Original Article

Municipal Solid Waste Landfill Site Selection using Analytical Hierarchy Process Method and Geographic Information System in Abadan, Iran

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Abstract

Background and purpose: An appropriate solid waste (SW) disposal has been a major problem in municipal environment. The use of landfills is the most economical and environmentally acceptable method for the disposal of SWs all over the world. However, landfill leachate can cause environmental issues such as soil and ground water pollution. So, finding suitable land fill site is one of the most significant tasks in SWM. In this study, Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) method were used for Abadan solid waste landfill site selection.

Materials and Methods: Six criteria were used in this study comprise distance from aquatic ecosystem, risk, residential, economical, geographical and social criteria. Each criterion weighted by using AHP method. After omission of inappropriate areas, the suitability examination of the residue areas was accomplished using GIS.

Results: Relative importance weight of each criterion and score value of sub-criteria in the GIS environment was determined and finally suitability map was prepared. Based on the final suitability map, appropriate solid waste landfill site was located in north part of the study area.

Conclusion: The combination of AHP method with GIS in our experiment proves it is a powerful tool for solid waste landfill site selection.

*[Ahmadi M. Teymouri P. Dinarvand F. Hoseinzadeh M. Babaei A.A. *Jaafarzadeh N. Municipal Solid Waste Landfill Site Selection using Analytical Hierarchy Process Method and Geographic Information System in Abadan, Iran. 2014;2(1):37-50] http://jhs.mazums.ac.ir*

Key words: Abadan, AHP, GIS, Municipal Solid Waste, Landfill Site Selection.

1. Introduction

One of the most important parts of integrated waste management (IWM) is the safe and reliable disposal of municipal solid waste (MSW) and solid waste residues-wastes that are not recycled, that remain after processing at a materials recovery facility, or that remain after the recovery of conversion products and/or energy. Historically, solid waste (SW) has been placed on or in the surface soils of the earth or deposited in the oceans. Landfills are physical facilities used for disposal of SWs and SWRs in the surface soils of the earth. Since last century, the use of landfills has been the most economical and environmentally acceptable method for the disposal of SWs all over the world (1). However, landfill leachate can cause soil and ground water pollution (2). So, finding suitable land fill site is one of the most significant tasks in SWM (3, 4). Recently, there have been different methods reported for landfill site selection   such as overlaying GIS digital maps (5, 6), integration of fuzzy methodology and GIS (7-9), weight linear combination (WLC) method and spatial cluster analysis (SCA) (10), combination MCA and GIS methodology (11, 12), Integration of GIS and AHP (7, 13-18), and Intelligent System (19). Siting a landfill requires a combination of social, environmental and technical parameters to locate the areas that will minimize public concerns over health and environmental impacts and will be cost-effective (12). Using the conventional methods for land fill siting would be difficult and complex, since various factors have to be considered (20). In order to consider all factors in landfill

siting process, Geographic Information System (GIS) is a powerful option due to its capability in handling and management of spatial and attributive data (13, 17, 21, 22). In many cases, allocating the relative weights for the different criteria involved in making a decision on suitability of land mapping unit for a land-use type is very difficult. The Analytical Hierarchy Process (AHP) is a method that helps to estimate the relative weight (20). Thus, using both GIS and AHP method for land suitability analysis can cause promising results. The aim of this study was describing a MSW landfill siting methodology with the combined utilization of GIS and AHP method.

2. Materials and Methods

Study area: Abadan is the capital of Abadan County, in the south-west of Khuzestan province, Iran. It lies on Abadan island (68 km long, 3–19 km wide), is bounded in the north by Shadegan wetland, in the west by the Arvand waterway and in the east by the Bahmanshir outlet of the Karun River. Abadan city has an area of 2796 km^2 and a population of 283601. This results in a population density of 171 people/km^2. The average per capita solid waste generation and the estimated landfill area for 50-year-design period in Abadan are about 800 g/d and 24 ha, respectively (23). Abadan's soil has been formed by alluvial deposits of the Karun and the Tigris-Euphrates rivers. The pH of the soil is 7.5- 8.3 and its electrical conductivity is 2 to 234 µmhos/cm. The land in the city has a slope of less than 5 meters at square kilometers. Electrical conductivity of

groundwater in the area is about 10,000 to 40,000 µmhos/cm and is unsuitable for most applications (23). The climate in Abadan is arid. Summers are dry and hot. Based on Emberger classification Abadan is a hot desert with maximum temperatures higher than 50 degrees during June to the end of September, soaring temperatures may advance to over 65 degrees. Winters are mildly wet and spring-like, though subject to cold spells. Winter temperatures are around 16–20 degrees. Relative humidity of Abadan in July and August is about 50 to 60% and in January and February it reaches 70 to 80%. The average annual rainfall of

146.3 mm has been reported in Abadan and it has 38 rainy days from November to May. Most of evaporation belongs to January and it is 55.6 mm (24). In this study, an integration of GIS and AHP method was applied to MSW landfill siting in the city of Abadan. Seven criteria were identified for siting a landfill in the study area, including topography, city and village points, roads, sensitive and protected area, surface water, land use and geology.All the data pertaining to the criteria were obtained from several government agencies and prepared in the GIS format using ARC GIS9.2(Table 1).

Table 1. Base map used in Abadan land fill site selection

Base map	Data source	Scale
Topography	National Cartographic Center of Iran	1/40000
Roads	National Cartographic Center of Iran	1/40000
City and village points	National Cartographic Center of Iran	1/40000
Sensitive and protected area	Khuzestan Department of Environment	1/100000
Surface water	National Cartographic Center of Iran	1/40000
Land use	Khuzestan natural resources Department	1/100000
Geology	Iran Geological Survey organization	1/150000

Before the application of AHP method, the restricted areas were excluded from the study area. These areas were assigned 0 during the data preparation step. Thus, a mask of unsuitable areas was prepared. To do this, all data layers were multiplied by each other so that if any pixel has a value of 0 coming from any layer, then the value of that pixel would become 0, which means that the pixel is definitely not suitable for the location of a landfill (21). The AHP method is the most widely used decision making approach across the world (12). This method is based on three basic steps. At the first step the main goal is decomposed into a number of simpler criteria and sub criteria to form a decision hierarchy. In this study a structural

hierarchy- with 3 levels including Abadan landfill site selection, criteria and sub criteria- based on standards and regulations for landfill siting in Iran and other literature was formed. The main important criteria were determined and divided into 6 categories as social, geographical, economical, places, risk and distance from the aquatic ecosystems. Also each of these criteria comprises different sub criteria (10, 12, 17, 18, 25-27) (See Figure1). It should be noted that hydrological and soil condition criteria were the same in study area and did not have any effect on landfill site selection. Thus, these two criteria and their sub criteria were ignored in decision making process.
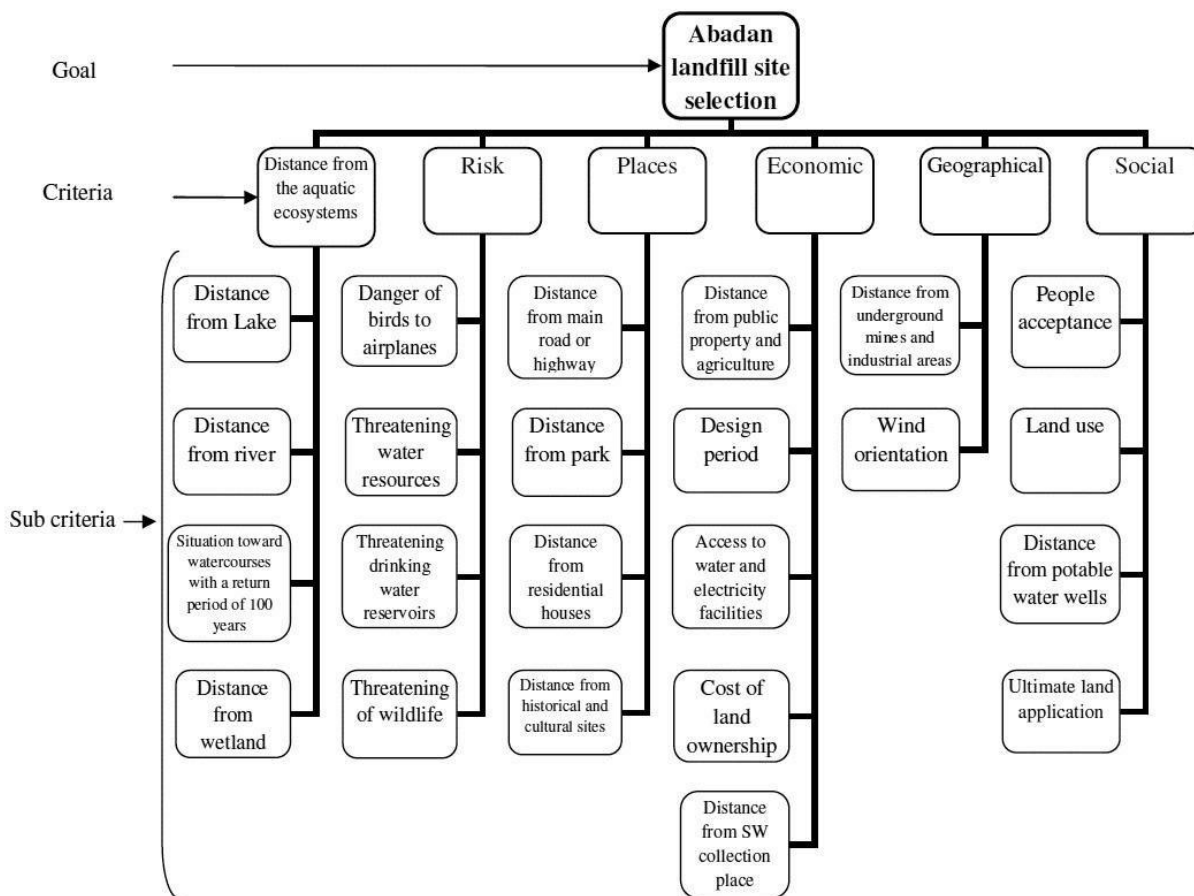
Figure1. Structural hierarchy of Abadan solid waste landfill site selection

The second step of the AHP method is comparative judgment. Within each level of the hierarchy, the relative weights of criteria and sub criteria are determined. This is done by pairwise comparison and involves three steps: (a) Expansion of comparison matrix at each level of hierarchy. This uses a scale with values range from 1 to 9; (b) Computation of weights for each element of the hierarchy; and (c) Estimation of consistency ratio (28), which is a measure of variation amount and it should be less than 10% (12). Table 2 shows the grading values that were assigned to any sub criterion based on the opinion of expert Delphi team (academic, technical, authority and stockholders), regulation of Iran and literatures.

Table 2. Criteria, sub criteria, range of each sub criteria and their weights

Criteria	Sub criteria	Alternative	Grade value	Criteria	Sub criteria	Alternative	Grade value
Distance from the aquatic ecosystems	Distance from Lake	>2500m	9	**Risk**	the danger of birds to airplane	No(> 8 km)	9
		2000 to 2500 m	7			Yes(< 8 km)	0
		1500 to 2000 m	5		threatening water resources with public use	>2500m	9
		1000 to 1500 m	3			2000 to 2500 m	7
		300 to 1000 m	1			1500 to 2000 m	5
		<300m	0			1000 to 1500 m	3
	Distance from river	>2500m	9			300 to 1000 m	1
		2000 to 2500 m	7			<300m	0
		1500 to 2000 m	5		threatening drinking water reservoirs	>2500m	9
		1000 to 1500 m	3			2000 to 2500 m	7
		300 to 1000 m	1			1500 to 2000 m	5
		<300m	0			1000 to 1500 m	3
	Distance from watercourses with a return period of 100 years	Is in	9			300 to 1000 m	1
		Is out	0			<300m	0
	Distance from wetland	>2500m	9		threatening of wildlife	>2500m	9
		1500 to 2500 m	7			1500 to 2500m	7
		500 to 1500 m	5			500 to 1500m	5
		300 to 500 m	3			300 to 500m	3
		<300m	1			<300 m	1
		In wetland	0			0(in wildlife)	0
Places	Distance from main road or highway	>3 km	9	**Economic**	Distance from public property and agriculture	>30 km	9
		> 1.5 km	7			25 to 30 km	7
		> 1 km	5			20 to 25 km	5
		300 to 1000m	3			15 to 20 km	3
		<300m	1			10 to 15 km	1
		0	0			<10 km	0
	Distance from park	>15km	9		Design period	30 to 40 year	9
		>10km	7			20 to 30 year	7
		>5 km	5			10 to 20 year	5
		2 to 5 km	3			<10 year	0
		<2 km	1		the landfill access to water and electricity facilities	yes	9
		0	0			no	0
	Distance from residential houses	>15 km	9		cost of land ownership	low	9
		>10 km	7			moderate	3
		>5 km	5			high	0
		2 to 5 km	3		Distance from waste collection place	<2 km	9
		<2 km	1			2 to 5 km	7
		0	0			5 to 10 km	5
	Distance from antiquity, historical and cultural sites	>2000 m	9			10 to 25 km	3
		1500 to 2000m	7			25 to 50 km	1
		1000 to 1500 m	5			>50 km	0
		500 to 1000 m	3				
		300 to 500 m	1	**Geographical**	Distance from underground mines and industrial towns	>15 km	9
Social	people acceptance	good	9				
						10 to 15 km	6
		bad	0				
	Land use	No application	9			<10 km	0
		Industrial areas	7				
		Cultivable lands	5		Situation of landfill to city considering the most wind orientation	Downstream the city	9
		Agricultural land	3				
		Tourism area	1			Upstream the city	0
		City and village areas	0				

At the third and final step of the AHP method, the relative weights of the levels were combined to generate composite weights. Following the AHP method, the map layers were formed in the GIS environment. According to the guidelines of the Iran Department of Environment regarding safe distances from landfills, the buffer zones were defined for each layer and these buffer zones were omitted from candidate sites. The final suitability map was created by overlay analysis of each criterion map.

3. *Results*

In the present study, six criteria were considered in arriving at the suitable site for landfill siting in Abadan city. Each criterion is explained in detail below.

3.1. Distance from the aquatic ecosystems criteria

This criterion consists of 4 sub criteria including the distance of landfill site from lakes, rivers, water courses with a return period of 100 years, and wetlands. The suitable distance of landfills from waterways, springs and qanats should be more than 600 m. Also, no landfill should be sited within the wetlands and the flood plains of rivers with a flood period less than 100-year (29). Figure 2 shows the suitable places for solid waste land filling based on distance from the aquatic ecosystems criterion. Red color with relative weight of 9 is suitable sites in this criterion. The sites with brown, yellow, green, pale and dark blue with weights of 8, 7, 6, 5 and 4 have the next priorities, respectively.
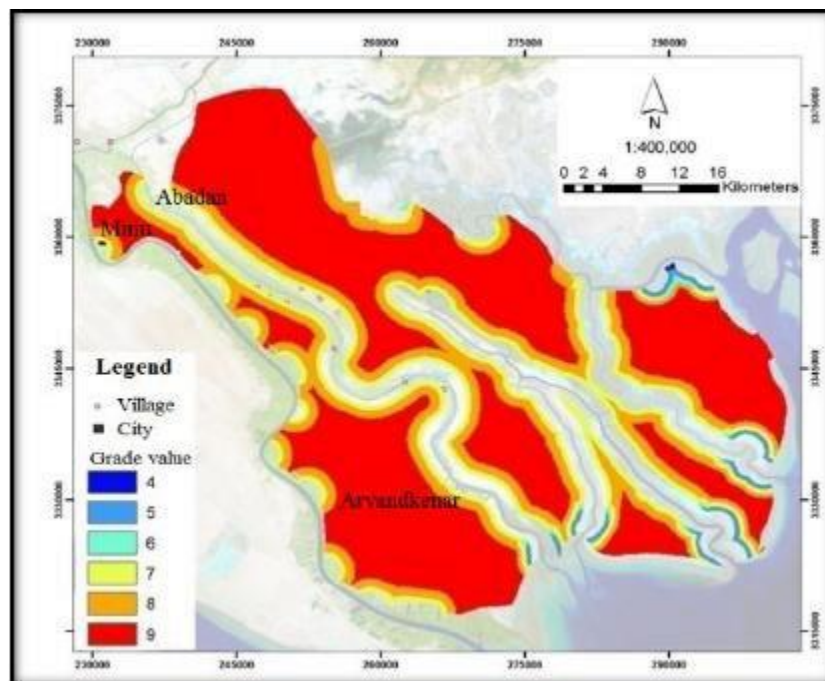

Figure 2. The suitable places for SW land filling based on distance from the aquatic ecosystems criterion

3.2. Risk criterion

The danger of birds to airplanes, threatening of water resources with public use, threatening drinking water reservoirs, and threatening of wildlife were sub criteria of the risk criterion. The presence of birds can be a real danger for airplanes. According to Iran regulations, landfills should be located at a distance of at least 8 Km from airports. Landfills should not be placed at national parks and conservation area. No landfill should be located over groundwater resources. For areas with high levels of

ground water to protect subsurface drinking water a 2 m impermeable layer made of silt-clay, with a permeability coefficient of 10^{-6} cm/s, should be prepared. A perpendicular distance of at least 5 m should be prepared between landfill floor and water table of ground water. Landfills and water wells should have a distance of at least 1500 m. Figure 3 shows the suitable places for SW land filling based on the risk criterion. Areas with green, yellow and red color, with weights of 9, 8 and 7 were the suitable places for Abadan landfill site, respectively.
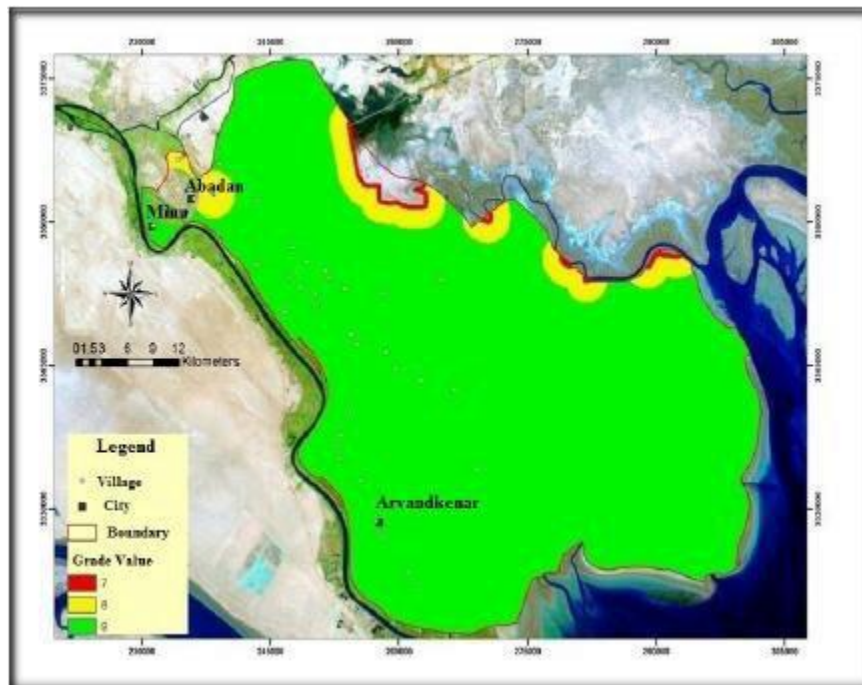

Figure 3. The suitable places for solid waste land filling based on risk criterion

3.3. Places criterion

Distances from Roads, public parks, residential, historical and cultural areas are sub criteria that were considered in this criterion. According to Iran regulations, landfill sites should be located at a maximum distance of 3km from the main roads. Landfill access roads should have

enough capacity and also should be located at places with a least traffic. To minimize the adverse effects of landfills on the environment and public health, and by considering transportation costs, landfills should be located at a distance of 10-15 km far from where SW is generated. To prevent adverse social effects, landfills should be

sited at a suitable distance from residential, historical, archaeological, cultural, and public promenades and cemeteries. Figure 4 shows the suitable places for SW land filling based on places criterion. Spots with dark green color, having the highest relative score 9, were the best places. The area specified by the pale green, very pale green, yellow, pale brown, dark brown and red color, with weights of 8, 7, 6, 5, 4 and 3 have a lowest suitability for the solid waste landfill site, respectively.
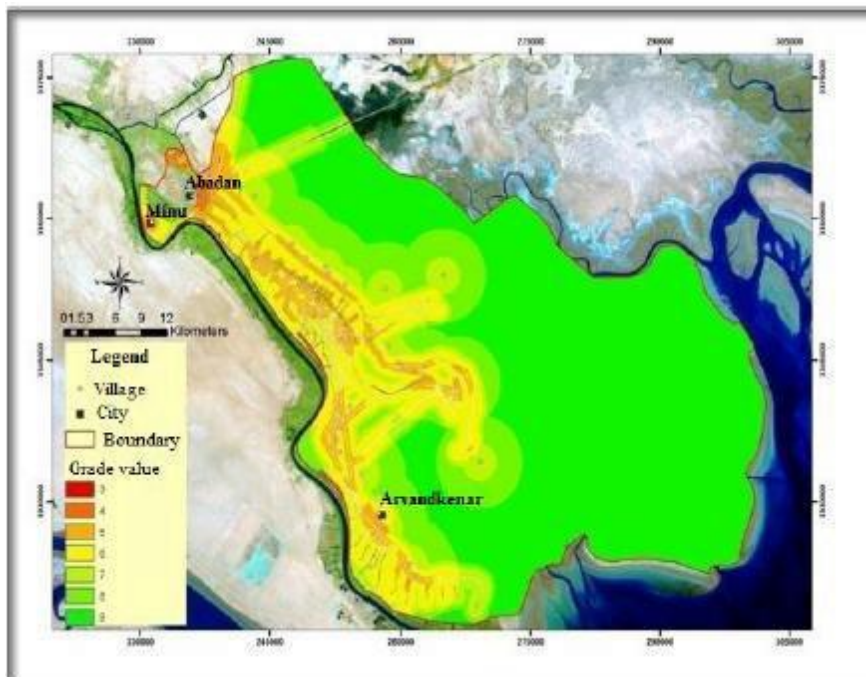

Figure 4. The suitable places for solid waste land filling based on places criterion.

3.4. Social criterion

Public acceptance and present land use were the two sub criteria of social criterion. To be accepted by the public, which is a very important factor in decision making process; landfills must not be located at populated centers and should not have interference with other facilities. Landfills should not be placed at public places. No landfill should be located in places with agricultural use or pasturelands, but in exigent situations. Figure 5 shows the suitable places for SW land filling based on social criterion. The best places were shown by the green color.

Figure 5. The suitable places for solid waste land filling based on social criterion

3.5. Economic criterion

The economic criterion consists of four sub criteria: (i) distance of landfills from public and agricultural places, (ii) design period, (iii) access to water and electricity, and (iv) costs of land. Facilities such as water, electricity and also wastewater systems should be considered in landfill locations. Land ownership with a minimum cost for preparation is the best choice. The land should have enough capacity for a design period of 20-40 years. Moreover, the minimum distance between landfill boarders and agricultural properties should not be less than 500 m. Figure 6 shows the suitable places for SW land filling based on the economic criterion. The best places were shown with dark green color with a relative weight of 7. Areas with pale green, brown and red colors with relative weights of 6, 5 and 4 had the lower priorities, respectively.
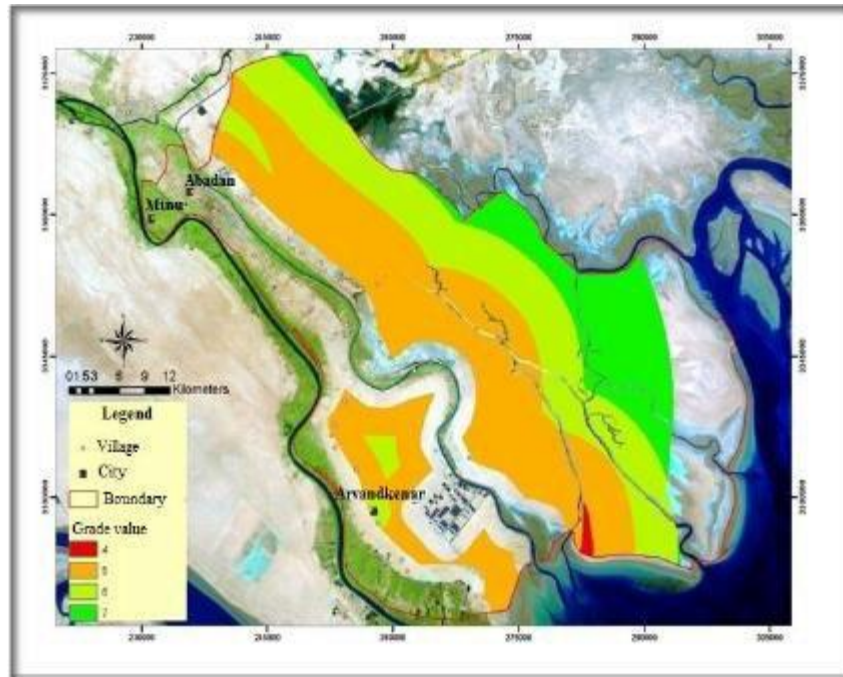
Figure 6. The suitable places for solid waste land filling based on economic criterion

3.6. Geographic criterion

The geographical criterion included distance from underground mines and industrial areas, and wind direction sub criteria. Site for landfill should be at a safe distance from the underground mines and industrial areas to prevent noise, odor and diseases vectors nuisances. Also, to prevent dust and odor nuisance, landfill site should not be located between the upstream prevailing wind and a residential area. Figure 7 shows the suitable places for SW land filling based on the geographic criterion. The best places were shown in dark green with a relative weight of 9, and areas specified by pale green, yellow, brown and red with relative weights of 8, 7, 6 and 4 have the next priorities, respectively.
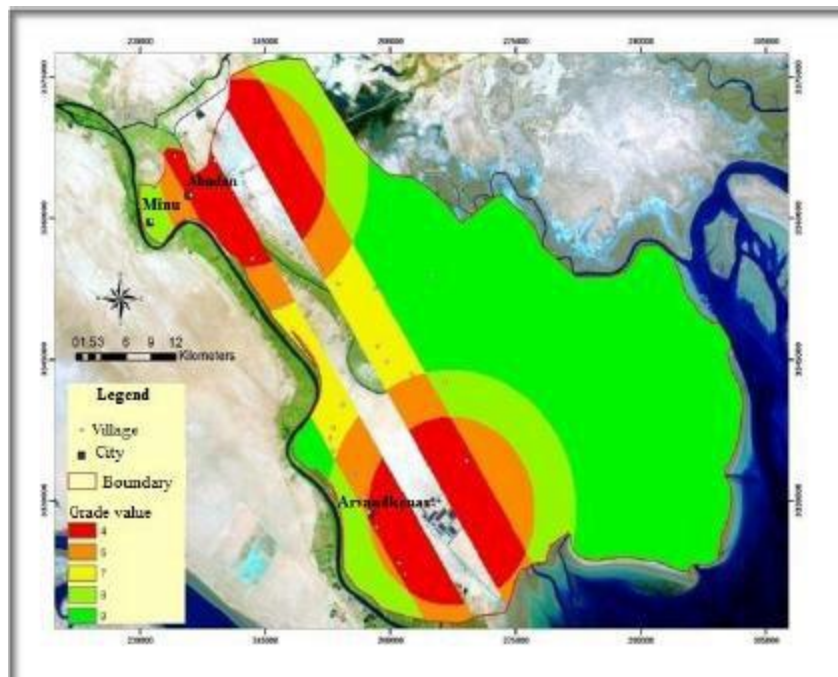
Figure 7. The suitable places for solid waste land filling based on geographic criterion

3.7. Suitable site

The importance weight for the criteria and the preferred weights for the alternatives is the most important step in landfill siting with the AHP method. Table 3 shows the relative importance of the criteria used to evaluate suitability of each site. The results show that due to existence of protected area such as Shadegan wetland and Arvand River, "Distance from the aquatic ecosystems" criterion by relative weight of 0.443 was the most important one. The economic, social and geographic criteria, with the weight of 0.073 were found to be the least important criteria. The value of the consistency ratio in this study was 0.0204, indicating consistency of the pair wise comparison matrix and a good understanding of decision problem and good homogeneity of factors in each group (30).

Table 3. Pair wise comparison matrix and relative importance weights of the site selection criteria

Criteria	Distance from the aquatic ecosystems	Risk	Places	Economic	Geographical	Social	Relative weight
Distance from the aquatic ecosystems	1	3	4	5	5	5	0.443
Risk	0.33	1	2	3	3	3	0.210
Places	0.25	0.5	1	2	2	2	0.129
Economic	0.2	0.33	0.5	1	1	1	0.073
Geographical	0.2	0.33	0.5	1	1	1	0.073
Social	0.2	0.33	0.5	1	1	1	0.073

The landfill suitability map was shown in Figure 8. Based on population growth and waste generation rate in Abadan, the priority areas for the Abadan landfill site were divided into 6 groups, red color area is the best choice with score of 9. Brown, yellow, pale green, dark green and rich green color areas have scores of 8 (very good), 7 (good), 6 (moderate), 5 (weak) and 4 (poor), respectively.
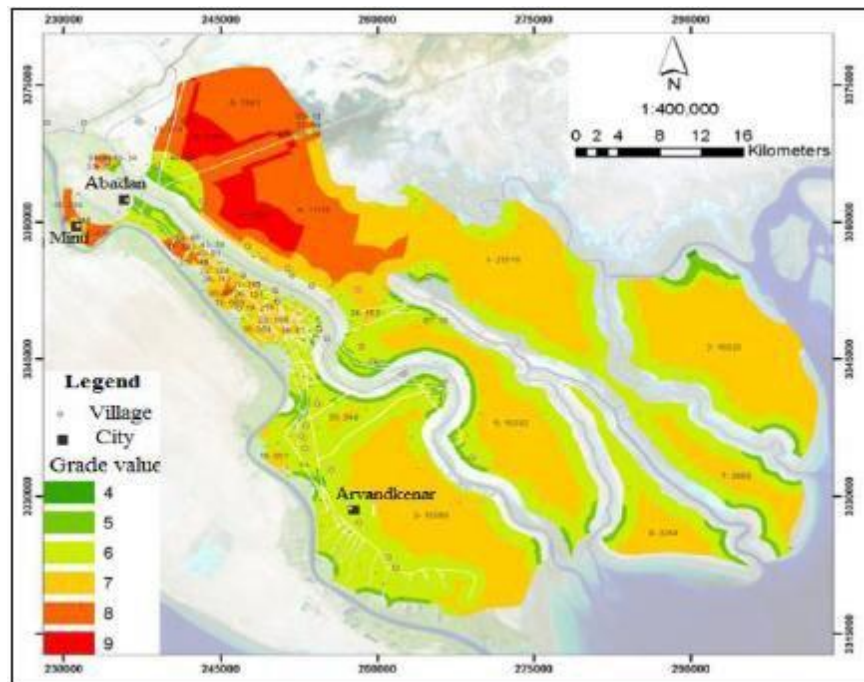

Figure 8. Landfill suitability map

By application the methodology described in the present paper, three zones including zone 8 (3,764 ha), 10 (2143 ha) and 32 (93 ha) had the highest scores. Therefore, to select the most suitable one, the distance from Abadan city was considered as the final factor. And finally, zone 10 was chosen as the best site for Abadan SW land filling.

4. Discussion

GIS in combination with different methods, such as AHP and fuzzy logic (22) fuzzy multicreteria decision making (25), and Fuzzy logic (31) has been used for Landfill site selection. Matkan et al., in their study applied two fuzzy methods (OWA and WLC) and Boolean method in combination with GIS. They found that site selection by OWA has better resolution (32). Using GIS combined with AHP for Givi SW land fill site selection, Fataee and Alesheikh introduced its current SW disposal site as the best option for its SW landfilling (33). GIS-based AHP can provide fast feedback for decision makers. It is easy for non-experts to understand, and helps to explore the decision problem by conducting a comprehensive yet easy-to-use procedure to examine weight sensitivity in both criteria and geographic space (34). In the present study the landfill site selection for municipal solid waste was performed using GIS and AHP method. The AHP method

was utilized to extract the relative importance weights of the evaluation criteria. 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. In this research, 6 important criteria which have principal effect on landfill site selection are identified including distance from aquatic ecosystem, risk, residential, economical, geographical and social criteria. After determination of relative importance weight of each criterion and score value of sub-criteria in the GIS environment, final suitability map was prepared. Based on the final suitability map, suitable areas for landfill construction are located in north part of the study area. The combination of AHP method with GIS in this experiment was found to be a suitable tool for solid waste landfill site selection.

Acknowledgements

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