# Municipal Solid waste Landfill Site Selection with GIS and AHP (A Case Study: Mahshahr County, Iran)

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Executive Summary

Siting landfill is a complicated process because it must combine social, environmental and technical factors. In this study, in order to considering all factors and rating criteria, a combination of geographic information systems (GIS) and Analytical Hierarchy Process (AHP) was used to find the best sites for disposal of Municipal Solid Wastes (MSW) in the Mahshahr County. In this study for the decision making problem a structural hierarchy formed and the most important criteria: surface water, sensitive ecosystems, land cover, urban and rural areas, land uses, distance to roads, slope and soil type were chosen according to standards and regulations for sitting landfill in Iran and literatures. Every criterion was evaluated by rating methods. In the next step the relative importance of criteria to each other were determined by AHP. Land suitability for landfill was evaluated by Simple Additive Weighting (SAW) method. Landfill suitability of the study area classified to three categories: high suitability, moderate suitability and low suitability. The results indicate that 67% of the study area has low suitability, 19% has moderate suitability and 14% has high suitability for a landfill site. By considering the parameters such as requirement area for landfill, distance to MSW generation points, political and management issues and consulting with municipalities managers in the study area, 6 sites were chosen for site visiting. The result of field study showed that it is a supplementary and necessary step to find the best candidate from the land with high suitability. Some parameters such as public acceptance and land ownership can be checked only through site visiting.

## Introduction

Disposal of wastes through landfills is an inevitable element of all solid waste management systems. Even if all activities for reduction, reuse and recycling are implemented, there will always be a need for land disposal of a residual proportion of the waste originally produced. Sanitary landfill is the most common and popular method of solid waste disposal used in many countries including developing countries(Yes_ilnacar and Cetin, 2005).

One of the most difficult tasks faced by most communities in planning solid waste landfill is finding suitable site for new landfills (Rushbrook p. and Pugh M., 1999; Tchobanoglous et al., 1993). Siting landfill is a complicated process because it must combine social, environmental and technical factors(Kontos et al., 2005). In order to considering all factors in landfill siting process, GIS is a powerful tool due to its ability to manage large volumes of spatial distributed data from a variety of sources. It efficiently stores, retrieves, analyzes and displays information according to user-defined specifications (Şener et al., 2006; Siddiqui et al., 1996; Wang et al., 2009). The techniques base on GIS are binary since the final result is a discrimination of the study region in suitable/unsuitable areas (Kontos et al., 2005). In landfill siting process, it is necessary to rank suitable sites and choose the best one in the next stages. For overcoming this problem we can use an analytical hierarchy process.

The combination of GIS and AHP is a powerful tool to solve the landfill site selection problem, because GIS provides efficient manipulation and presentation of the data and AHP supplies consistent ranking of the potential landfill areas based on a variety of criteria(Şener et al., 2006).

A decision modeling procedure is developed based on the AHP to locate obnoxious facilities (Erkut and Moran, 1991). Siddiqui et al., (1996) by integrating GIS and AHP developed a methodology to find best locations for landfills. The evaluation of the land suitability was based on the environmental characteristics of the site and proximity to the populations. Kontos et al. (2005) evaluated the suitability of Lemnos Island to select an optimal landfill site using a spatial multiple criteria analysis methodology. Vatalis and Manoliadis, (2002) overlaid GIS digital maps to find the suitable landfill sites in Western Macedonia, Greece. Wang Guiqin et al (2009) with considering economic factors, calculated criteria weights using the AHP and built a hierarchy model for solving the solid waste landfill site selection problem in Beijing, China. Sener S., et al for finding the most suitable landfill site, combined an AHP with a GIS to examine several criteria, such as geology/hydrogeology, land use, slope, height, aspect and distance from settlements, surface waters, roads, and protected areas. Moeinaddini M., (2010) used weighted linear combination (WLC) method and spatial cluster analysis (SCA), to find suitable sites for landfill of Karaj city in Iran and found that 6% of the study area is suitable for landfill siting.

In this study, a combination of GIS techniques and AHP methods was applied for finding the best solid waste disposal sites in Mahshahr County, Iran (Figure1).

## Materials and method

### The study area

Mahshahr County with high rate population growth was located at sensitive costal areas in the south-western of Iran and it is the center of petrochemical industries in Iran (Figure 1). Three city and about 100 villages are located in this area. The population of this area is 250000 and it will be increased to 400000 in the 2035 because of growing petrochemical industries and sea transportation activities in this area. According to Mahshahr Integrated Solid Waste Management Plan (ISWMP) the amount of municipal solid waste and land required for landfill sites in the study area has been estimated as $3683003m^3$ and $920750m^2$ (92ha), respectively (Alavi, 2010). At the present time, MSW are disposed through dumping around the urban and rural areas. It is lead to many problems in this area such as water resources pollution and deterioration of sensitive ecosystems and threat to public health in residential areas.

### Methodology

In this study, landfill site selection is performed using the GIS and the AHP. The AHP was selected for the decision rules to analyze the data for landfill site selection using GIS. The AHP divides the decision problems into understandable parts; each of these parts is analyzed separately and integrated in a logical manner(Malczewski, 2004; Saaty, 1980a). In this study for the decision making problem a structural hierarchy formed as following levels: 1- Landfill site selection, 2- environmental, socio-cultural and technical- economical factors 3-criteria and subcriteria (Figure 2).

Every criterion was evaluated by point allocation approach. It is one of the simplest rating methods. It is based on allocating points ranging from 0 to 10, where 0 indicates that the point is not suitable, and 10 represents the best situation for that criterion.

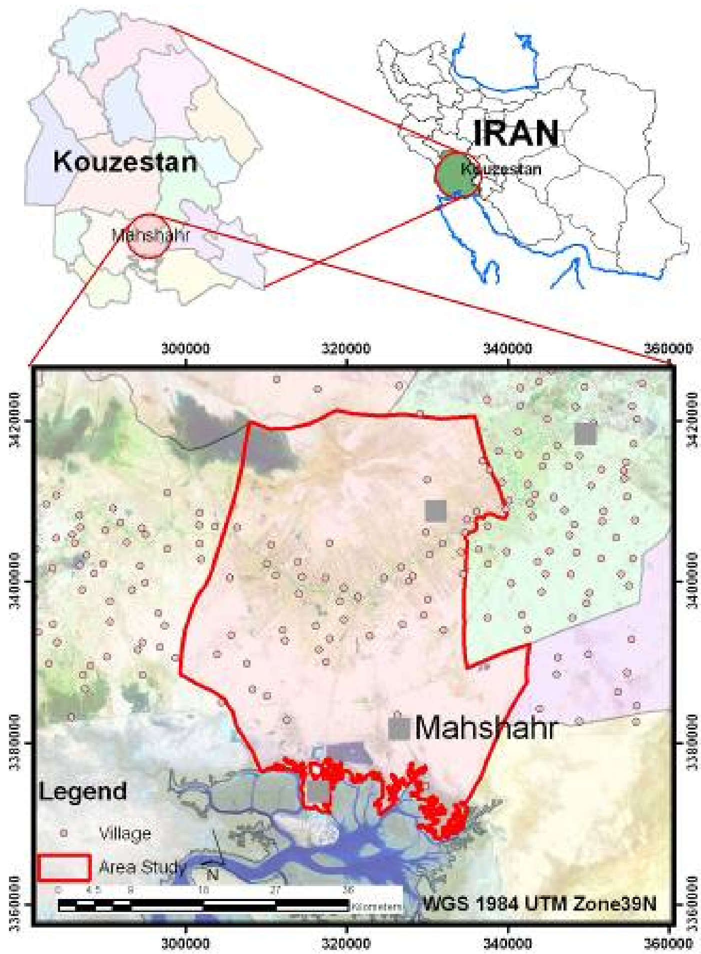


**Figure 1: Study area boundary**

## Input Data:

For preparing a comprehensive data base, 12 input map layers including topography, settlements (urban centers and villages), roads (main roads and village roads), railways, airport, wetlands, infrastructures (pipelines and power lines), slope, geology, land use, land cover and surface water are obtained and prepared in GIS environment. All layers are converted into individual raster maps. Base on the standards of Iranian department of environment about the safe distances to a landfill sites, the buffer zones determined for each layer and these buffered areas missed from the study.

### Evaluation criteria

The main factors that are important in siting of MSW landfills were determined in the first step. They were divided to three categories: Environmental, socio- culture and technical-economical factors. For any factor defined some criteria and subcriteria. They were chosen according to standards and regulations for sitting landfill in Iran and literatures(Chang et al., 2008; Kontos et al., 2005; Moeinaddini et al., 2010; Nas et al., 2010; Şener et al., 2006; Şener et al., 2011; Sener et al., 2010; Wang et al., 2009)

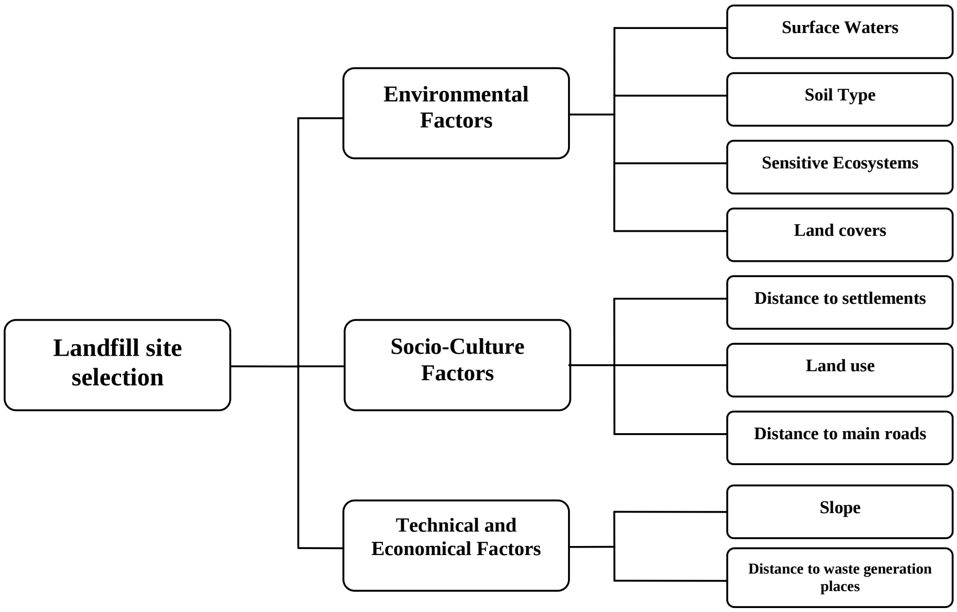


**Figure 2: Hierarchy structure for the landfill site selection problem**

Surface water:
Surface waters are an important parameter for landfill sitting in this area because there are some important rivers such as Zohreh and Jarahe that are the main source of water supplying for domestic and agriculture users in this area. Base on the landfill siting regulations of environment department of Iran, disposal of solid waste to any surface water body such as sea, lakes and rivers is forbidden. The minimum distance of landfill sites from surface water should be more than 300m therefore the distance less than 300m took zero score. The highest grade (10) was taken to a buffer of >2500m. (Table 1)

Sensitive Ecosystems:
The Mahshahr County is located in the vicinity of some sensitive areas like Shadeghan wetland, coast areas and a lot of coves such as Mosa cove. According to the regulations of environment department of Iran, MSW landfills not allowed to be in wetlands. If the distance to sensitive ecosystem is more than 2000 m, it is gained the score of 10, reversely if the distance to sensitive ecosystem is less than 300 m; it is gained the score of 0. The score of others ranges illustrated in table 1.

Land Cover:
The land cover is an important criterion in landfill siting because the landfill operations such as drilling lead to destroying of land cover. The Locating landfills in wetlands forest is unacceptable, therefore the grading value for these areas was 0. The areas with irrigated farming lands that are important in the agriculture activities in the study area have a 3 grade. The dry farming lands, rangelands and barren lands were considered optimal for landfill siting having grading values of 6, 8 and 10, respectively.

Urban and rural areas:
In order to protect the community public health, landfill sites should not locate near the residential areas. According to Iran legislations, disposal of municipal solid waste at a distance less than 10 km from residential areas is not allowed. In addition, according to Iran regulations, distance to airport should be more than 8km to prevent birds' hazard. The

airports were buffered base on this guideline. A distance to residential area less than 2km gain a 0 grade and a distance more than 10 km gain the highest grade, 10 because many of landfills in Iran haven't been operated in a good manner. A distance 2-5 km, 5-10 km and more than 10 km gain 2, 5 and 10 grads respectively.

Land uses:
The land-use plans are useful in delineating areas with definite zoning (Bagchi 2004). The selected lands for landfill must be base on the zoning restrictions. The land uses were divided to residential, agricultural, industrial and unused lands. The highest score allocated to the last group. Disposal of MSW to residential lands is not allowed therefore it takes the 0 grade. The creational and tourism areas are not suitable for landfills which received a score of 2. The agricultural and industrial lands received a score of 4 and 8 respectively.

Distance to roads:
Locating landfills near main roads have aesthetic problems for passengers. This criterion was based on radial distances from main roads (highways and main roads). Therefore, the places farther from main roads get further score. According to the landfills siting regulations in Iran, the minimum distance of landfill to main roads is 300 m therefore It took 0 score. A distance of 300 to 700 m to roads get a score 2. The highest score (10) was assigned to a distance more than 3 km (Table 1).

Slope:
The slope of the land surface is a crucial factor for the constructing and operating a landfill site. Very steep slopes will lead to higher excavation costs. The flatter areas are more suitable for landfill construction therefore received more grades. The very steep areas (>45%) were assigned a grade of 0, the steep areas (25–45%) were assigned a grade of 2 and the moderately steep areas (20–25%) were assigned a grade of 4. The inclined planes (10–20%) were assigned a grade of 8. The slightly sloping areas (<10%) that are the best candidate for landfill operations received a grade of 10 (Kontos et al., 2005).

Land Type:
Classification of land type is base on the manual of the water and soil research institute of Iran. This classification is according to Mahler 212 manual. The land is divided to different unit base on geology, morphology and soil characteristic of land. The main land type in the study area is river alluvial plains.

Land unit of 5.1 is included by river alluvial plains. It is consisted of deep soil with moderate to heavy texture and low salt. It is cultivated by annual or perennial plants. It is permeable to water and suitable for cultivation therefore get lowest score (2) for landfill.

Land unit of 5.6 is consisted of very deep and heavy soil with high alkalinity and salt. It is covered by salinity resistance plants in low canopy cover. It is considered as barren land. It has a low porosity and low water permeability. It is the best candidate for landfills and took the highest value (10).
Land unit of 5.8 is consisted of deep and heavy soil with moderate to high alkalinity and salt. It is covered by salinity resistance plants in low to medium canopy cover. Its permeability to water is moderate and it gets a score of 5.

Land unit of 6.2 is consisted of deep and heavy soil with moderate to high alkalinity and salt. It is covered by salinity resistance plants in low to medium canopy cover. It is considered as barren land and sometimes used as temporary rangeland. Its permeability to water is moderate to low and it gets a score of 8.
Distance from generation points:

Proximity to waste production centers is an important factor in economic feasibility of a candidate landfill site. The selected sites that are closer to solid waste generation points are preferred more than the sites that are farther.

According to ISWMP of Mahshahr County, a transfer station will be established near Mahshahr city to receive the total MSW of Mahshahr, Bandar Emam and Chamran cities. This point is designated as a bench mark and distance of all candidate points to this point evaluated. A buffer zone with 2000m radium was scored 10, with 2000 to 3000m radium was scored 8, with 3000 to 5000 m radium was scored 5, with 5000 to 10000 m radium was scored 2 and with more than 10000 m was scored 1.

Determination of relative importance weights of criteria:
After determining of importance of any criteria individually, the next step is the determination of relative importance of criteria to each other. One of the most common methods that have been used in recent years is AHP. It is a multiattribute technique which has been incorporated into the GIS-based land-use suitability procedures (Saaty, 1980a). It is an accepted decision making method, which is applied to determine the relative importance of the different criteria in landfill site selection (Kontos et al., 2005; Moeinaddini et al., 2010; Şener et al., 2006; Şener et al., 2011; Sener et al., 2010; Sharifi et al., 2009; Yes_ilnacar and Cetin, 2005). The AHP is based on pairwise comparisons and any criterion or subcriterion is compared to another criterion at the same time. Decision makers can quantify their opinions about the criteria's magnitude.

For the decision making problem as mentioned above, a structural hierarchy formed (Fig.2). In the next stage, the pairwise comparison matrix (PCM) formed in which $a_{ii} = 1$ and $a_{ij} = 1/a_i$. (Table2). In the next step relative importance of the criteria's weights were calculated by geometric mean of each row of the PCM (Saaty, 1980a). The obtained geometric means then were normalized and the relative importance weights were extracted.

Evaluation of land suitability:
In the next stage the landfill suitability index (LSI) of every point was calculated by SAW method. It is a widely utilized method for the calculation of final grading values in multiple criteria problems because of its easiness and proportional linear transformation of the raw data (Malczewski, 2004). Considering the following Equation, the LSI for each point is:

$$V_i = \sum_{j=1}^{n} W_j V_{ij}$$

Where $V_i$ is the suitability index for each point i, $W_j$ is the relative importance weight of criterion j, $V_{ij}$ is the grading value of each point i under criterion j, n is the total number of criteria.

## Result and discussion

Municipalities of Mahshahr area are faced with annual increasing in volume of municipal solid waste because of population fast growth. Dumping MSW is one of the main reasons of public health problems and environmental pollutions in this sensitive and strategic area of Iran. Therefore municipalities are looking for suitable places to dispose MSW according to public health and environmental regulations.

Using GIS in landfill site selection as an efficient, precision and powerful tool has been developed in last decades because of saving time and cost by processing a remarkable volume of data in a short time and reducing errors at the same time. Application of GIS in this process faced by some obstacles such as lack of digital maps in desired scales for all necessary elements and uneducated people in solid waste management systems in developing countries including this area(Delgado et al., 2008; Sharifi et al., 2009). For example in the area under study no any map for groundwater because the water table and the Total Dissolved Solids (TDS) are high and it is not used as a water source therefore it was not possible to use this layer in this study. However it is necessary to check these elements through field inspections.

**Table 1: Grading values for the the selected criteria**

| criterion | Base map (Scale) | Buffer zone | Rating | Area (%) |
|---|---|---|---|---|
| Distance to water surfaces | Iranian Cartography Organization ( 1/50000) | > 2500 m | 10 | 80 |
| | | 2000 – 2500 m | 8 | 5 |
| | | 1500 – 2000 m | 6 | 4 |
| | | 1000 – 1500 m | 4 | 4 |
| | | 300 – 1000 m | 2 | 4 |
| | | < 300 m | 0 | 3 |
| Sensitive Ecosystems | Environment Department of Khozestan( 1/100000) | > 2500 m | 10 | 80 |
| | | 2000 – 2500 m | 8 | 4 |
| | | 1500 – 2000 m | 6 | 4 |
| | | 1000 – 1500 m | 4 | 1 |
| | | 300 – 1000 m | 2 | 2 |
| | | < 300 m | 0 | 9 |
| Land cover | Khozestan Natural Resources Head Office ( 1/100000) | Barren land | 10 | 2 |
| | | Rangeland | 8 | 29 |
| | | Dry farming | 6 | 26 |
| | | Irrigated farming | 3 | 41 |
| | | Wetland and forest | 0 | 2 |
| Distance to urban and rural areas | Iranian Cartography Organization ( 1/50000) | > 15 km | 10 | 0 |
| | | 10 – 15 km | 8 | 4 |
| | | 5 – 10 km | 5 | 21 |
| | | 2 – 5 km | 2 | 44 |
| | | < 2 km | 0 | 31 |
| Land uses | Khozestan Natural Resources Head Office ( 1/100000) | Unused lands | 10 | 2 |
| | | Industrial | 8 | 29 |
| | | Agricultural | 4 | 67 |
| | | Tourist area | 2 | 0 |
| | | Residential | 0 | 2 |
| Distance to roads | Iranian Cartography Organization ( 1/50000) | > 3 km | 10 | 31 |
| | | 1.5 – 3 km | 6 | 22 |
| | | 1 – 1.5 km | 4 | 11 |
| | | 300 – 1000 m | 2 | 22 |
| | | < 300 m | 0 | 14 |
| Slope | Iranian Cartography Organization ( 1/50000) | < 10 % | 10 | 99 |
| | | 10 – 20 % | 8 | 0 |
| | | 20 – 25 % | 4 | 0 |
| | | 25 – 45 % | 2 | 0 |
| | | > 45 % | 0 | 1 |
| Soil Type | Iranian Soil and Water Research Institute ( 1/150000) | Land unit 5.6 | 10 | 22 |
| | | Land unit 6.2 | 8 | 13 |
| | | Land unit 5.8 | 5 | 54 |
| | | Land unit 5.1 | 2 | 11 |
| Distance to waste generation places | Iranian Cartography Organization ( 1/50000) | < 2 km | 10 | 1 |
| | | 2-3km | 8 | 4 |
| | | 3-5km | 5 | 14 |
| | | 5-10km | 2 | 60 |
| | | > 10km | 1 | 21 |

According to landfill site selection regulations in Iran and condition of study area, the most important criteria selected. In order to protect the sensitive areas such as sensitive ecosystems, water surfaces and urban and rural areas according to present regulations in Iran, they were removed from the study area through assigning 0 for them during the data preparation stage. The exclusion of certainly unsuitable areas is done by mask operation. To prepare a mask of unsuitable areas, all data layers are multiplied by 0 so that if any pixel has a value of 0 coming from any layer, then the value of that pixel will become 0 which means that the pixel is completely unsuitable as a landfill site(Şener et al., 2006). Table 1 show the grading values that assigned to any criteria base on the opinions of expert's team, regulations of Iran and litreatures.

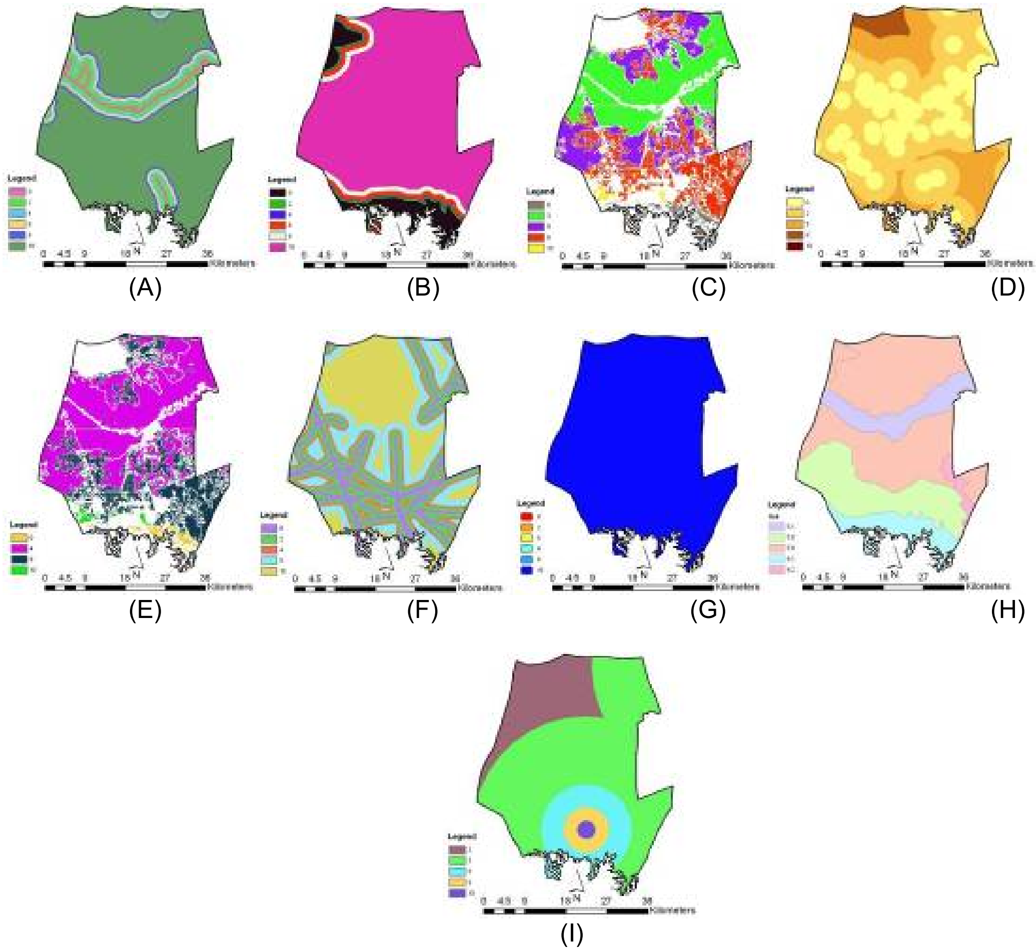


**Fig. 3: A: surface Waters Suitability Index, B: Sensitive Ecosystems Suitability Index, C: Land cover Suitability Index, D: Distance to urban and rural areas, E:Landuse Suitability Index, F: Distance to roads Suitability Index, G: Slop Suitability Index, H: Soil Suitability Index, I: Distance to waste generation places Suitability Index**

The most important part in the siting with AHP is the importance weights for the criteria and the preferred weights for the alternatives. Table 2 shows relative importance (weight) of the criteria used to evaluate suitability of each sites. The results showed that sensitive ecosystems and surface waters are the most important criteria because there are some protected areas such as Shadeghan wetland and Persian Gulf coast. However, slope is the least important criteria because the study area is flat.

The Consistency Ratio (CR) of the PCM is used to indicate the overall consistency of the PCM. This ratio is affected by homogeneity of factors in each group, number of factors in the group, and level of understanding the decision problem (Saaty, 1993). According to Saaty (1980), a CR value less than 10%, indicate consistency of the matrix. For this study, the value of CR was 0.0187. It is less than10%, and indicates consistency of the PCM and a good understanding of decision problem and good homogeneity of factors in any group (Kontos et al., 2005; Saaty, 1980b).

The map of landfill suitability base on SAW method in the study area is shown in Figure 4. The range of the landfill suitability index was between 3 and 7. According to obtained values, landfill suitability of the study area classified to three groups: high suitability (6–7), moderate suitability (5–6) and low suitability (3–5). The results indicate that 67 %, of the study area has low suitability, 19 % has moderate suitability and 14 % has high suitability for a landfill site. This shows the shortage of land suitable for MSW landfill.

**Table 2: Pairwise comparison matrix and relative importance weights of the evaluation criteria**

| Criteria | A | B | C | D | E | F | G | H | I | Weights |
|---|---|---|---|---|---|---|---|---|---|---|
| **A** | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 9 | 0.259267 |
| **B** | 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 9 | 0.259267 |
| **C** | 0.5 | 0.5 | 1 | 2 | 3 | 3 | 3 | 4 | 5 | 0.147988 |
| **D** | 0.33 | 0.33 | 0.5 | 1 | 2 | 2 | 3 | 4 | 5 | 0.106635 |
| **E** | 0.25 | 0.25 | 0.33 | 0.5 | 1 | 2 | 2 | 2 | 4 | 0.071947 |
| **F** | 0.2 | 0.2 | 0.33 | 0.5 | 0.5 | 1 | 2 | 2 | 3 | 0.056883 |
| **G** | 0.16 | 0.16 | 0.33 | 0.33 | 0.5 | 0.5 | 1 | 2 | 2 | 0.04244 |
| **H** | 0.14 | 0.14 | 0.25 | 0.25 | 0.5 | 0.5 | 0.5 | 1 | 2 | 0.033049 |
| **I** | 0.11 | 0.11 | 0.2 | 0.2 | 0.25 | 0.33 | 0.5 | 0.5 | 1 | 0.022524 |

**$\lambda_{max}$ = 9.21, CI = 0.0271, RI9 = 1.45 and CR = 0.0187≤ 0.1.**
**A: surface waters B: Sensitive Ecosystems C: Distance to Settlements D: Soil Type E: Land Uses F: Land Cover G: Distance from waste generation places H: Roads I: Slope**

It must be notice that GIS analysis is not a substitute for field analysis; however, it does identify areas that are more suitable and directs efforts to these areas rather than areas that are unsuitable or restricted by regulations or constraints(Şener et al., 2006). By considering the parameters such as required area for landfill, distance to MSW generation points, wind direction, land ownership, political and management issues and public acceptance, 6 area ( site)(no. 1,2,3,4,5,6) have been chosen for site visiting (Figure 4).

The No.1 and No.2 candidate were rejected because of north-west frequent wind. The candidate of No. 3, 4 and 5 were rejected because of land ownership problems and local people objections. The result of site visiting showed that some parameters such as public acceptance and land ownership are very important in finalizing selected sites but it is not possible to check it by GIS and other available software programs however it can be checked through site visiting. Although using GIS software and hardware have been increased over the last decade in order to consider environmental and technical aspects of landfill site selection but involving public in GIS based decision making process has not been achieved completely(Malczewski, 2004). The area No. 6 selected as the best point for MSW disposal site. The final selected site requires further geotechnical and hydrogeological analyses to obtain design requirements.

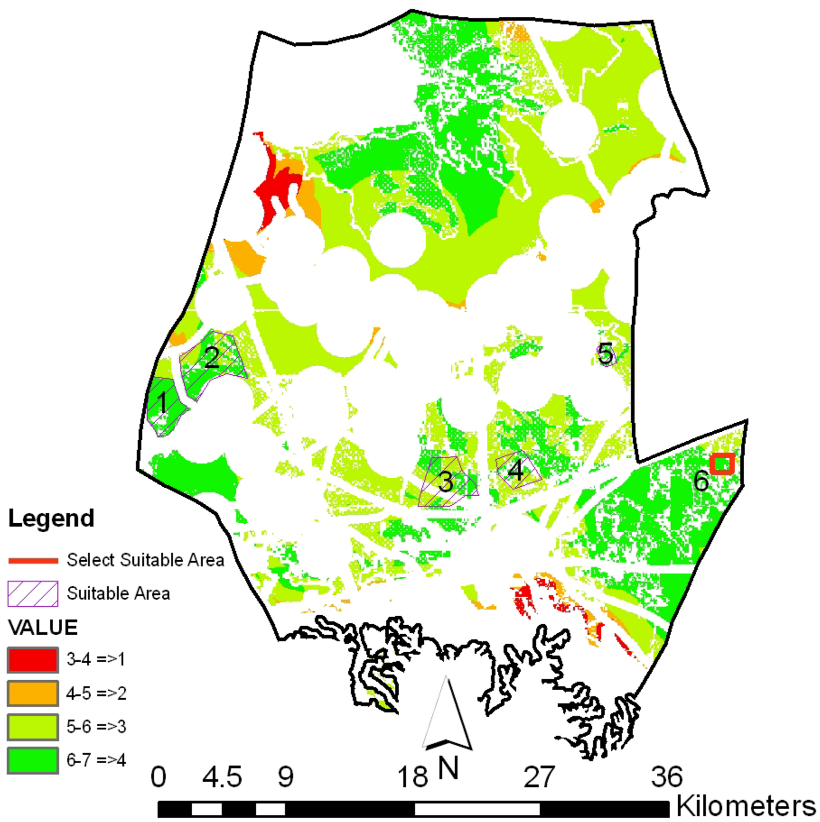


**Figure 4: The selected area for site visiting**

## Conclusions

Finding suitable site for new landfills according to environmental regulation and economical and technical issues is one of the most challenges in developing countries including Mahshahr County in Iran. In order to consider all factors and regulations, we used a combination of GIS and AHP to solve this complicated problem. In attention to condition of study area and regulations, the main criteria were chosen. The relative importance of criteria determined by AHP showed that the most important were sensitive ecosystems and surface water and at least importance was slop. In the next stage the suitability index of every point was calculated by SAW method. About 14% of study area was suitable for landfilling. This showed the shortage of land suitable for MSW landfill.

Six sites were selected for detail investigation and site visiting. The result of site visiting showed that this method is an efficient tool for preliminary screen in a wide area but detail inspections in order to involving public in landfill site selection process and checking unavailable digital data have required yet.

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