable	Unsuitable	Suitable	Suitable
Noshahr	Unsuitable	Unsuitable	Suitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable
Noor	Suitable	Suitable	Suitable	Unsuitable	Unsuitable	Suitable	Unsuitable
Suitability percent of the total study area	58.17	62.38	77.9	48.5	20	95.32	38.9

Choosing the evaluation criteria

At first, the Delphi technique was used to identify the suitable criteria. This method is an effective tool to achieve a well-thought-through consensus among experts. Delphi technique has been applied in MSW landfill site sitting in the past (Sumathi et al., 2008; Hatzichristos et al., 2006; Koshik et al., 2014). Therefore, the findings of twenty experts in the field, with the most relevant experience, have been included to determine which factors should be considered for alternative ranking. This was accomplished using questionnaire form. A list of criteria based on the 7 mentioned guidelines, as well as a review of the scientific periodicals on previously works was conducted in the questionnaire form. The experts who were familiar with the studied area and participated in the study were requested to supply a list of the preferred evaluation criteria for landfill site selection and evaluation. To data, 18 important criteria have been determined to evaluate landfill sites, and thus, were prepared as input map layers.

Standardizing map layers

Considering the fact that to measure the criteria a variety of scales are used, therefore, it is necessary that the values present in layers of different criteria could be changed into proportional and comparable units. The map layers were standardized in a GIS environment using fuzzy and Boolean logic functions. Boolean logic was used to standardize the constraint map layers. Therefore, in ArcGIS software with the reclassified module was determined. In map layers the value of the restricted area (unsuitable area) was 0 and that of the other area was 1 (suitable area) (Yazdani et al., 2015a). To standardize the factor map layers the criteria-related fuzzy approach was used. To make fuzzy factor maps the threshold should be determined for the values of the criteria, the type and shape of the membership function which are shown in *Table 4* are required.

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The maps were standardized in the 0-255 range for each criterion with 0 as the least and 255 as the maximum suitability range. The linear function which is provided using IDRISI software is applied in the present study.

Due to its high capabilities, IDRISI software was applied to calculate the weights of the criteria, to standardize the criteria by fuzzy functions and also to merge the criteria by MCE model. Therefore, IDRISI software is a suitable option for decision-making using spatial information (Moeinaddini et al., 2010). To quantify the fuzzy diagrams (membership functions), linear scale conversion method was used based on minimum and maximum values as scaling points. In monotonically increasing functions, the linear scale transformation method was used as shown in equation (1) (Eastman, 2012).

$$X_i = 1 - \frac{(Ri - Rmin)}{(R_{max} - R_{min})} * \text{standardized\_range} \qquad \text{(Eq.1)}$$

$$X_i = \frac{(Ri - Rmin)}{(R_{max} - R_{min})} * \text{standardized\_range} \qquad \text{(Eq.2)}$$

where:

X_i is pixel value after standardization,

R_i is pixel value before standardization,

R min is minimum point in factor,

R max is maximum point in factor,

Standardized _range is range standardization (on a scale of 255 bytes).

In monotonically decreasing linear functions, linear scale transformation method was sued based on equation (2). In symmetric (trapezoidal) functions, a combination of equations (1) and (2) was used. All these steps were carried out in the ArcGIS and IDRISI software with Con conditional statement. In the case of discontinuous functions, such as land use and geological factors, the fuzzy values associated with each class were determined using equation (1).

Table 4. *Factors used to form the landfill site sitting suitability map, with indications on their endpoints (the 2^{nd} one shows to the highest suitability value and the 1st endpoint to the lowest) and their comparative weight, M.I (Monotonically increasing), M.D (Monotonically decreasing) and S (symmetric)*

Criteria [unit of measurement]	End point 1	End point 2	Weight	Fuzzy function
Distance from population center [m]	5000 9000	7500	0.109	S
Soil depth [qualitative classes]*	1	5	0.034	M.I
Distance from sea[m]	3000	5000	0.082	M.I
Distance from faults [m]	1000	3000	0.016	M.I
Bedrock material [qualitative classes]*	1	5	0.015	M.I
Soil infiltration	1	5	0.054	M.I
Distance from industrial center[m]	300	600	0.041	M.I

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Distance from surface water [m]	3000	4500	0.112	M.I
Distance from airport [m]	3000		0.040	M.I
Distance from main road [m]	3000 10000	5000	0.040	S
Distance from wetland, lake [m]	500	1000	0.059	M.I
Distance from sensitive ecosystem [m]	500	1000	0.029	M.I
Slope [percent]	40	20	0.015	M.D
Land use [qualitative classes]*	1	5	0.029	M.I
Distance from flood basin [m]	2000	5000	0.061	M.I
Soil texture [qualitative]*	1	5	0.049	M.I
Ground water table [m]	5	10	0.049	M.I
Distance from underground water sources [m]	500	1000	0.109	M.I

* are mentioned in *Table 5.*

Application of AHP method

After the GIS database for landfill site sitting and the thematic map layers for each criterion were prepared and their importance were identified, a relative classification was carried out for each factor based on the relative influence of each criterion. In this study, analytical hierarchy process (AHP) was applied for pair-wise comparison to create comparative weights. In the AHP, the first step is the decomposition of a difficult complex decision into the easier decision subject to form a hierarchical model. In each hierarchical model, the upside level is the final goal (in this study the goal is landfill site evaluation). In analysis step, simultaneous pair wise comparisons between each both criteria and their relative values was carried out using the Expert Choice software for a simple classification. The comparison matrix was developed for eighteen criteria. The criteria weights are shown in *Table 4*.

Combining criteria using MCE (Multi Criteria Evaluation)

Multi criteria evaluation is mainly used to incorporate the different criteria to form a single evaluation index (Voogd, 1983). After standardization of criteria maps (factors and constraints) and determining the weights factors, the next step was to perform multi-criteria evaluation process. The Boolean intersection logic, AND logic or the multiplied or logic function according to equation (3) were used to integrate layers of constraints and provide the final layer. All criteria weights were considered equal (Eastmen, 2012).

$$C = \Pi c_j \quad \text{(Eq.3)}$$

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where C is final constraints, Π is multiplied index, cj is constraints criterion j score.

Considering the fact that, the Weighted Linear Combination (WLC) is one of the best and useful methods of multi-criteria decision making (Heydarzadeh 2001), was used throughout this study. In order to perform the assessment process using this method in the present study, each factor (criterion) was multiplied by its corresponding weight according to the equation (4).

The unsuitable areas were omitted by summing the gathered results and multiplying the constraints. Consequently, the suitable area(s) for landfill sitting was obtained.

$$S = \Sigma\ WiXi\Pi cj \qquad \text{(Eq.4)}$$

where S is suitability, Wi is weight of factor i, Xi is fuzzy value of factor i, Π is multiplied index, Cjis is constraints criterion j score.

WLC approach was applied in IDRISI software according to equation (2). After generating a raster map in ArcGIS software (this map is based on the pixel level) using the "Re class" command, (Re class), the final plotted map was divided to 5 sections from 0 as the minimum to 250 as the maximum suitability rate.

Results

After reviewing each waste deposit site, considering all the criteria in every 7 methods applied in the present study, the incoherence in suitability was apparent in first phase. For example, some sites were suitable using one method, but unsuitable using another. The suitability report of the studied landfill sites is shown in *Table 3*. Thus, presenting unique locally parameters suited to particular ecological conditions, seems necessary for evaluating all landfill sites. To achieve a comprehensive and applicable evaluation, the criteria should be defined in accordance with the locally condition of the studies area. The review of all existing methods has shown that none of them have considered the distance from sea, which is critically important for the entire region. Considering the importance of high priority data layers in MCE, the weighting of these layers and the fact that each of these criteria and their importance changes in accordance with the special environmental conditions, it is necessary to localize the criteria for different environmental zones. Therefore, 18 factors were used for alternative ranking (shown in *Table 4*) in CLC model. The map layers of each of these 18 factors are essential to be thought out. Consequently, the eighteen essential evaluation criteria including their regulations and constraints were prepared based on the prior inspections, present regulations, point of view and questionnaires answered by twenty specialists familiar with the field of study and also familiar to studied area (the Delphi method).

Based on the availability of the data, these 18 important criteria were modified in order to evaluate the landfill sites, as input map layers. In the present study, a GIS/MCE integrated method has been used for the data analysis. Furthermore, the results were compared and the accuracy was checked using an AHP/Fuzzy integrated method. *Table 4* indicates that the fuzzy approach was applied for standardization and the weights of each criterion (preferred value). The description of qualitative criteria is indicated in *Table 5*. Five standard maps out of eighteen are showed as samples in *Fig. 7*. The standardized maps were divided into 5 classes in the 0-255 range for each criterion with 0 (unsuitable) to 255 (most suitable areas). In this study, a multi-criteria evaluation approach integrated with Arc GIS overlay analysis was used to choose the most

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preferable landfill site in studied area. The suitable regions were recognized for landfilling considering the final map layer. In executing the CLC model, the important of the weights and the preferred value of each of the criterion are critical.

In the present study, parameters and their prioritization includes distance to river, distance to population centres, distance to springs and wells, distance to sea, flood plains, distance to lakes and lagoons, the rate of soil infiltration, soil texture and underground level, distance from the airports and main roads, the depth of soil, distance from sensitive habitats and land use, distance from fault and, the least important one, the stone material of context and slope.

The results of this study have been achieved using fuzzy multi-criteria decision making and analytic hierarchy process, which are similar to that used in researches on locating and evaluating landfill sites. This integrated method can be used in areas similar to those in this study or, to be more general, in the coastal regions of the Caspian Sea.

Table 5. *Qualitative criteria description*

Criteria	**1**	**2**	**3**	**4**	**5**
Suitability range	Very unsuitable	Unsuitable	Low suitability	Suitable	Very suitable
Bed rock material	Permeable flood basin floor	Sand, stone, limestone, dolomite, deposits range, conglomerates, alluvial fans, alluvial present covenant	Igneous and metamorphic rocks with low breakage and silt	Schist, clay ,tuff, evaporated rock, clay and mud, fine loss	Shale, marl and clay
Soil type (depth and texture)	Shallow to moderately deep soils with limestone, or with gravel bearing	Shallow to moderately deep soils, medium to heavy pebble texture on the rocks, moderately deep to deep loamy to gravelly soil	Deep heavy texture soils in some areas with limestone floor concentration	Deep soil with moderate to heavy texture	Deep soil with heavy texture, moderately deep to deep soils
Land use	Forest, dense range, populated area, river floor	Very low densities of forest ,agricultural lands, Gardens	Semi dense range, agricultural land, incorporating gardens	Poor range, low density other land	Land without vegetation, rocky protrusions
Infiltration	Very high	High	Medium	Low	Very low

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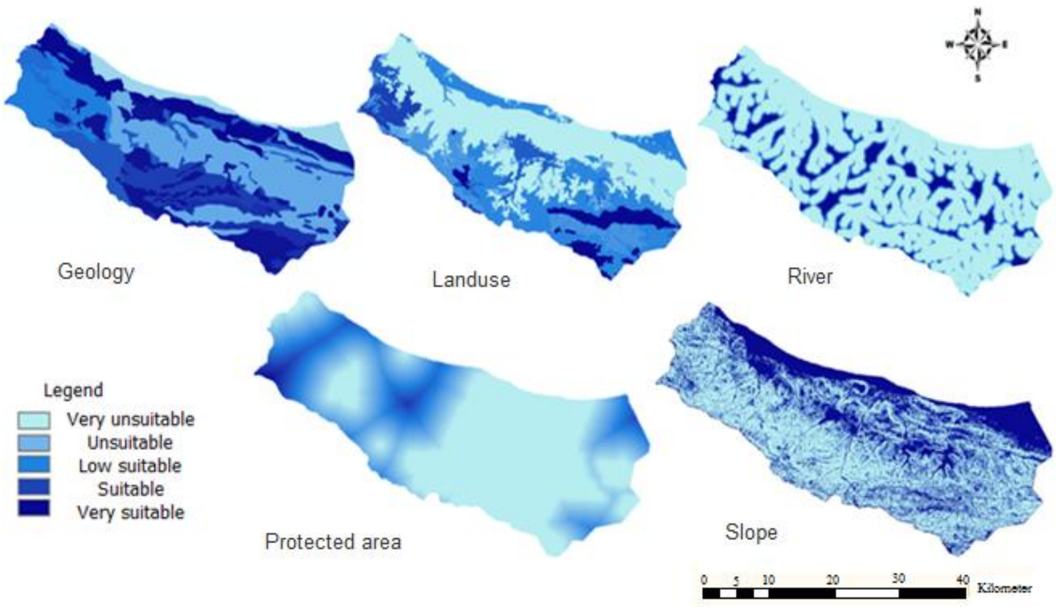

Figure 7. *Some of the standardized maps in phase 2 according to fuzzy logic*

Discussion

Unfortunately in Iran, similar to other developing countries, there have been few studies carried out on evaluating current landfill sites. Municipalities rarely consider the ecological properties of an area, adequately, in accordance to the governmental organizations and international standards and the pre-defined criteria before depositing the waste material at the edges of the cities and degrading the valuable natural ecosystems. Therefore, the applicable criteria are hardly used in most of the MSW landfill sites. Comparing the applied criteria indicated that all the criteria have some similar aspects in common. According to the previously studies, some parameters are joined in all methods. These common parameters have been considered in the present study. Parameters such as hydrology, distance form roads and airports and preserving special habitats are some of the factors taken into account in most of the methods due to their crucial significance. The studied parameters and their prioritization can be different based on the ecological characteristics. Choosing a set of effective parameters for selecting the location and evaluation of the landfill sites in relation to the environmental conditions of the studied area is critical and has a direct effect on prioritizing parameters (Sener, 2004). For instance, one study has shown that the highest prioritised parameters in landfill site selection are distance from urban and rural areas, surface water, geology, land use and fundamental instalments and roads, respectively (Khan and Anjaneyulu, 2003). In another study the priority of parameters was distance from geologic faults and the depth of earth, distance to the airports, distance to urban areas, distance to lakes, dams and slope of the soil, land use, paths network and in final run the least priority belonged to instalments and telecommunication (Delgado et al., 2008). In this study, preservation of the ecosystems of the vast water resources, both underground and surface, as well as the Caspian Sea was the preeminent concern. (Tajziehchi and Monavari, 2013) mentioned in their research that geographical features and special environment in this region are the main reasons for the complex landfill site sitting process. All of the considered criteria in this study and previously researches are

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to prevent land degradation and protect the environment. To evaluate the landfill sites in the studied area in the present research, which is situated in western part of Mazandaran province, noble approaches are required because of its special topographic conditions (closeness to the forest and the sea), high level of underground water and high rate of tourism (especially in spring and summer). Considering the importance of prioritizing the data layers in multi-criteria evaluation and defining the value of the layers based on their specific ecological conditions, the criteria and their importance can be changed. Therefore, locally criteria—Caspian landfill criteria—appropriate to the ecological condition of the area has been presented.

Conclusion

This research shows the incoherence in suitability status of the 10 current landfill sites in west area of Mazandaran province with using seven different landfill site sitting approaches. In second phase, the proposed Caspian Landfill Criteria with effective and native criteria has been used to determine the status and (un)suitabilty of the current landfills and the studied area. The suitability of the CLC (Caspian Landfill Criteria) model for landfill site sitting and evaluation of the current landfill sites were considered through field observations. Finally, only about 0.4% of the whole studied area was appropriate for landfilling. The most principal parts in the CLC model were the importance of the weights of the criteria and the preferred weights of them which in this research, distance to residential area parameter has the highest and slope has the least weight. As the findings of the present study have revealed, there are insufficient suitable areas in the western part of Mazandaran province for landfill site sitting. Furthermore, landfilling is not an appropriate approach for waste disposal in this region. There for other approaches should be considered for waste disposal with regard to the environmental characteristic of this specific region. The results of this study have been achieved using the same method applied for processing the consequent and phasic analysis in multi-criteria decision making in researches on locating and evaluating the landfill sites. The Caspian Landfill Criteria model with effective and native criteria has been used to determine the status of the current landfills and recognize the ruined areas, which are a good illustration of land degradation, in order to achieve an optimal management approach to convert the land into a sustainable natural ecosystem of the southern coast of the Caspian Sea.

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