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Municipal solid waste landfill site selection using analytic hierarchy process method for Tafresh Town

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Abstract

Waste disposal is the last stage of waste management which is the subject of a precise process including site selection, preparation and operation; every stage needs research and management actions. Selection criteria include engineering, environmental, and economic criteria. Geographical Information System (GIS) is a framework for storage, maintenance, management and analysis of geographical data and it has been designed for working with data that has spatial and descriptive dependency. No site selection study focusing waste disposal has been performed in Tafresh town in Iran, which is located at 222 Km southwest of Tehran and have a population of over 16900 people and total waste production of 7665 tons per year. This study has been done using Analytic Hierarchy Process (AHP) in which criteria such as distance from residential areas, distance from roads, land use, distance from wells, distance from faults, geology, distance from sensitive ecosystems, etc. were used and after data geo referencing, the weighting of the criteria and adjusting them with the geographical features of the area, data overlaid and finally three locations proposed for landfill were introduced in Tafresh town. Among the proposed areas, one was selected as the best location according to the hypotheses. The obtained results of this study may be helpful for policy makers of Tafresh town.

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Introduction

Waste disposal is a problem which has existed from the beginning of human life and has been of a major concern for every country in the world. Municipal solid waste management (MSWM) is a crucial purpose for integrated urban management support; it refers to the processes of assortment, transfer, treatment, reuse, and disposal of solid waste (Schubeler, 1996). An MSWM system benefits from techniques of solid waste management like dumping, biological treatment, thermal treatment, reuse, etc. In case of employing a combination of the above or other management techniques and also the implementation of policies of waste reduction and reuse, the existence of a sanitary landfill is critical to an MSWM system (Tchobanoglous & Theisen & Vigil, 1993)

MSWM is a matter of concern experienced by all countries in the world. It is an issue mostly witnessed in urban areas as a result of fast population growth and it has remained as one of the major environmental problems. Nowadays, investigating the waste management is becoming increasingly critical in developing countries (Kyessi & Mwakalinga, 2009)

Several techniques for landfill site selectors mentioned in the literature reviews. These techniques utilize Geographic Information Systems (GIS) to perform an initial screening of the study region in order to find suitable areas (Halvadakis, 1993; Bonham-Carter, 1994; Ehler & Cowen & Mackey, 1995; Balis *et al.* 1998; Dorhofer & Siebert, 1998; Yagoub & Buyong, 1998; Herzog, 1999; Lukasheh & Droste & Warith, 2001; Kontos & Komilis & Halvadakis, 2003) .Multi-Criteria Decision Analysis (MCDA) techniques are effective instruments to investigate the complex phenomenon and promote programming. Analytic Hierarchy Process (AHP) is a systematic decision-making approach which was first developed by Saaty (Saaty, 1980). It is a decision-making technique which helps in analyzing and supporting decisions which have multiple and competing objectives. To do so, a complex problem is hierarchically divided into simpler problems. The main advantages of AHP are simple handling of multiple criteria, simple understanding, and effective handling of each quantitative and qualitative data. Along with GIS, AHP is a powerful tool to research criteria within the modeling process. The combination of AHP and GIS would result in the creation of a powerful instrument to solve the problem of landfill site selection. It is generally used to consider location problems (Makropoulos & Butler, 2006).

Among the examples of combining GIS with MCDA methods, the studies performed by Sener *et al.* (2006); Sharifi and Retsios (2004); Basag˘aog˘lu *et al.* (1997); Allen *et al.*(2003); Sener *et al.*(2010); Minor and Jacobs (1994); Kao and Lin (1996); Siddiqui *et al.*(1996); Lin and Kao (1998); Allen *et al.* (2002); Kontos and Halvadakis (2002) can be mentioned. Refereeing to the latest cases of MCDA with GIS for landfill site selectors, the studies performed by Sumathi *et al.* (2008), Changa *et al.* (2008), and Gemitzi *et al.* (2007). Kontos *et al.* (2005) presented an article describing a spatial methodology comprising of several methods such as MCDA, GIS, spatial analysis and spatial statistics from different scientific fields. The ultimate goal of the methodology was to assess the suitability of the study region to site a landfill optimally. The employment of the methodology in the island of Lemnos in the North Aegean Sea in Greece demonstrated that 9.3% was appropriate for landfill sitting with values greater than 9. Identifying a suitable landfill site for waste disposal in Ibadan North Local Government Area of Ibadan, Nigeria, GIS and Multi-Criteria Evaluation (MCE) were applied to display and rank the candidate sites. The analysis was limited to criteria which were selected and relevant to the area under study (Yahaya, 2010)

This study was conducted to locate Landfill of Tafresh town. The study was done to offer an appropriate location for a landfill and proposed management actions to mitigate adverse environmental effects. This paper examines the current conditions of waste collection and disposal system in the Tafresh town and in addition to evaluation of current waste disposal site; it was offered the new locations using the criteria of Department of Environment of Iran and America and Europe union.

Materials and methods

Case Study Region

Tafresh is a town in Markazi province of Iran, locating at 222 Km southwest of Tehran and amidst high mountains of the Zagros range, at longitude of 49°57' and latitude of 4°45' N. The area under the study is mostly formed by Triassic sedimentary units outcropped by Jurassic and Cretaceous sedimentary units. There are also Eocene volcanic- sedimentary units which outcrop beyond the study region.

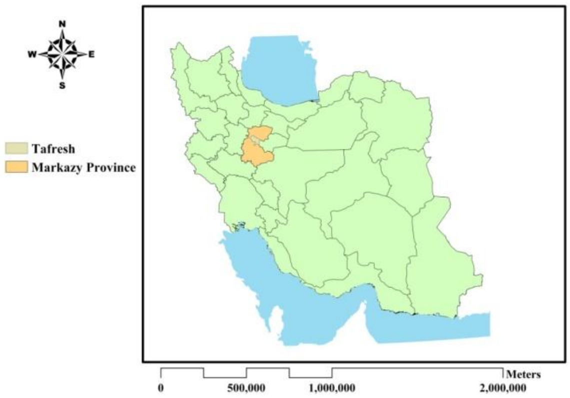

Fig.1. Markazi Province in Iran.

Sitting Methodology

GIS landfill site location methodology was provided by GIS with MCA to assess the entire region, on the basis of certain evaluation criteria from hydrological/hydro-geological, environmental and social point of view. The methodology consists of the following steps (Kontos & Komilis & Halvadakis, 2005):

(a) Development of a digital GIS database including all spatial information;

(b) Determination of the analysis and evaluation criteria and formation of the hierarchical and gradable structure;

(c) Implementation of the AHP method to calculate the criteria and factors with relative importance weights;

(d) Implementation of the Simple Additive Weighing (SAW) method to estimate suitable indices, and

(e) Implementation of a spatial clustering process to reveal the most suitable areas.

Criteria and measures are the most important elements in any evaluation, based on which evaluation is done.

The region was visited in order to identify natural features, to match the existing maps with the region, and to research vegetation of the study area and earth control spots with GPS. The acceptable boundaries in every layer were selected and as a result, the map of appropriate sites was designed. The information required for selecting the best optimal site were collected and fed into GIS.

AHP has been utilized in the present study. At first, a binary comparison of all measures and sub-measures was performed. The first level of the hierarchy selects the best optimal site; the second level constitutes of major measures such as accessibility, geology and hydrogeology; and the third level includes 12 sub-measures. The relative importance of every pair of measures and sub-measures ranges from 1-7, which have been placed in a matrix.

Application of the AHP Method

The pair-wise comparisons utilized in the present work appear to be reasonable according to the review of relevant landfill site selection literature (Lin & Kao, 1998; Mandylas *et al.*, 1998; Kontos & Halvadakis, 2002, 2003). However, there could be a different judgment for the relative magnitude of the criteria in comparison with pairs. The decision making process in multiple criteria problems is a subjective process which depends on the decision makers. In a complicated problem such as landfill site selection, it seems logical for the people concerned to have different opinions (Kontos & Komilis & Halvadakis 2005).

Table 1. Pair-Wise Comparison Scale for AHP Preferences.

Numerical Rating	Verbal Judgments of Preferences
1	Equally Preferred
2	Equally to Moderately
3	Moderately preferred
4	Moderately to Strongly
5	Strongly preferred
6	Strongly to very Strongly
7	Very Strongly Preferred
8	Very Strongly to Extremely
9	Extremely Preferred

MCA techniques are unit effective tools to analyze complex phenomenon and promote programming. The integration of the two techniques of MCA and GIS results in a technique named as Spatial Decision Support System (SDSS) which is generally used to investigate location problems (Makropoulos & Butler, 2006). In AHP, all criteria and factors are doubled up and are compared; the results are registered in a weighting index matrix. There are nine scales ranging from 1 to 9 which gradually show priority factors (Saaty & Vargas, 1991), such that1shows equal values, whereas 9 shows the maximum priority (Table 1).

After using sub-measures from EU and EPA (Table2) and providing the required layers which have been weighted and cumulated, land suitability rate (1-10) was calculated. Any increase in the rate ends up in the promotion of better indices. Sites with ratings of 7 and below are not appropriate for disposal, whereas those rating higher than 8 are the best optimal sites.

Auto CAD Map is used to digitize maps and topological construction of vector layers. Besides, Arc GIS is employed for reading map information of the study region as the best and the fastest method for representing geographical data and accumulation of maps. GIS is a powerful instrument for data manipulation and combination of various data layers; it provides unique tools for using satellite pictures and their interpretations. Without using GIS, the possibility of site selection studies which are fast and accurate and with large scales, would be both complicated and costly (Ahmadpour, 2007).

Table 2. The grading values utilized for the specific criterions are shown in Table.

specific criterion		Classification and Valuation			
Slope (Degrees)	Rating	<9	9-18	18-25	25<
	Grading value	10	8	4	0
Distance from Road (meter)	Rating	<1000	1000-2000	2000-5000	500<
	Grading value	0	3	7	10
Water Table Depth (meter)	Rating	<9	9-18	18-25	25<
	Grading value	0	3	6	10
Distance from Faults	Rating	<200	200-500	500-1000	1000<
	Grading value	0	3	7	10
Distance from Wells	Rating	<300	300-500	500-1000	1000<
	Grading value	0	3	7	10
Distance from Rivers	Rating	<200	200-500	500-1000	1000<
	Grading value	0	5	7	10

specific criterion		**Classification and Valuation**			
Distance from Residential Areas	Rating	<1000	1000-2000	2000-3000	3000<
	Grading value	0	5	8	10
Distance from Sensitive Ecosystems	Rating	<500	500-1000	1000-2000	2000<
	Grading value	0	5	7	10
Wind	Rating	In path of prevailing wind	Lesser exposure in the direction of the prevailing wind	Not being under the Direction of the prevailing wind	
	Grading value	0	5	9	
Soil	Rating	Karsticorganization,sandy soils and beach soils	Flat and plateau soils	Marlite, coal and granite	Clay,rocks and soil in the mountains
	Grading value	0	5	8	10
Geology	Rating	Andesite ,dolomite, salt, limestone, shale, gypsum, and micaschist, gabbro silt	Silt ,sand ,gravel and Alluvial fan	sandstone or Maroon, conglomerate, gypsum, silt, stone, lime orbitolina	sand, silt stone, clay
	Grading value	0	3	7	10
Land use	Rating	Urban areas and airport	gardens	Dry farmlands	Meadows and wastelands
	Grading value	0	2	8	10

Evaluation Criteria

The evaluation criteria employed in the present paper are classified into three main categories of the hydrological/hydro-geological, environmental, and social criteria, as it is shown in fig. 2.

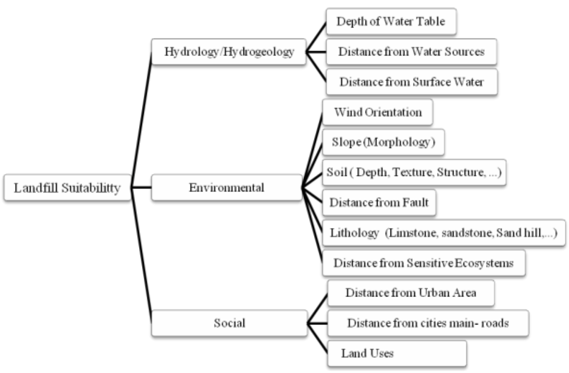

Fig. 2. Hierarchical Structure of the Decision Problem for Landfills Site Location.

Every criterion has limited range for being appropriate

Depth of Water Table: The depth of water table must be considered as an extremely effective factor. This criterion categorizes the whole area in three zones which are: deep enough, relatively deep, and shallow.

Distance from Water resources: A landfill site must not be next to any water Resources or groundwater resources where the ground water table is high; this may have irretrievable human and environmental consequences. A period of 50–60 day is required for the inactivation of pathogens; while groundwater has an average linear velocity starting from a few centimeters to 10 m/d. The spatial determination process of this criterion is incredibly complicated.

Distance from Surface Water: The waste disposal areas should not be in the vicinity of rivers, lakes or swamps. This criterion has a direct relationship with land suitability for being used as landfill. In other words, farther lands from streams and river banks are more preferred. In some literature reviews, the researchers have suggested a distance up to 500 m away from a freshwater body. Based on EU directives, the disposal of solid waste to any surface water media such as sea, lakes and rivers is not allowed. Besides, the size of the water body's hydrological basin must be considered (Kontos & Komilis & Halvadakis, 2005).

Wind Orientation: This criterion is not based on any legal restrictions, but on the fact that a landfill site should not be exposed to wind. Site morphology and wind orientation frequency are considered during the development of a particular criterion (Kontos & Komilis & Halvadakis, 2005).

Slope (Morphology): The slope facet is one of the most effective factors in land slide. The slope of the land surface is a crucial factor as far as construction costs are concerned such that very steep slopes can end in higher excavation costs; the higher the value of the slope, the lower the suitability and quality of the land for landfill construction will be. As Oweis *et al.* (1990) has stated, areas with slopes greater than 15° should be avoided in a landfill site selection. Rather, very flat slopes would affect the runoff drainage. High slope scan favor leachate drainage to flat areas and water bodies and cause contamination. Areas whose slope is greater than 20% are not suitable to be selected as landfills (Saaty & Vargas, 1991). Areas with high altitude or high slope are not suitable landfill sites. The best places for waste disposal are areas with medium altitude surrounded by hills and with slopes less than 20% (Sener & Suzen & Doyuran, 2006).

Soil (Depth, Texture, Structure, etc.): This criterion classifies the complete area in hydro-geological zones on the basis of the values of hydraulic conductivity. According to the characteristics of geological texture of the region, this criterion divides the complete area into three distinct classifications; soils having high rate of permeability (district cambisols, haplic and gleyic solon chalks, cambic podzols with karst formations, etc.) are considered unsuitable for being used as a landfill, while soils with medium and relatively low rate of permeability (mollic gleysols, calcaric and eutric cambisols, etc.) and very low permeability (clayey soils, shale, calcaric fluvisols, etc) are fairly suitable and optimal to site a landfill, respectively.

European legislation does not offer specific guidelines regarding landfills with hydrogeology and groundwater pollution. According to EU directive, "landfill selection procedure must take into account the existence of groundwater bodies and prevent the pollution of groundwater by either physical or technical means" (Kontos & Komilis & Halvadakis, 2005).

Distance from Fault: Waste disposal areas must be away from faults; otherwise the wastes can pollute the groundwater or damage the surrounding engineering structures in case of an earthquake (Halvadakis, 1993). Areas which do not have faults or have safe distance from the faults are appropriate for landfill site selection. Faults increase permeability of rocks such that groundwater may be polluted with leachate of the landfill. This sub-criterion divided into two elements of major faults and minor faults. There is no main fault in the studied area and minor faults are dominant (IWRM, 2012).

Of the typical examples of tension fissure within the region are several fissures resulting from the collision of the Arabian Plate and also the Eurasian Plate. Buffer zones of 1000 m along either side of faults were assigned so as to prevent the locating the proposed facility to be on or too close to the known active faults. Moreover, the distance from faults has been considered (Sharifi *et al.*, 2009).

Lithology (Limestone, sandstone Sand hill, etc.): Geologically speaking, materials have different suitability for being chosen as landfill sites. Geology/hydrogeology literature and field studies were performed in order to create a geological map of the study area. The geological map was digitized using Arc GIS software and changed into a grid map with a 30*30 m resolution. The main lithologic units consisted of instable homogenous phyllite, sustainable andesite, marble and crystalline limestone, and quaternary deposits. The most sensitive units to landslide are phyllite, slate, shale, and Mila formation. Therefore, a geologic map was provided by considering the unit's susceptibility (IWRM, 2012).

Distance from Sensitive Ecosystems (ecologic, scientific or historic): This criterion is critical due to the potential polluter degradation of sensitive ecosystems. Consistent with EU legislation, solid waste management must not degrade natural environment or areas of unique ecological or aesthetic interest (Kontos & Komilis & Halvadakis, 2005). Furthermore, the disposal of municipal solid waste at a distance of less than 150 m from protected areas is not permitted.

Distance from Urban Area: Landfill sites located close to the settlement areas cause numerous environmental problems. The establishment of landfills within cities, towns or villages is not suitable due to the unfavorable odor and noise; waste disposal areas must not be in the vicinity of the populated urban or rural areas, either. For this purpose, a buffer of 300 m around these areas is considered; a sanitary landfill cannot be located within 500 m of residential areas.

Distance from cities' main roads: Landfill location must be near the roads in order to facilitate transportation and consequently decrease the costs. Distance greater than 1 km from main roads and highways should be avoided. On the other hand, the landfill site should not be placed too far away from the existing road networks to avoid the expensive cost of constructing connecting roads.

Roads other than highways and railways are treated as contraries; the closer the distance, the higher the scores. Additional costs for road construction in areas far from present roads make them less attractive. An awfully low suitability value, however, was appointed to areas within a distance of 100 m from the existing roads so that landfill vehicles would not interfere with current traffic (Guiqin *et al.* 2009).

The proximity to roads must be considered for landfill site selection. Sanitary landfills must be located at a site that can be reached by alternative roads under all weather conditions. On the other hand, landfill sites should not be placed too distant from the existing road networks to avoid the expensive cost of constructing connection roads. Moreover, landfill vehicles should not interfere with the current traffic (Sener & Suzen & Doyuran, 2006).

Land Uses: Since there are some restrictions associated with landfill sites, land use of the region must be taken into account. Forest/heath lands and pasture areas should not be used for various purposes. The employment of garden areas depends on particular conditions. In addition, irrigated and non-irrigated arable lands do not seem suitable for landfillsites (Sener & Suzen & Doyuran, 2006). Land use classification has been based on the nature and property of soil. However, other factors such as aspect, elevation and soil types have also been taken into account. The land use criterion differs from the land cover criterion such that it aims to protect "sensitive" areas under economic development that may be affected by locating an adjacent landfill. The permeability of the underlying soils and bed rock will greatly influence how much leachate is escaping a landfillsite (Sharifi *et al.*, 2009).

Results and discussion

MCDM method

MCDM method was used in the present study to perform an environmental evaluation of disposal sites in Tafresh, which necessitates the investigation of a set of alternatives in terms of the determined measures. To locate a new site for this purpose, the influential variables such as the annual production of wastes were defined and 12 information layers were identified including Depth of Water table, Distance from Wells, Distance from Surface Water, Wind Orientation, Slope (Morphology), Soil (Depth, Texture, Structure, ...), Distance from faults, Lithology (Limestone, sandstone, Sandhill...), Distance from sensitive ecosystems, Distance from residential areas, Distance from cities main- roads, and Land use which were then, transformed into information layers in GIS. For each of these layers (Fig. 3 to 14) a unified image system of UTM was assigned, using Weighted Overlay function of GIS to combine them. For this purpose, vector layers were converted to raster layers. Relative importance of layers was formerly determined by AHP.

Table 3. Pair-wise Comparison Matrix and Relative Importance Weights of the Evaluation Criteria.

Criteria	Priority Vector * 1000
Depth of Water table	37
Distance from Wells	27
Distance from Surface Water	6
Wind Orientation	154
Slope (Morphology)	27
Soil (Depth, Texture, Structure, ...)	6
Distance from faults	26
Lithology (Limestone, sandstone, Sandhill...)	6
Distance from sensitive ecosystems	295
Distance from residential areas	295
Distance from cities main- roads	59
Land use	6

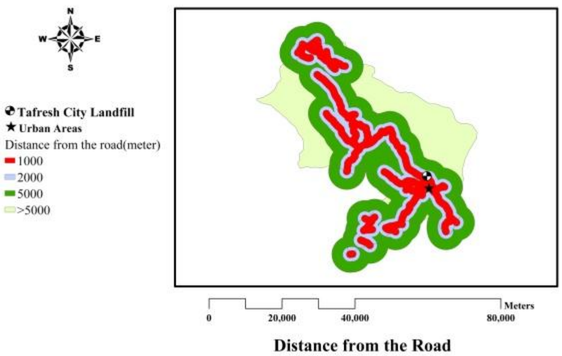

Fig. 3. Distance from the Road(meter).

The evaluation criteria shown in Figs 3–14 are in a raster GIS format with a 100 m cell size, because the specific digital data format is very useful when complex spatial joins and calculations are considered. Raster data requires less processing time than vector data to perform a specific spatial analysis process. Evaluation criteria were combined in a grid that contained all grades calculated from each of the separate grids. The grading values for each evaluation criterion are included in the complex grid at the appropriate attribute field. The relative importance weights of the evaluation criteria have been shown in the last column of Table 3.

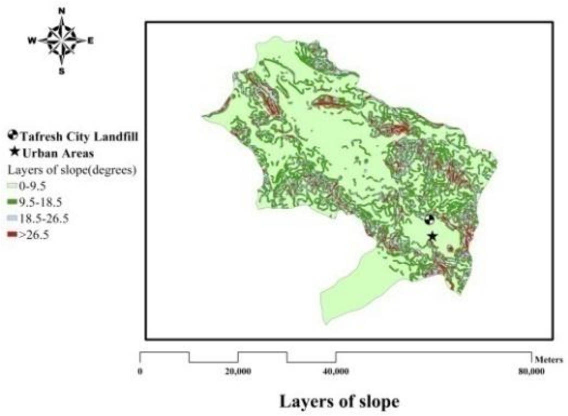

Fig. 4. Regional Classified Slope.

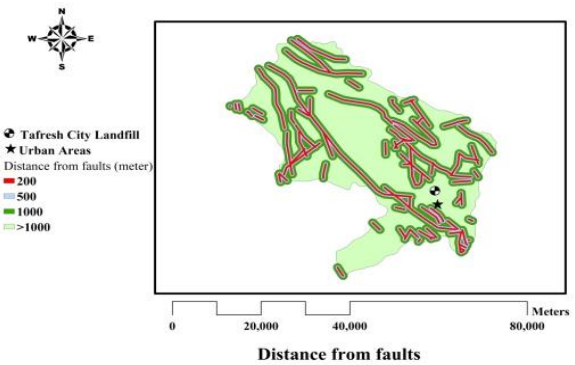

Fig. 5. Distance from Faults (meter).

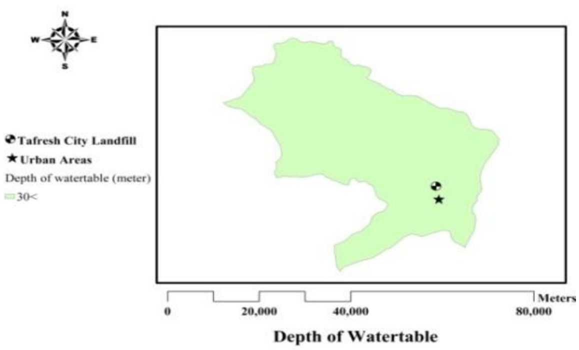

Fig. 6. Areas Even with Groundwater in Depth.

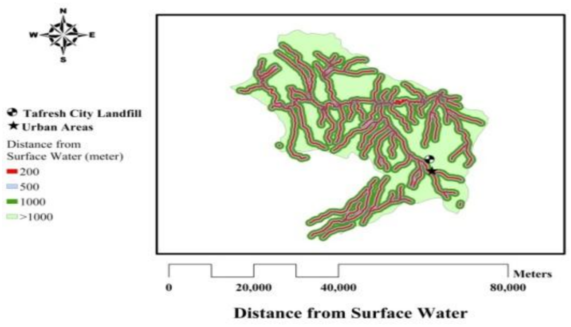

Fig. 7. Distance from River(meter).

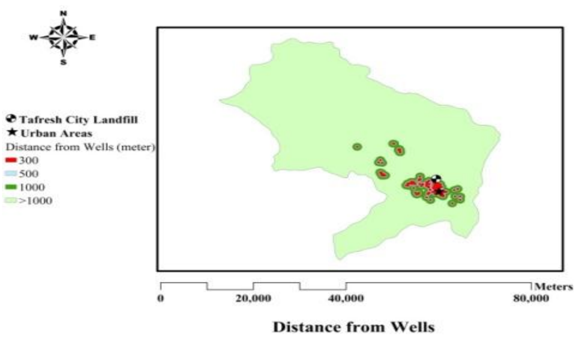

Fig. 8. Distance from Wells.

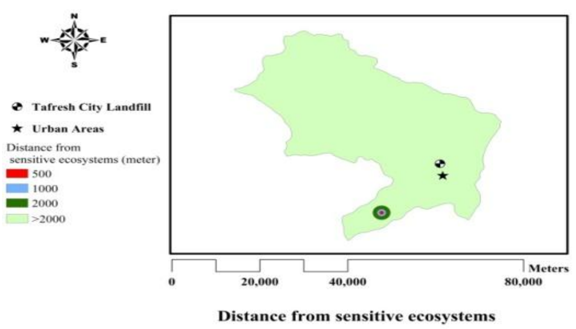

Fig. 9. Distance from Sensitive Ecosystems.

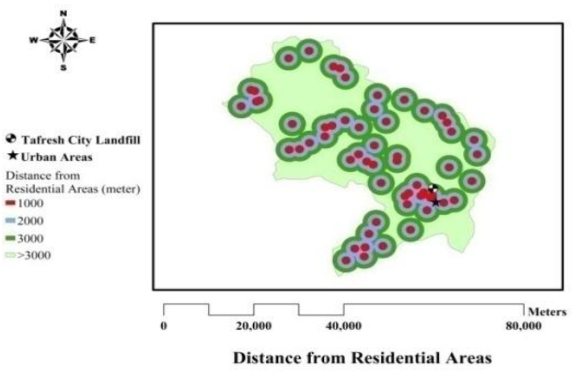

Fig. 10. Distance from Residential Areas.

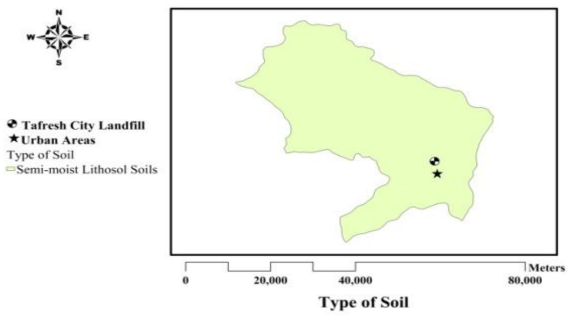

Fig. 11. Type of soil.

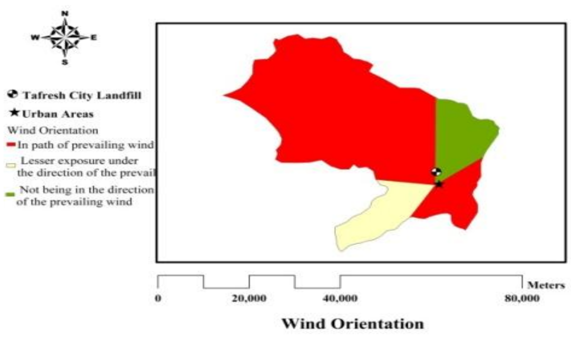

Fig. 12. Influence of Wind.

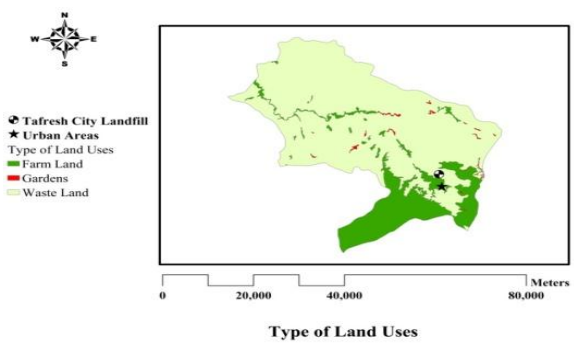

Fig. 13. Type of Usage.

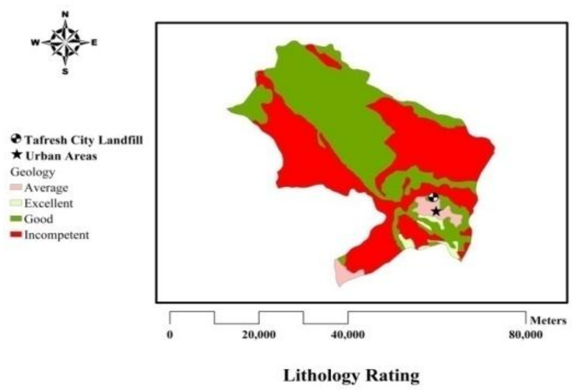

Fig. 14. Geological Rating.

SAW method

The suitability index is computed using the SAW method. The formed PCM by the authors in the present work has been shown in Table 3, and the priority vectors of all criteria (relative importance weights) have been included in the last column of the same table. In addition, the AHP parameters have also been shown in the table indicating that the judgments (and therefore the final relative importance weights) seem to be reasonable.

Evaluation and Calculation of the Suitability Index,(Weight Criteria)

The suitability index is estimated using simple additive weighing (SAW) method, which is a widely utilized method for the calculation of final grading values in multiple criteria problems; the mathematic formulation of the method is described by Eq. (1)(Yoon & Hwang, 1995):

$$V_i = \sum_{j=1}^{n} w_j v_{ij} \quad (1)$$

Where

V_i is the suitability index for area i

w_j is the relative importance weight of criterion j

v_{ij} is the grading value of area i under criterion j

n is the total number of criteria.

The result is a map which was divided into four classes; grade 0 was considered as inappropriate; grades 7 to 9, however, were appropriate areas; regions with the score of 6 were selected as acceptable areas. Then the area of each class was calculated by the AREA Function (Fig. 15).

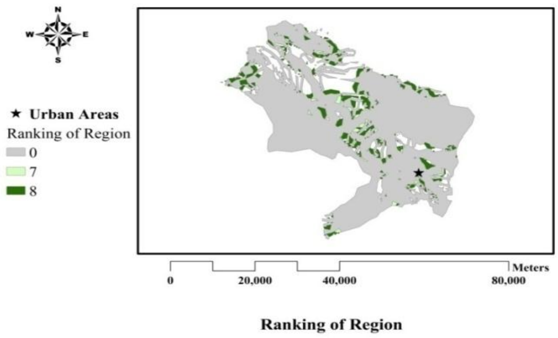

Fig. 15. Ranking of Regions Based on Final Score.

Considering the required area for landfill over the past 20 years, three ranges have been offered for Tafresh town. Then, each option in relation to the criteria was weighted using AHP form. Finally, the proposed option number two received the highest score (Fig. 16).

• **The First Proposal:** It is located at a radius of 4 kilometers northeast of Tafresh with the point UTM and position X: 411993 and Y: 3842267 which receives number 8 in classification and the surface area is 334 acres.

• **The Second Proposal:** It is located at a radius of 7 kilometers northeast of Tafresh with the point UTM and position X: 412313 and Y: 3845992 which receives number 8 in classification and the surface area is 782 acres.

• **The Third Proposal:** It is located at a radius of 8 kilometers northeast of Tafresh with the point UTM and position X: 412436 and Y: 3848796 which received number 8 in classification and the surface area is 114 acres. The current landfill location of Tafresh town is in 3 kilometers distant from it with the point UTM and position X: 409833 and Y: 3842642 which is in an inappropriate classification and in the path of the prevailing wind.

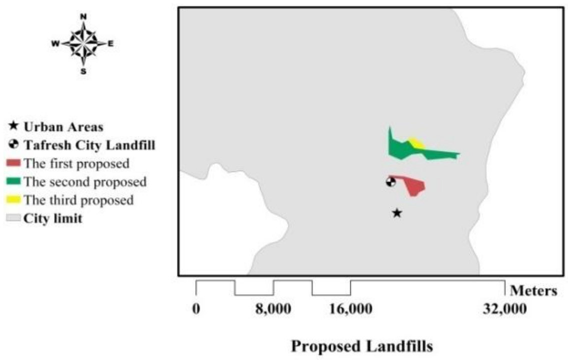

Fig. 16. Proposed landfill sites for the city Tafresh.

Conclusion

The methodology described in the present paper is an efficient approach in a landfill site selection process.

The methodology combines the evaluation abilities of MCA methods and the analytic tools of GIS. The MCA was utilized to form site location problem into a decision structure of three hierarchical levels, namely, the goal (suitability), evaluation criteria/sub-criteria, and spatial attributes. AHP method was utilized to extract the relative importance weights of the evaluation criteria and SAW method was employed to calculate the suitability indices in order to solve landfill site location problem.GIS was utilized to create the spatial determination of the evaluation criteria and create the land suitability map. In addition, GIS was utilized to perform spatial statistics and spatial clustering processes in order to reveal the most suitable areas to site a landfill.

It is argued that the current site of waste disposal in Tafresh is not appropriate in terms of environmental considerations, and it threatens the surrounding areas since it is located at prevailing wind direction. Unfortunately, there is no fence around the trenches and no soil is used to compress and level the wastes. Therefore, a major part of light wastes is driven to the surrounding areas.

The size of disposal site in Tafresh will not meets the requirements in the short run. The study proposes new sites to meet these requirements up to 20 years, and their far distance allows for establishing recycling facilities and equipment. On the other hand, high level of fermentable material in the wastes building a compost plant is proposed as an executive mechanism.

Economic and social factors such as land value and ownership type and acceptability of the plan by people living in the region must be studied in detail, in addition to the consideration of all environmental measures in evaluating disposal sites. It should be borne in mind, however, that a comprehensive and accurate environmental study needs more field work like performing accurate geological soil tests.

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