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Hazardous Waste Landfill Siting using GIS Technique and Analytical Hierarchy Process

Ozeair Abessi [a] and Mohsen Saeedi [b]

[a] *PhD Candidate, Department of Hydraulics and Environmental Engineering, School of Civil Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran.*
[b] *Department of Hydraulics and Environmental Engineering, School of Civil Engineering, Iran University of Science and Technology, Narmak, Tehran, 16846, Iran.*

Abstract

Disposal of large amount of generated hazardous waste in power plants, has always received communities' and authorities attentions. In this paper using site screening method and Analytical Hierarchy Process (AHP) a sophisticated approach for siting hazardous waste landfill in large areas is presented. This approach demonstrates how the evaluation criteria such as physical, socio-economical, technical, environmental and their regulatory sub criteria can be introduced into an over layer technique to screen some limited appropriate zones in the area. Then, in order to find the optimal site amongst the primary screened site utilizing a Multiple Criteria Decision Making (MCDM) method for hierarchy computations of the process is recommended. Using the introduced method an accurate siting procedure for environmental planning of the landfills in an area would be enabled. In the study this approach was utilized for disposal of hazardous wastes of Shahid Rajaee thermal power plant located in Qazvin province west central part of Iran. As a result of this study 10 suitable zones were screened in the area at first, then using analytical hierarchy process a site near the power plant were chosen as the optimal site for landfilling of the hazardous wastes in Qazvin province.

Keywords: Landfill siting; priority processing; hazardous waste; power plant

1. Introduction

Different types of hazardous solid wastes are generating in industrial areas which should be safely disposed off in the environment. There are various methods such as incineration, immobilization, landfilling, offshore and underground disposal that currently used for the disposal of hazardous waste. Land filling the waste has been the most common way in disposal of residual which still is using all over the world (Komilis *et al*., 1999). It is actually the final and vital step of an effective solid waste plan in an area (Visvanathan, 1996). Despite the intensive efforts in the other methods of disposal, landfills still remain as the essential part of the solid waste management plans in majority of the world. Secure landfilling, the most granted mode of hazardous waste disposal, is the one that is mostly used in developed countries. But in developing and undeveloped countries generally the most part of the hazardous wastes are presently being disposed off in uncontrolled dump sites or municipal solid waste (MSW) landfills. In these countries adverse environmental impacts, public health problems and socio-economic challenges associated with landfills have led to the issuance of stricter regulations and increases in public opposition to the siting of landfills (Ham, 1993). Therefore nowadays, suitable siting of landfills becomes one of the important tasks involved in waste management plans of the developing communities (Tchobanoglous *et al*., 1993). For siting a hazardous waste landfill, extensive evaluation process is needed to be considered to determine the best available site in an area. Large sets of parameters including economic, environmental, socio-ecological and technical and public health costs in the siting of landfills have long been emphasized in the literature (Siddiqui *et al*., 1996; Noble, 1992; McBean *et al*., 1995). Because of the conflicts involved amongst the parameters the landfill siting procedure has always been a complicated process (McBean *et al*., 1995; Kontos *et al*., 2003). To ensure the acceptable outcome by governmental environmental protection agency and stakeholders, maximum use of the available information and management tools were emphasized in the studies (Dorhofer and Siebert, 1998; Gomez-Delgado and Tarantola, 2006).

Several techniques for landfill siting and site selection have been introduced earlier (Balis *et al*., 1998; Yagoub and Buyong, 1998; Herzog, 1999; Lukasheh *et al*., 2001; Gomez-Delgado and Tarantola, 2006, Sener *et al*., 2006, Sumathi *et al*., 2008, Zamorano *et al*., 2008). These techniques utilize geographic information systems (GIS) for initial screening of the study area. The techniques are binary, since the final result discriminate the study zone in limited numbers of suitable/unsuitable areas (Yesilnacar and Uyanvk 2005). There are some other techniques which utilize Multiple Criteria

Analysis (MCA) and GIS together (Lin and Kao, 1998; Allen *et al*., 2002; Kontos and Halvadakis, 2002) or Multi Criteria Decision Analysis (MCDA) method and GIS for optimal landfill siting within an area of study (Hipel, 1982; Vuk *et al*., 1991; Hokkanen and Salminen, 1994; Siddiqui *et al*., 1996; Hokkanen and Salminen, 1997; Chenga *et al*., 2003, Kontos *et al*., 2005; Chang *et al*., 2008). In all these studies GIS was generally used to manipulate and present spatial data, while the MCDA was used to rank potential landfill areas based on more important involved criteria.

In fuel oil burning thermal power plants, low volume but highly polluted hazardous wastes are usually generated (e.g. air heater washing sludge waste, boiler tubes chemical washing sludge, furnace bottom ash) that should be disposed off in specific safe landfills (Saeedi and Amini, 2007). Siting the suitable landfill for these types of waste is one of the main environmental problems in thermal power plants. In the present study a scientific effort is made to locate the best Hazardous Solid Waste (HSW) landfill site for the disposal of the wastes generated in Shahid Rajaee thermal power plant, west central of Iran. A methodology with the combined utilization of GIS and Analytic Hierarchy Process (AHP) has been used to find the best site. Geographic information system was used to highlight some limited number of sites within the large study area, the sites that entirely fulfill all the dominated standards and considerations. The evaluation criteria are determined based on practical guidelines, Iran national regulations and standards and international practice in landfill siting (Savage *et al*., 1998; Al-Jarrah and Abu-Qdais, 2006; Iran Department of Environment, 2006; New Zealand Ministry for the Environment, 2004). AHP as one of the most popular approach in Multiple Criterion Decision Making methods (MCDM) were here used to determine the optimal site among the selected alternatives. Based on mathematics and human psychology, analytical hierarchy process method was developed by Thomas L. Saaty in the 1970s (Gal *et al*., 1999). The applications of AHP in complicated situations introduced it as a strong tool for working out the problems involving alternative selection, planning and resource allocation (Chang *et al*., 2008, Gomez-Delgado and Tarantola, 2006). The computational steps of AHP have long been described in the literature (Cheng and Li, 2002; Gal *et al*., 1999; Omkarprasad and Kumar, 2006; Saaty, 1980; Saaty, 2008; Saaty and Millet, 2000; Safir *et al*., 2007). The utilization of spatial analysis processes and using localized evaluation criteria in the landfill siting process besides using a sophisticated management tool is the innovation of this study which provides some more efforts in optimal siting of the landfills.

2. Material and Methods

2.1. Study area and the waste characteristics

In this study landfill siting was conducted within the province of Qazvin which located at western central part of Iran 100 km off Tehran (Fig. 1). The province is limited to Mazandaran and Gilan province from north, Hamedan and Zanjan from west, Markazi province from the south, and Tehran from the east. Qazvin plateau, the main part of the province, is bounded by Alborz, Rameneh, and Kharghan mountains. Total area of the province is 15821 km^2 and the agricultural and industrial applications are the main land uses within it.

Shahid Rajaee power plant, the only thermal power plant of the province, is located at 25 km east of Qazvin (capital of the province) and has power generation capacity of 1000 MW consisting four 250 MW natural gas and fuel oil burning units. The hazardous solid wastes of the power plant (20 tones/year) consist of furnace bottom ash residuals and the dried sludge of waste water treatment plants contain considerable amounts of heavy and other hazardous metals such as V, Ni, Zn, Cr, Cu, Pb, Cd, Sn and Hg (Saeedi and Amini 2007a, b; Saeedi and Rezaei Bazkiaei, 2008) which have to be disposed off in a safe HSW landfill. The mentioned waste typical contents of metals are presented in Table 1.

2.2. GIS maps and evaluation criteria

In siting projects using GIS, the factors' related spatial data (maps, aerial photographs, satellite images) and quantitative, qualitative and descriptive information are visually integrated in order to present a community understandable outline (Tchobanoglous *et al*., 1993). In the current study in order to find suitable zones for hazardous waste land filling in the study area a GIS-aided methodology is developed to assimilate evaluation criteria with the spatial data. The criteria that used for the suitability analysis were grouped into four main categories including physical, environmental, social-economical and technical information. Topography, soil and geological characteristics and climate feature of the area are the sub-criteria that chosen as the physical parameters, vegetation maps, surface and ground water characteristics, specific environmental zone (protected areas) and residential zones features are the sub criteria of environmental criteria, accessibility, distance to water resources and residential areas are also the sub criteria of social- economical criteria and applicability and waste transport facilities are the sub criteria of the technical criteria that each contains series of individual maps and qualitative information (Table 2).

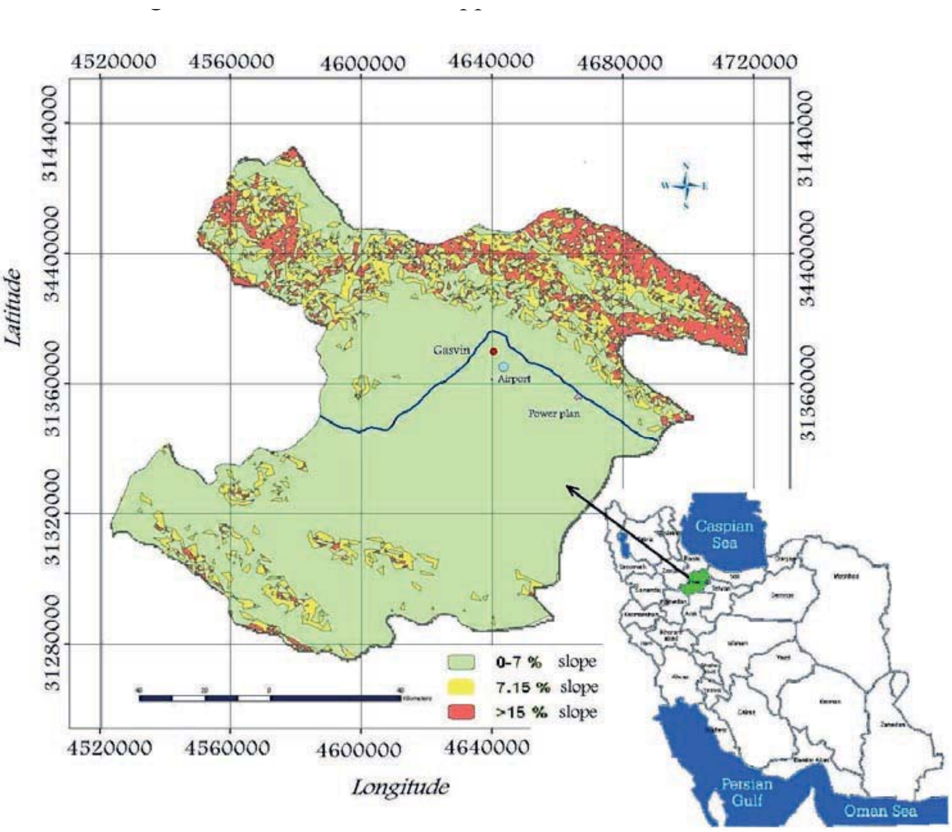

Figure 1. Location of Qazvin province and land slope characteristics of the area

In this study the over layer technique used to prepare the final site selection map. This technique is an approach that utilized various features of the zones to make joint comparison of maps possible. In this technique the separated information layers are superimposed on each other to form an integrated digital geo-database. In the current study to develop the GIS database of the study area the large varieties of maps in various scales were used as the information layers. The spatial clustering process which is used here consists of the following steps:

(a) Development of a digital GIS database including all information in 1:250,000-scale maps

(b) Development of a digital GIS database including detail information of primarily selected zones in 1:25,000-scale maps

For screening of the study area, political segmentation map, maps of mine and industrial zones, maps of residential area and archeological sites, map of specific environmental zones (protected areas), vegetation map, road and rail road maps, topography and land slope map, geology and soil characteristics map, groundwater and surface water maps, depth of groundwater, isothermal and iso-height maps, land use maps, maps of channel and wetland location, maps of major infrastructure facilities, seismic activity map and highway and airport location maps in the mentioned scales were extensively used. At first phased, based on available 1:250,000 scale information layers and using zonal screening techniques the large study area reduced (entire province), to manageable number of discrete zones. Considering the involved criteria and sub criteria these zones are

Table1. Mean concentration of heavy metals in wastes of Shahid Rajaee thermal power plant (ppm) (Saeedi and Amini 2007a; b; Saeedi and Rezaei Bazkiaei, 2008)

Waste type	Cu	Cd	Cr	Ni	Zn	Fe (%)	Pb	V
Residual bottom ash of furnaces	111.6	0.8	532.4	6775.4	310.2	18.67	151	29644
dewatered sludge of chemical washing waste water treatment	360	0.8	454.4	9127.4	646	15.95	192.4	31244
Dewatered residuals of water treatment plant	2.26	0.7	10	13.1	22.4	0.21	2.1	-

Table 2. The criteria and sub criteria used in development of GIS database

Criteria	Sub criteria
Physical Criteria	Topography Soil and geology characteristics Climate
Environmental Criteria	Vegetation maps Surface and ground water characteristics Specific environmental zone Residential zones
Social- Economical Criteria	Accessibility Distance to residential areas Distance to water resources
Technical Criteria	Applicability Waste transport

the areas that satisfy all dominated considerations. Some of the considerations involved in primary phase of screening are presented in Table3.

3. Results and Discussion

Taking into account the mentioned considerations the province was screened for potential landfill sites. Suitability of sites was classified into three categories; weak, normal and appropriate. Potential landfill sites in terms of suitability within the province are illustrated in Fig. 2. At last three different zones which contained appropriate sites within the province were determined for more detailed evaluations and analysis. The three mentioned zones called Abyeck, Takestan and Khoramdasht are shown in Fig. 3. In the next phase, on the basis of 1:25,000 scale maps, selected search areas providing scaled information layer were evaluated in details. Further more the detailed information of the criteria, Iran national related environmental regulations and standards were entirely considered in this phase (Table 3). Finally, based on minimum needed volume for landfill 10 sites in the predetermined zones were identified for hazardous solid waste land filling. Seven candidate sites in one of the mentioned zones are illustrated in Fig. 4. The characteristics of all ten selected alternative sites are also presented in Table 4. Determining the best site for land filling the residual in an area is the final aim of any landfill siting study which proceeds through decision making process below.

Table 3. Some of the evaluation criteria involved in the first phase of screening

No	Consideration
1	The area has to be 500 meters far away the fault
2	The area has to have minimum 1000 meters distance from mines and local industries
3	The area has to be 500 meters far away the forest and garden
4	The area has to be 1000 meters far away the wetland and rivers branches
5	The area has to be 2000 meters far away from the streams
6	The area has to be 3000 meters far away the national parks
7	The area has to be 2000 meters far away the wild life refugees
8	The area has to be 1000 meters far away the protected areas
9	The area has to have minimum 2000 meters distance from cities
10	The area has to have minimum 1500 meters distance from villages and any residential communities
11	The area has to be 300 meters far away from roads
12	The area has to be 500 meters far from high ways
13	The area has to be 500 meters far away the rail roads

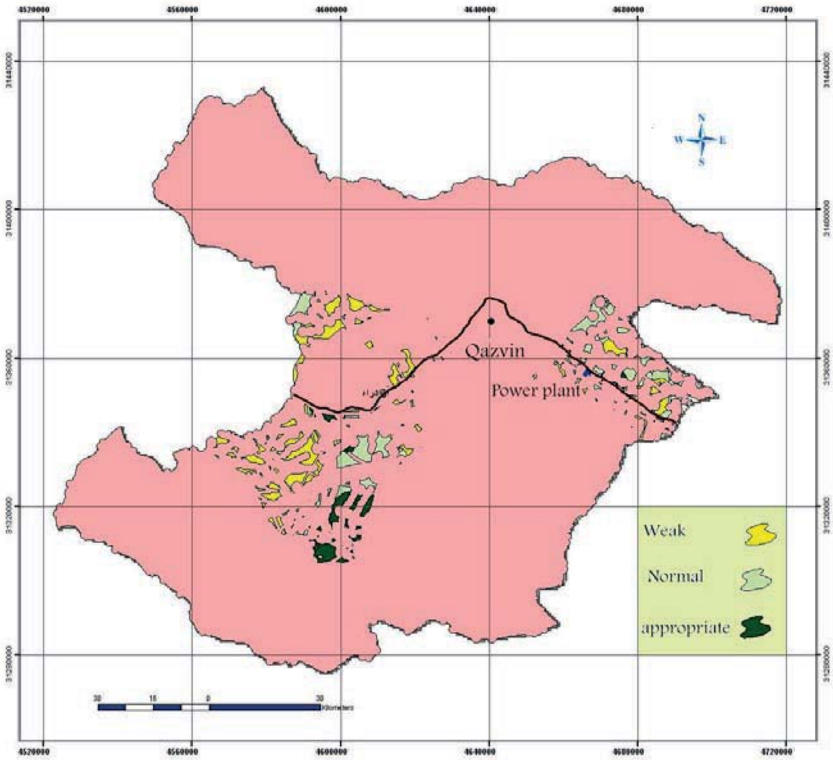

Figure 2. Determined sites within the study area in terms of suitability

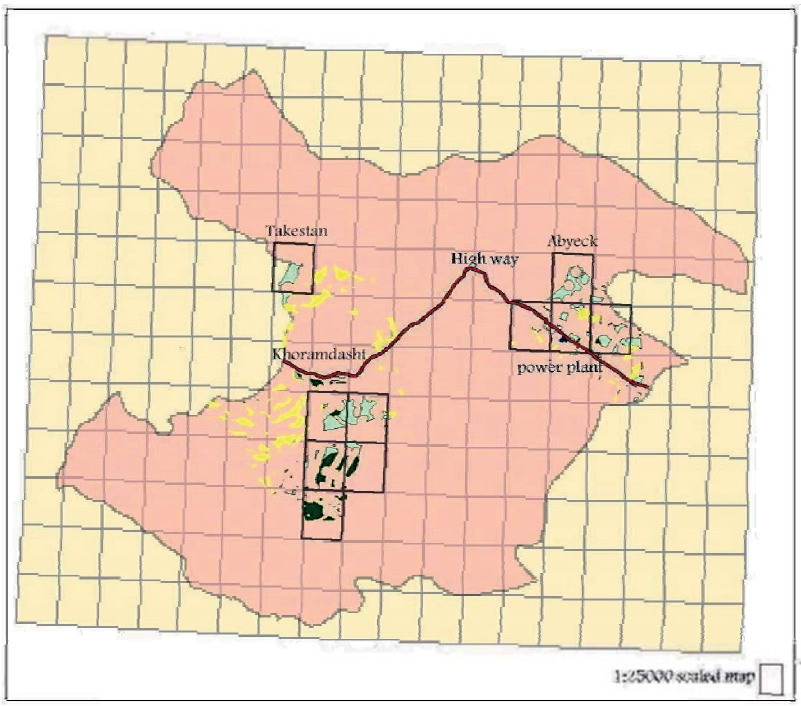

Figure 3. Ten sheet maps in 125,000 scale that considered for more detail studies

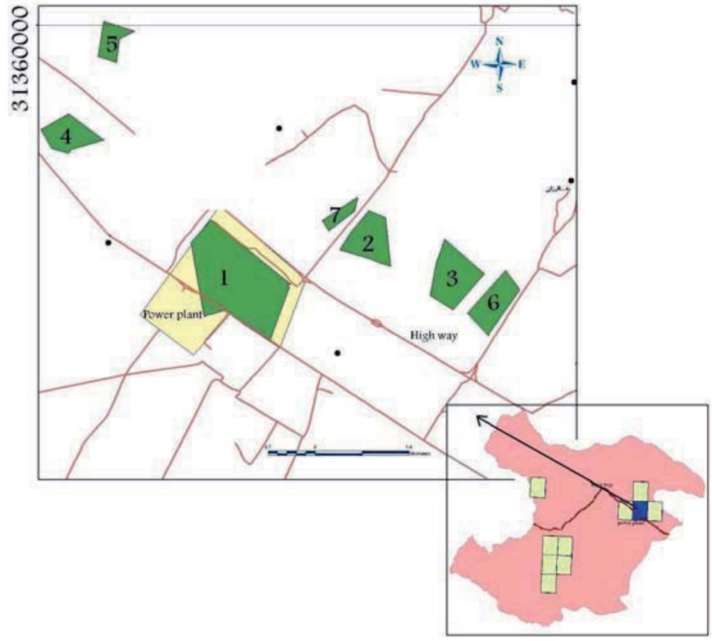

Figure 4. Seven candidate landfill sites in Abyeck zone

3.1. Optimal site

In the present study AHP as an efficient method for solving the multi objective decision-making problems was used to locate the optimal landfill site between primary selected zones. As the alternatives in hierarchy process ten screened sites in the first phase which satisfy all involved considerations and standard were utilized. Seven criteria (within the used sub criteria) that nominated by the local authorities as the more important parameters in the study area were selected in AHPcomputations. These criteria include depth of ground water level, soil type, distance from residential area, land slop, ease of ownership, distance from waste generation source and distance from sensitive environmental areas. In the present study, in order to distinguish the more important factors from the less important ones pairwise comparison method was employed. Through a sequence of calculations some matrixes of the selected criteria created to achieve the relative importance weights of the alternatives. In the process the vector of priorities (eigenvector) is also calculated for each paired matrix. Two developed matrixes for calculation of relative weight in each criterion and sub criteria are presented as example in the equation (1) and (2);

$$D_{7\times7}=\begin{bmatrix} 1 & 1.5 & 1 & 3 & 0.75 & 0.75 & 1.33 \\ 0.67 & 1 & 0.67 & 2 & 0.5 & 0.5 & 0.5 \\ 1 & 1.5 & 1 & 3 & 0.75 & 0.75 & 0.75 \\ 0.33 & 0.5 & 0.33 & 1 & 0.25 & 0.25 & 0.25 \\ 1.33 & 2 & 1.33 & 4 & 1 & 1 & 1 \\ 1.33 & 2 & 1.33 & 4 & 1 & 1 & 1 \\ 0.75 & 2 & 1.33 & 4 & 1 & 1 & 1 \end{bmatrix} \xrightarrow{normalize} \begin{bmatrix} 0.16 & 0.14 & 0.14 & 0.14 & 0.14 & 0.14 & 0.23 \\ 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.1 & 0.09 \\ 0.16 & 0.14 & 0.14 & 0.14 & 0.14 & 0.14 & 0.13 \\ 0.05 & 0.05 & 0.05 & 0.05 & 0.05 & 0.05 & 0.04 \\ 0.21 & 0.19 & 0.19 & 0.19 & 0.19 & 0.19 & 0.17 \\ 0.21 & 0.19 & 0.19 & 0.19 & 0.19 & 0.19 & 0.17 \\ 0.12 & 0.19 & 0.19 & 0.19 & 0.19 & 0.19 & 0.17 \end{bmatrix} \xrightarrow{rowmean} W_1=\underset{\overline{0.16}}{\begin{bmatrix} 0.16 \\ 0.1 \\ 0.14 \\ 0.05 \\ 0.19 \\ 0.19 \\ 0.18 \end{bmatrix}} \quad (1)$$

$$D_2=\begin{bmatrix} 1 & 2 \\ 0.5 & 1 \end{bmatrix} \xrightarrow{normalize} \begin{bmatrix} 0.67 & 0.67 \\ 0.33 & 0.33 \end{bmatrix} \xrightarrow{meanrow} W_2=\begin{bmatrix} 0.67 \\ 0.33 \end{bmatrix} \quad (2)$$

Table 3. Iran environmental legislation on landfill siting

No	Criteria
1	Minimum 1000 meters distance from any lake, pool, wetland, protected areas and national parks
2	Minimum 200 meters distance from any stream, river and water source
3	Minimum 1000 meters distance from residential zones
4	Minimum 3000 meters distance from cities boundary
5	Minimum 150 distance from any passage, roads and highways
6	Minimum 500 meters distance from any clinic, hospital and health care center

T able 4. Ten primary selected sites in Qazvin province that identified using GIS-aided landfill siting

Land fill number	Longitude	Latitude	Altitude (m)	Distance form main road	Rang of slope (%)	Area (ha)	Depth of groundwater table	Geology character
1	50°17′39″	36°09′33″	1285	150	0-3	148	60-120	Alluvial fan
2	50°18′56″	36°09′57″	1325	600	0-3	37	60-120	Alluvial fan
3	50°19′46″	36°09′38″	1325	700	0-3	46	60-120	Alluvial fan
4	50°20′11″	36°09′26″	1330	700	0-3	34	60-120	Alluvial fan & tuff
5	50°18′39″	36°10′07″	1330	700	0-3	92	60-120	Alluvial fan
6	49°34′32″	35°50′15″	1450	3000	0-3	83	60-120	Alluvium terrace
7	49°36′53″	35°55′59″	1310	6000	0-3	24	45-60	Alluvial fan
8	49°34′04″	35°49′42″	1470	4000	0-3	28	60	Alluvium terrace
9	49°26′34″	36°17′44″	1890	2000	3-7	25	45-60	Igneous rock
10	49°26′21″	36°16′34″	1770	1000	3-7	1.6	45-60	Igneous rock

For each mentioned criterion the relative weights were similarity obtained as follows:
$W_1 = 0.16$, $W_2 = 0.1$, $W_3 = 0.14$, $W_4 = 0.05$, $W_5 = 0.16$, $W_6 = 0.19$, $W_7 = 0.18$,
Finally, when the criteria were weighted, the information was inserted into the model. Relative scores for each choice were computed within each leaf of the hierarchy. Scoring was on a relative basis, comparing one choice to another. The local priority weights of all main criteria and sub-criteria were first calculated then combined with all successive hierarchical levels in each matrix to obtain a global priority vector. The higher the mean weight of global priority vector, the greater relative importance is. This helps to distinguish the more important elements from the less important ones. In this study, using pairwise comparison to calculate the weight of global priority vector in 10 mentioned sites, the site number 1 have received the greatest relative importance. The weight of global priority vector for site 1 and 2 are shown as equations (3) and (4).

$$W_{sit1} = (0.16 \times 0.5)+(0.1 \times 0.67)+(0.14 \times 0.75)+(0.05 \times 0.67)+(0.19 \times 0.8)+(0.19 \times 0.85)+(0.18 \times 0.75) = 0.729 \quad (3)$$

$$W_{sit1} = (0.16 \times 0.5)+(0.1 \times 0.33)+(0.14 \times 0.25)+(0.05 \times 0.33)+(0.19 \times 0.2)+(0.19 \times 0.142)+(0.18 \times 0.25) = 0.27 \quad (4)$$

3.2. Assessing Inconsistency

The consistency test is one of the essential features of the AHP method which aims to eliminate the possible inconsistency revealed in the weights through the computation of consistency level of each matrix (Saaty, 2000). The consistency ratio (CR) is developed to determine and justify the inconsistency in the pairwise comparisons made by the respondents, or to screen out the inconsistency of responses (Saaty, 2000). Saaty (1980) and Cheng and Li (2001) have set the acceptable CR values for different matrix's sizes. For large matrices (over 5×5) the CR value is equal to 0.1. If the CR value in these matrixes is lower than the acceptable value, the weight results are valid and consistent. The consistency ratio was calculated through following steps (Cheng and Li, 2001):
(1) Calculation of the relative weights and maximum relative weights (λmax) for each matrix of order n.
(2) Computation of the consistency index for each matrix of order n by the formula:

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

(3) The consistency ratio was then calculated using the formulae:

$$IR = \frac{CI}{CRI}$$

Where RI is a known random consistency index.
Considering calculated consistency ratios of the matrixes and comparing them with acceptable CR values all the weight results were lower than 0.1. Therefore pairwise comparisons are valid and consistent and there is no need to recheck.

4. Conclusions

In this paper, a multi-criteria approach based on GIS screening maps and multiple criteria decision making for solving a hazardous waste landfill siting problem in an important province of Iran is presented. Using this method an accurate scientific siting procedure for disposal of the generated waste in the huge area of Qazvin platuea had been made possible. This technique as a practical approach considers the resources availability and explains clearly the analysis and results in an easily understandable format. In the approach using available information and considering national regulations and standards an acceptable outcome has been guaranteed for the local environmental agency. Utilizing two independent steps of screening on the basis of local characteristics and legislations is the main trait of the current study that could be improved in further studies. The proposed method might future be used and tested for more general conditions and locations where the intensity of introduced parameters shows discrepancies. Other management tools can also be used to reflect decision maker's local subjective preferences which will result in more process- inefficiency.

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Correspondence to
Mohsen Saeedi
Department of Hydraulics and Environmental Engineering,
School of Civil Engineering,
Iran University of Science and Technology,
Narmak, Tehran,
16846, Iran
Email: msaeedi@iust.ac.ir