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APPLYING ANALYTIC HIERARCHY PROCESS AND MULTIPLE CRITERIA ANALYSIS FOR MUNICIPAL LANDFILL SITE SELECTION IN BOJNOURD, IRAN

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ABSTRACT
One of the important environmental issues in today's life is the undesirable influence of municipal landfill site on the environment, especially ground water. Thus, it is very important to find appropriate landfill sites. The most important aim of site selection for municipal landfill is to ensure that the selected site has minimum negative effects on the environment and society. There are various methods for landfill site selection, most of which are GIS-based and use digital information and their weighting to determine susceptible and inappropriate landfill zones. To determine the zones with acceptable landfill potential in city of Bojnourd, 16 digital layers prepared in GIS software were combined; as a result, the whole studied region was divided into different zones (appropriate to inappropriate) and classified according to the priorities. In this process, the best landfill site was identified in the west of the aquifer of Bojnourd. Finally, characteristics of the proposed and current landfill sites were separately investigated.

KEYWORDS: municipal landfill, site selection, Bojnourd aquifer, GIS

Introduction
Municipal waste is the inseparable part of human life and the generation of its various quantities and qualities is one of the most important environmental issues in today's life. Burial is the simplest and most economic method for waste disposal. Municipal waste management in landfills is one of the important environmental issues.[1] Landfills and their consequences, such as leachate, can cause environmental pollution, especially in ground and surface waters. Leachate of municipal landfills contains organic and chemical compounds as well as many suspended solids, which can adversely affect human health and the environment.[2]

In this regard, inappropriate landfill site selection is among the issues which cause numerous economic, operational, social, and environmental problems as well as water, specifically ground water, contamination. The important point is selection of the site which could result in the best cost-efficacy in terms of the considered factors. The major aim of municipal landfill site selection is to assure that the selected site has minimum adverse effects on the environment and society. Appropriate selection of municipal landfill site is a difficult and complicated process, because a combination of social, environmental, technical, economic, and other factors is involved.[3]

Introducing the studied region

City of Bojnourd is the capital of North Khorasan Province and located between 56° 18' and 57° 44' east longitude and 37° 13' and 38° 17' north latitude. Area of this city is 6157 km², which constitutes about 22% of the province area. Residents of this city produce 140 ton waste per day, the major part of which is buried in the only landfill of the city located in the northeast. The present landfill of this city is located within the approved frontage of the city, which is 1 km away from the residential areas. Landfill location in the heights, its proximity to the climbing ways used by the public (considering the blowing direction of the prevailing wind), and closeness to the new cemetery (located at 1 km from the landfill) have caused specific problems.[4]

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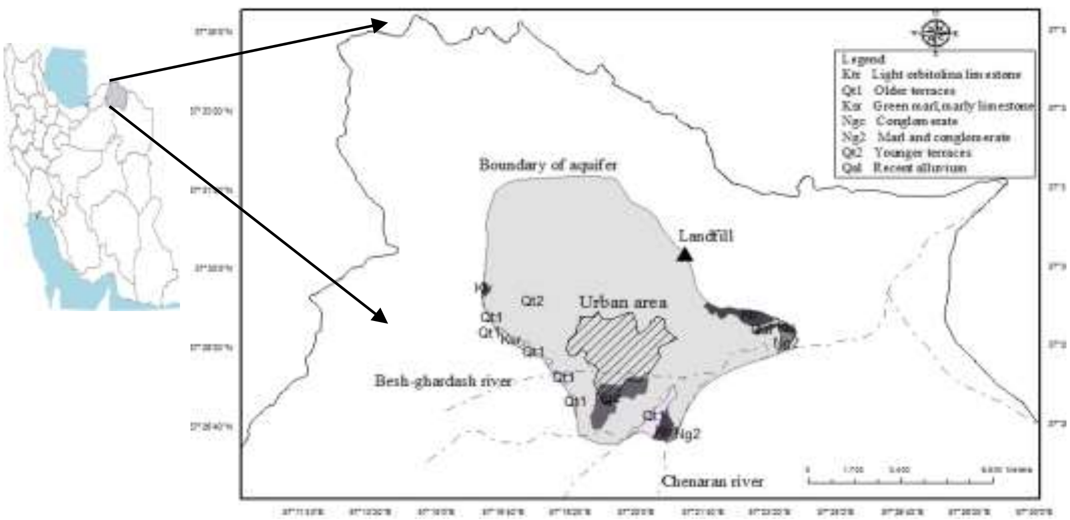

Figure 1- Bojnourd's studied region

Ground and surface water

Aquifer of Bojnourd Plain with the area of about 90 km² is free, single-layer, and alluvial and surrounded by the heights around the plain. Geometrical shape of its reservoir is like a small syncline. Bottom layer is made of clay-marl deposits. Bojnourd Plain has two permanent rivers, which enter from the south, join each other, feed the aquifer, and exit the plain from its southeast. Main entry and exit boundaries of ground water into and from Bojnourd aquifer correspond to the entry and exit of the river. In general, water transferability of Bojnourd aquifer increases in the direction of west to east and northwest to southeast. Reserving ratio of the aquifer is about 5.2%.[4]

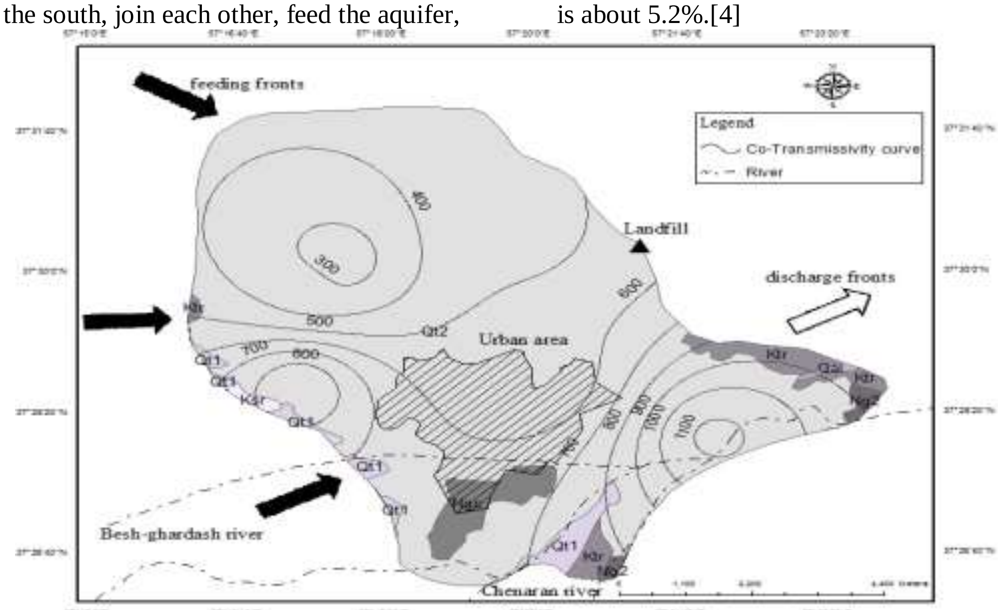

Figure 2- Bojnourd aquifer, its feeding and discharge fronts, and its transmissivity distribution

Geology

The studied region includes relatively high mountains with round, and sometimes flat, peaks. This region has calcareous, metamorphic, conglomerate, sandstones, and shale stones, a very shallow to shallow soil layers, non-uniform pebbles, and average to high number of watercourse branches. Formation type of the region is mostly Tirgan (K_t) which includes thick limestone of Maceio oolitic layer and marl layers. Because of its hardness, rock-forming topography exists in the region, which

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basically forms peaks. Relatively vast expansion of carbonated lithology of these formations has the appropriate ground water potential and the most watery springs of the region originate from there.[5]

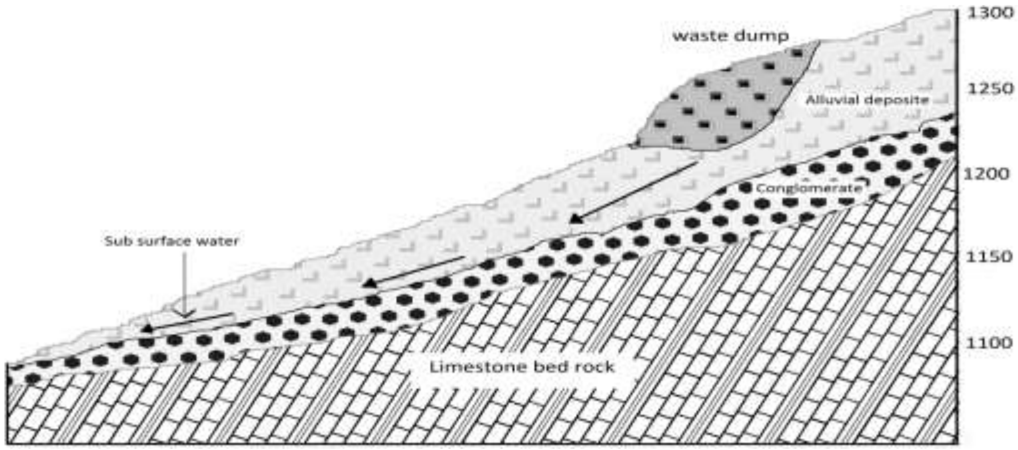

Figure 3- Sub-surface cross-section of Bojnourd landfill

MATERIALS AND METHODS

There are various methods for landfill site selection. Since many factors are involved, GIS (geographic information system) is usually applied. Site selection requires familiarity with multiple criteria decision making. Most site selection methods are GIS-based and use digital information and their weighting to determine inappropriate and susceptible landfill zones.[6]

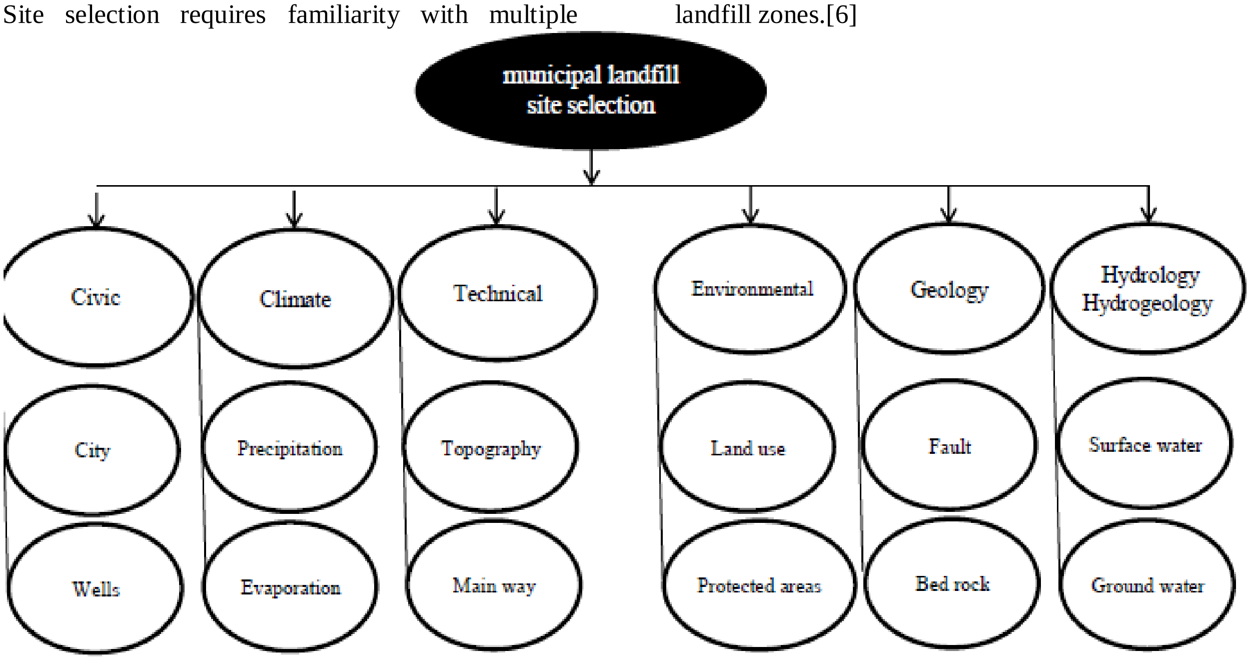

Figure 4- Hierarchical structure in decision making for municipal landfill site selection

GIS is one of the appropriate tools in this regard owing to its high accuracy and speed, ease of operation (despite having many layers), and high ability in combining and mixing different information layers.[6] To obtain the potential map for appropriate municipal landfill site selection in Bojnourd, the required information layers including geological map, land use, topography, city frontage, ground and surface water, and so on were collected and then weighted and prepared in the GIS environment.

Scoring and combining the layers

The criteria considered for the landfill site selection of the studied region were according to the standards, rules, and geographical conditions of the region shown in Table 1 [7]. First, each information layer was scored; then, weigh of the layers was added to it. This weighing was according to scores. Scoring was in the range of 1 to 10: 1 was the lowest and 10 the highest scores. After scoring the layers, it was necessary to consider total weight for the layer. The information layers were superimposed based on the obtained total weight and the final map of landfill site was acquired. The final scoring was determined based on the score multiplication of the parameters shown in Tables 2 to 6 as follows:

$$\bar{S} = \sum_{1}^{n} S_{ij} \times W_i \qquad (1)$$

S is final weight of the polygon, W_i is weight of the ith parameter, and S_{ij} is score of the jth class from ith parameter.

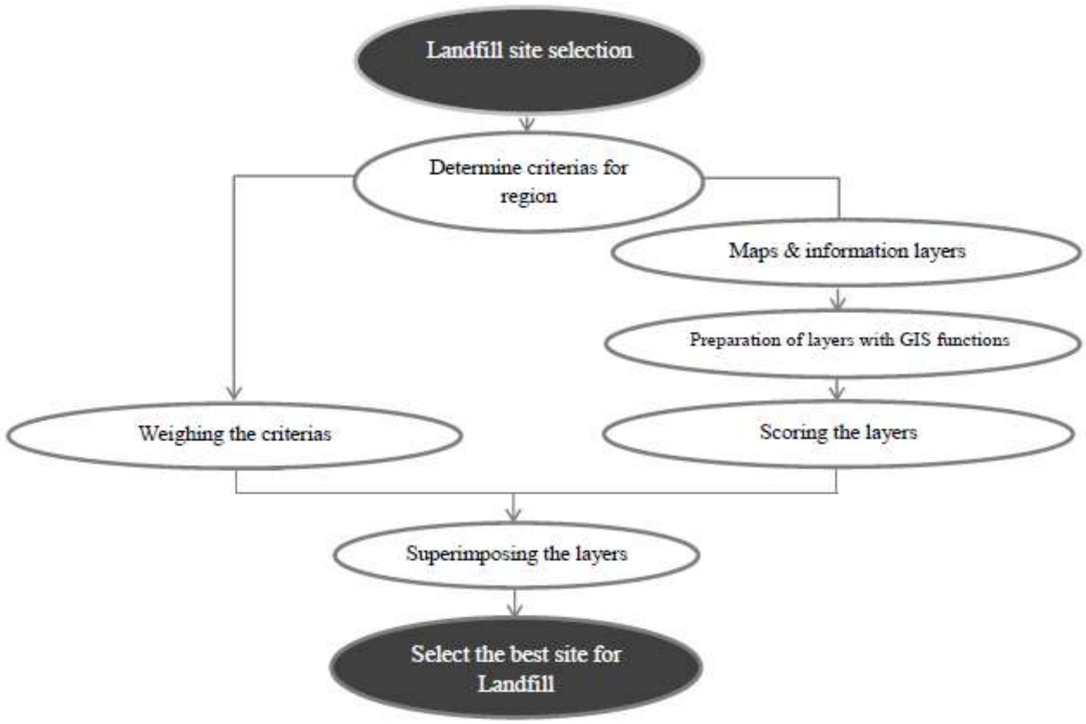

Figure 5 – Main framework and method of landfill site selection[8]

Table 1- Rules considered for the municipal landfill site[7]

No.	Name of criteria	Effect and rules
1	Urban centers	Minimum distance = 1000 m
2	Surface water resources	Minimum distance from main rivers = 300 m; Minimum distance from streamlet = 200 m
3	Ground water resources	Minimum depth of groundwater level: 10 m
4	Geology	Having a bedrock with the maximum possible impermeability
5	Land use	Having valuable use such as forest, farm, wetland, and grassland
6	Agrology	Having surface soil made of silty clay and silty sand, respectively
7	Slope	Slope = less than 10°

RESULTS AND DISCUSSION

A summary of the layers, basemaps, buffer zones, and the gradation used in this study is given below:

Climate criterion

Precipitation and evaporation are two effective parameters in assessing landfill sites. High precipitation and low evaporation rates are influential for the generation of a high volume of leachate.[9] Accordingly, maximum score was given to low-rain and high-evaporation regions. The following figures show the distribution of precipitation and evaporation in the studied region (considering distribution type of precipitation and evaporation in the region, scores of

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precipitation and evaporation parameters were 250 and 1600 mm/year, respectively).

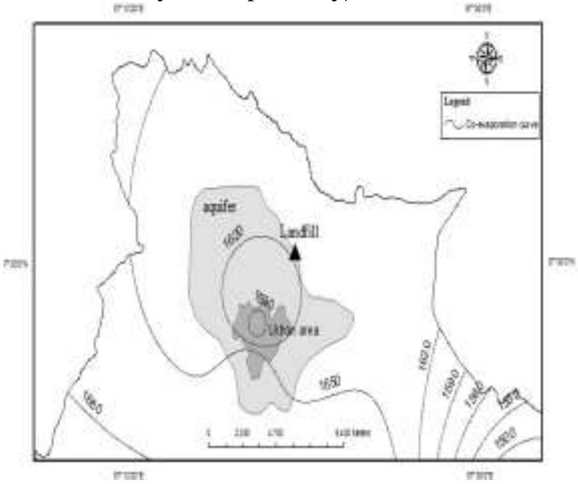

Figure 6- Co-evaporation curve in the studied region

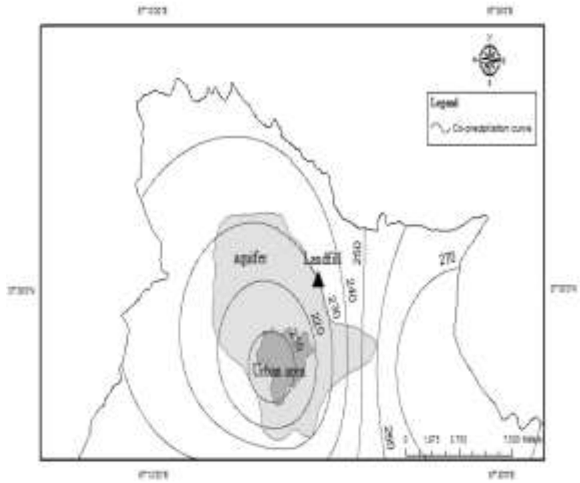

Figure 7- Co-precipitation curve in the studied region

Table 2- Summary of layers, buffer zones, and gradation of precipitation and evaporation parameters

Name of layer	Buffer zone	Gradation	
		Score	Total weight
Precipitation (mm/yr)	< 250	10	4
	> 250	5	
Evaporation (mm/yr)	> 1600	10	4
	< 1600	5	

Topographic and geological criteria

Location of a landfill should have impermeable bedrock (distant from main faults) and be in low-value lands (without any vegetation, low-density grasslands, etc.). Also, they are better to be in lower heights with low slope to prevent leachate movement.[10] So, scoring method of these parameters is shown in the following tables:

Table 3 – Summary of layers, buffer zones, and gradation of slope and height parameters

Name of layer	Buffer zone	Gradation	
		Score	Total weight
Slope (degree)	0-10	10	6
	10-20	7	
	20-30	5	
	30-40	3	
	> 40	1	
Height (m)	< 1250	10	5
	1250-1500	7	
	1500-1700	5	
	> 1700	1	

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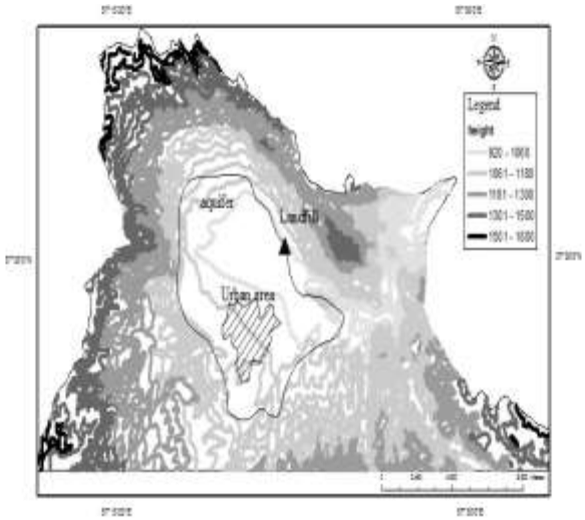

Figure 8- Topography of the studied region

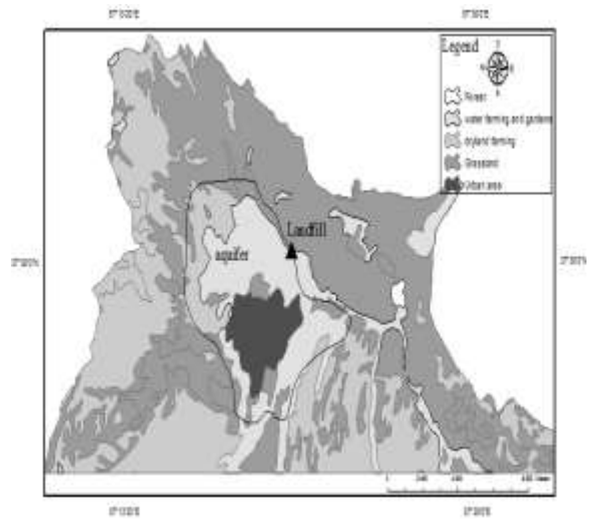

Figure 9- Land use of the studied region

Table 4- Summary of buffer zones and scoring geological, land use, and fault frontage parameters

Name of layer	Buffer zone	Gradation	
		Score	Total weight
Geological units	Basalt, andesite, and tuff stones	10	9
	Neogene sediments and Spring and Shourijeh formations	7	
	Sandstone and marl	5	
	Tirgan formation with mid-layers of lime-quaternary sediments	1	
Land use	Without vegetation and rock protrusions	10	7
	Low-density grassland	7	
	Semi-dense grassland, dryland farming	5	
	Dense grassland, water farming, and gardens, woodlands, and shrubbery	3	
	Forests and residential areas	1	
Fault frontage (m)	<1000	1	6
	1000-4000	5	
	>4000	10	

Frontage criterion

A landfill should be established at appropriate distance from urban and rural areas as well as main roads. [7]

Ground and surface water criteria

Depth, quality of ground water, hydraulic parameters of aquifers such as transmissivity, and distance from surface water resources are influential in landfill site selection. Thus, parts of the aquifer with high depth, low quality (with high TDS, EC, and $C1^{-}$), low transmissivity, and further points from rivers and surface waters were in priority.[11]

Table 5- Summary of layers, buffer zones, and gradation of city, well, and main road parameters

Name of layer	Buffer zone	Gradation	
		Score	Total weight
Distance from city (m)	<3000	1	5
	3000-7000	10	
	7000-20000	5	
Frontage of wells (m)	<1000	1	4
	1000-3000	5	
	>3000	10	
Main road frontage (m)	<1000	1	3
	1000-3000	5	
	3000-5000	10	
	>5000	3	

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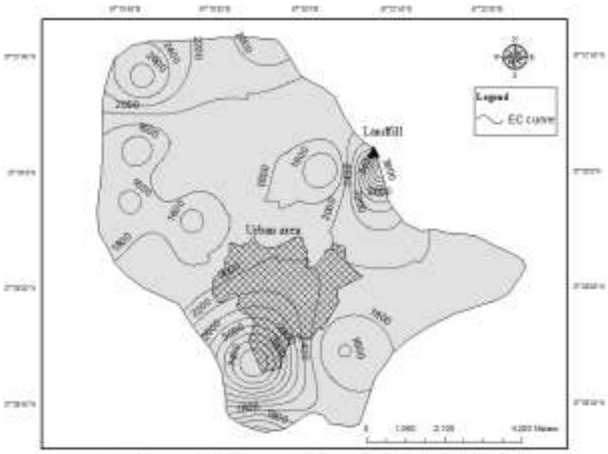

Figure 10- Map of EC changes

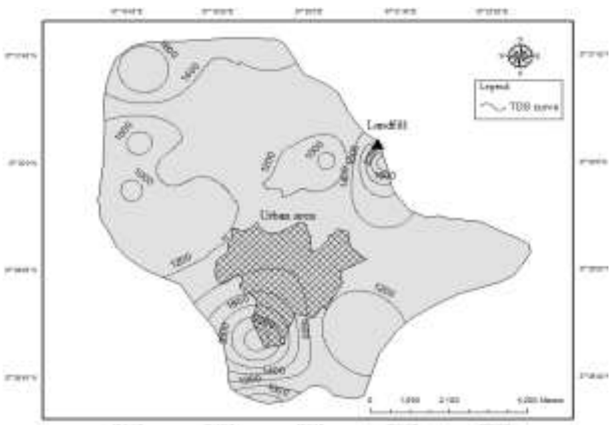

Figure 11- Map of TDS changes

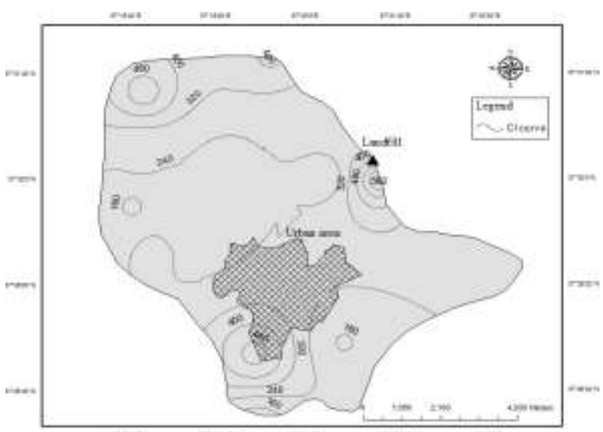

Figure 12- Map of C1[-] changes

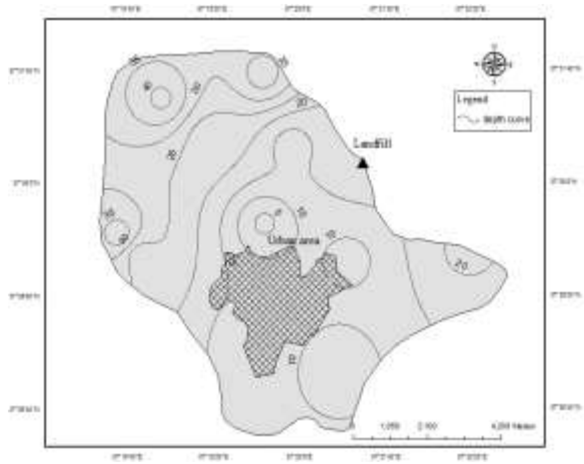

Figure 13- Map of depth changes of aquifer

Table 6- Summary of buffer zones and scoring aquifer's quality, depth, and transmissivity parameters along with surface water frontage

<table>
<tr><th colspan="2" rowspan="2">Name of layer</th><th rowspan="2">Buffer zone</th><th colspan="2">Gradation</th></tr>
<tr><th>Score</th><th>Total weight</th></tr>
<tr><td colspan="2" rowspan="5">Ground water depth (m)</td><td><10</td><td>1</td><td rowspan="5">10</td></tr>
<tr><td>10-20</td><td>3</td></tr>
<tr><td>20-30</td><td>5</td></tr>
<tr><td>30-40</td><td>7</td></tr>
<tr><td>>40</td><td>10</td></tr>
<tr><td rowspan="9">Ground water quality</td><td rowspan="3">TDS (mg/lit)</td><td><1000</td><td>1</td><td rowspan="9">8</td></tr>
<tr><td>1000-2000</td><td>5</td></tr>
<tr><td>>2000</td><td>10</td></tr>
<tr><td rowspan="3">EC (µmohs/cm)</td><td><2000</td><td>1</td></tr>
<tr><td>2000-3000</td><td>5</td></tr>
<tr><td>3000-4000</td><td>10</td></tr>
<tr><td rowspan="3">Cl^- (mg/lit)</td><td><300</td><td>1</td></tr>
<tr><td>300-600</td><td>5</td></tr>
<tr><td>>600</td><td>10</td></tr>
<tr><td colspan="2" rowspan="5">Aquifer transmissivity (m^2/day)</td><td>>1000</td><td>1</td><td rowspan="5">6</td></tr>
<tr><td>800-1000</td><td>3</td></tr>
<tr><td>500-800</td><td>5</td></tr>
<tr><td>300-500</td><td>7</td></tr>
<tr><td><300</td><td>10</td></tr>
<tr><td colspan="2" rowspan="3">Surface water frontage (main river) (m)</td><td>0-1000</td><td>1</td><td rowspan="3">7</td></tr>
<tr><td>1000-3000</td><td>5</td></tr>
<tr><td>>3000</td><td>10</td></tr>
<tr><td colspan="2" rowspan="3">Surface water frontage (streamlet) (m)</td><td>0-500</td><td>1</td><td rowspan="3">4</td></tr>
<tr><td>500-1500</td><td>5</td></tr>
<tr><td>>1500</td><td>10</td></tr>
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Wind factor

Considering that the blowing direction of prevailing wind in this region was from west to east [4], the parts on the eastern side of the residential areas were more appropriate for landfill construction (weight of wind parameter was considered 4).

CONCLUSION

In this study, the general method was based on separating and scoring appropriate and inappropriate regions and zones for waste disposal considering the aquifer. Then, the final result, i.e. proper landfill site, was selected. To determine zones with the acceptable potential for waste disposal of city of Bojnourd, 16 digital layers of wind, ground water (depth and quality of ground water and transmissivity of aquifer), surface water (main river and streamlet), geology (bedrock type and land use), climate (precipitation and evaporation), frontage (city, road, drinking water wells, and fault), and topography (height and slope) were prepared and combined in GIS software. As a result, the whole studied area was divided into various zones and classified according to their priority (points with higher scores showed more appropriate regions).

In landfill site selection process for city of Bojnourd, the best point (with maximum score) for waste disposal was found in the west of the aquifer (as shown in the figure 14). Specifications of this point (the proposed landfill) and current landfill are compared in Table 7.

It should be mentioned that, since the most serious threat for the contamination of ground water is leachate, maximum weight was given to ground water and bedrock type (because of the existence of karst formation in the region).

The proposed landfill site did not have very good conditions in terms of wind and ground water quality parameters. To solve the wind problem, fences can be used to make barriers in a proper direction (east side of the landfill) to prevent waste scattering. Also, by landfill implementation based on engineering principles and using natural and artificial vegetation at the bottom of landfill, leachate penetration into the aquifer can be reduced in order to cause less degradation in the ground water quality of the region.[12]

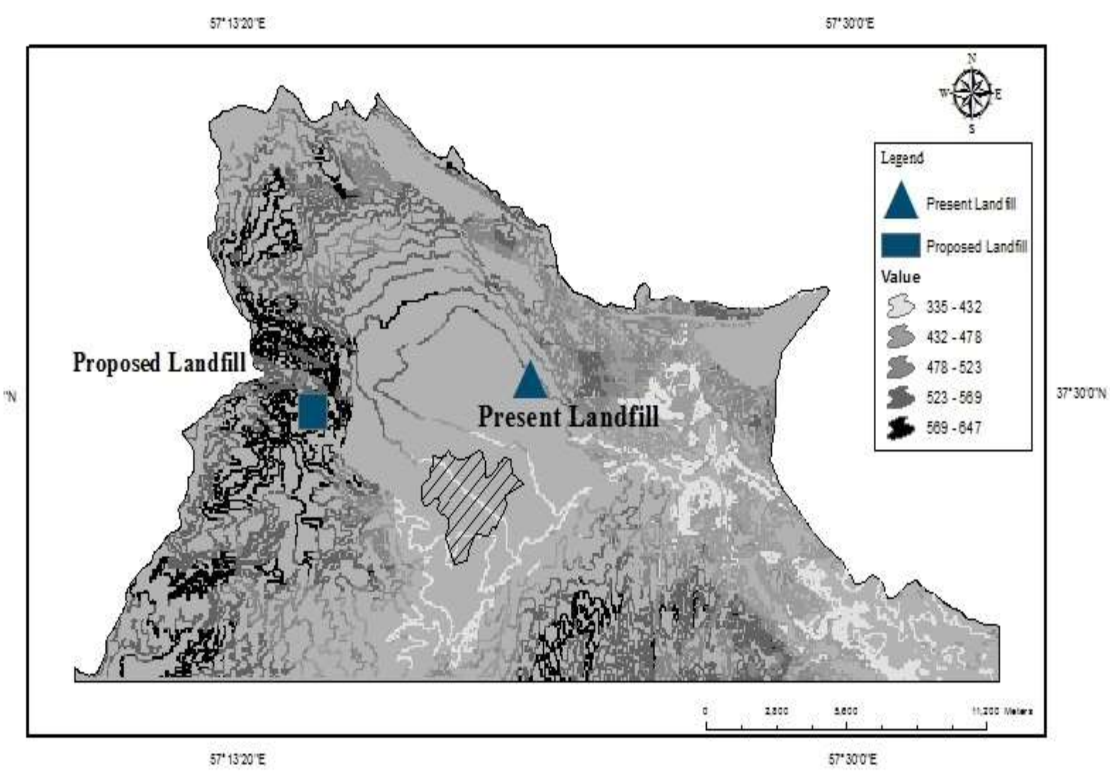

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Figure 14- Zoning landfill in Bojnourd

Table 7- Comparing present and proposed landfills in the landfill site selection process of Bojnourd

Name of criteria	Current landfill	Proposed landfill
Height (m)	1250	1150
Slope (degree)	0-5	0-5
City frontage (km)	5	7
Frontage of wells (km)	1	4
Fault frontage (km)	2/5	5
Surface water frontage (main river) (km)	4	5
Surface water frontage (streamlet) (m)	200	500
Road frontage (km)	1	3/5
Evaporation rate (mm/yr)	1500	1650
Precipitation rate (mm/yr)	250	220
Land application	Dryland farming	Low-density grassland
Geology	Quaternary sediments	Spring formation
Depth (m)	15	32
TDS (mg/lit)	1300	1000
EC (µmohs/cm)	2100	1500
Cl^- (mg/lit)	350	250
Aquifer transmissivity (m^2/day)	600	400

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