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Industrial landfill site selection using Analytical Hierarchy Process (Case study: Razi industrial town of Isfahan-Iran)

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ABSTRACT

Suitable landfill site selection is a significant step in the integrated management of solid waste. Because of some dangerous industrial waste, landfill site selection is more important. The selection process should be considered different criteria. The purpose of this study was to determine the appropriate location of industrial waste landfill Razi complex by using Analytical Hierarchy Process (AHP). In this study, three locations were proposed as site of landfill. Socio-economic (such as distance of industries, availability, cost of site preparation and access to soil cover) and physical factors (for example: dominant wind direction, soil permeability and ground-waters flow direction) were considered in the decision process. The Super Decisions software used to develop decision-making process. Based on the results, "2nd alternative"(mountain of Fish Pool) that is the current landfill site of Razi industrial town with a score of 0.593, based on software output, was chosen as the best alternative for disposal of Razi industrial wastes of Razi town-Isfahan. Inconsistency rate in this study, 0.039 was obtained.

Key words: Industrial waste, Analytical Hierarchy Process, Razi Industrial complex, landfill site selection

Introduction

The growth of urban population, municipal various activities and the continued discharge of wastes in the environment, affected the quality of human health. [1,2] Waste production, is a one of the most important sources of threats to health and the global environment. The aim of the design and implementation of solid waste management system, is contributing to health and welfare of citizens. At present, landfilling is the most important of solid waste management method in many countries, including Iran. [2,3] Application of landfill method, compared to other methods due to low cost and simplicity of management, is popular in the many countries.The landfill is an unavoidable part of solid waste management system. To select a suitable site for landfill is required special investigations. Finding a suitable site to dispose solid waste is a difficult task for municipality because it is necessary to consider the different factors and criteria in the landfill siting process. Often all important deleterious effects that appear during the environmental impact assessment should be considered during the site selection process. Locating of landfill site, properly, can eliminate worries in the landfill issues. Important factors in locating of landfill sites are site topography and geology, region hydrology, climate, needed land, soil cover, groundwater level, the position of urban development, waste characterization, adjacent lands use, distance from surface water, the price

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of land and landfill lifetime. [2-4] Landfill like any other engineering project requires precise planning and basic information. Selection of multiple factors led to a multiplicity of layers of information and trying to find a solution for the analysis on a large number of data layers and obtaining the correct result, it causes, the decision makers subconsciously pushed toward the system that have high speed and simplicity.[4] Among the models of decision-making, the Analytical Hierarchy Process (AHP) is used by various experts.

Theoretical Principles of Analytical Hierarchy Process (AHP)

Multiple criteria decision making (MC DM) is a generic term for all methods that exist for helping people making decisions according to their preferences, in cases where there is more than one conflicting criterion. Multi-Criteria Decision Analysis (MCDA) is a set of analytical methods that help to decision-makers in solving complex problems and uses decision-makers information to solve these issues. There are different approaches for multi-criteria decisions, depending on the various issues can be successful. Analytic Hierarchy Process (AHP) is a decision-making method is used to determine the relative importance of criteria in a certain decision-making problem. One of the fundamental steps in any issue with multi-criteria is accurate estimation of related data. AHP is based on the comparison of pairs, used to determine the relative importance of each criterion. This method with a network system, uses various indices and criteria for ranking or determining different alternatives importance a complex decision-making process. The ability to analyze a decision-making issue with a classification structure is basic infrastructure in AHP.[5-7] AHP is one of the most comprehensive systems designed for decision-making with multiple criteria, because this technique formulates the problem as hierarchical, as well as provides a quantitative and qualitative comparison. This process is used different alternatives in decision making and sensitivity analysis on criteria and sub criteria is possible in this method. In addition, this method is based on pair-wise comparison and facilitates the judgment and calculations. As well as it shows the compatibility and incompatibility of decisions that is the benefit of multi-criteria decision-making technique and is based on strong theoretical axioms. [7-11]

Hendrix et al. evaluated landfill site selection of Vermont in America in terms of physical and economic indicators. [11] Govinda et al. in 2009 with regard to environmental and economic factors and using AHP and GIS, determined places to landfill of Beijing in China.[12] Kamyabi et al. in 2012 conducted a study on landfill site selection of Semnan industrial zone (in Iran) based on analytical hierarchy process using some criteria such as: geomorphology, hydrology, environmental, land uses, etc., with an emphasis on issues of geomorphological. [13]

Ghaed Rahmat et al. evaluated landfill site selection of Behbahan using GIS and AHP. For the purpose of making decisions in landfill site selection a hierarchy structural was formed and different parameters have been identified, including distance to groundwater, distance to surface water, sensitive ecosystems, land cover, distance to urban and rural areas, land uses, distance to roads, slope, soil type and distance to waste generation places. [14]

The aim of this study was to determine suitable location for industrial waste landfill of Razi industrial town of Isfahan, according to the analytical hierarchy and decision-making processes. In all studies, engineering and economic parameters for locating landfills are major parameters. In this study also, the parameters that have a greater impact on the selection of landfill sites are selected. Due to the extent and breadth of industries located in the town of Razi, it is essential that a suitable site for landfill the industry be selected.

Materials and Methods

The geographical location of Razi industrial town, Isfahan-Iran

This town is located on the 56 km of Isfahan-Shahreza road (figure 1). The town has an area of approximately 1000 hectares and it is the largest industrial town in Isfahan-Iran. The Razi town is located in the approximate position of 32̊ 12́ 30˝ north latitude and 51˚ 49́ 28˝ east longitude. Since the majority of located industrial units in this town, are the chemical industry, the Razi town is very important from the environmental point of view. Figure 1 shows the geographical location of the Razi industrial town. Based on field visit, three locations proposed as alternatives for waste landfill. Figure 2 shows a satellite image of the proposed alternatives.

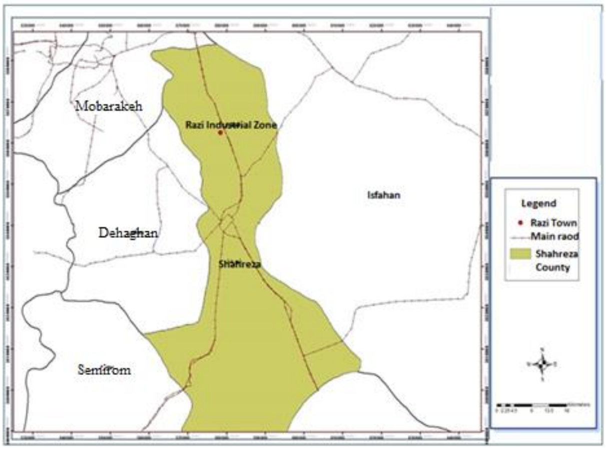


Fig.1 The geographical location of Razi industrial town

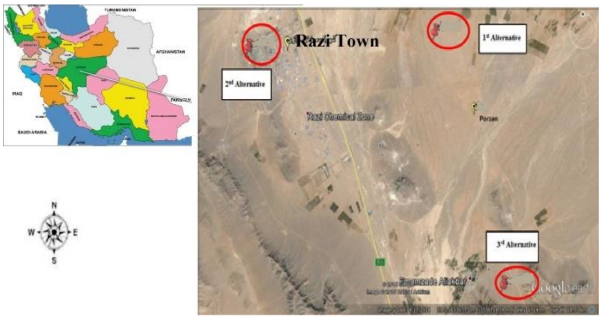


Fig.2 The satellite image of the proposed sites for landfill

In figure 2 a spot on the map as the "1st Alternative" with geographical coordinates $32^{\circ}\ 12'\ 46.2''$ north and $51^{\circ}\ 54'\ 9.7''$ eastward, a point with geographical coordinates $32^{\circ}\ 12'\ 30.7''$ north and $51^{\circ}\ 48'\ 1.4''$ eastward as a "2nd Alternative" and a point with geographical coordinates $32^{\circ}\ 07'\ 35''$ north and $51^{\circ}\ 56'\ 07.7''$ eastward is considered as the "3rd Alternative".

Developing a hierarchical structure for locating landfill

Developing a hierarchical structure is the most important stage for locating landfill. Hierarchical structure is the graphical representation of a complex problem that general purpose of the issue is placed on top and the next levels includes criteria, sub-criteria and alternatives. Hierarchical structure, criteria and sub-criteria considered for selection of the preferred option has been shown in Figure 3.

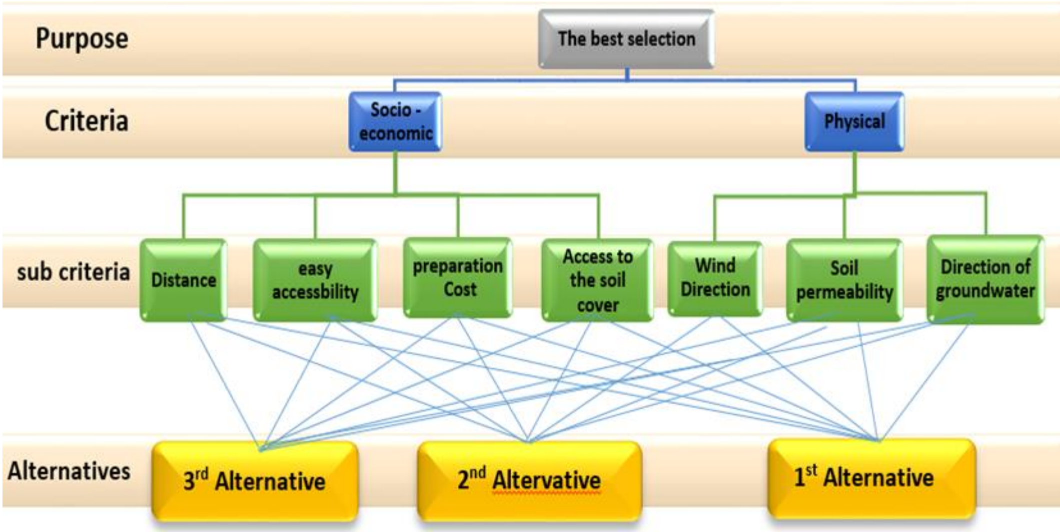


Fig. 3 Hierarchical structure for selection of the preferred alternative

Weighting the factors affecting to the location of the landfill

In the hierarchy Analysis, the greatest weight given to layer that has the greatest impact in determining the target. In other words, weighting criteria to each data unit is based on the role that it plays inside the layer. Table 1 shows weighting to criteria and factors based on the preference through pair-wise comparison.

Table 1 Weighting factors based on the preference through pair-wise comparison[5]

Preferences	Value
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1
Preferences between strong distances	2,4,6,8

Preparation of normalized matrix (R) and calculation of the weight vector (W) of criteria and options

For this purpose, we need to sum together the values of each of the columns of the pair-wise comparison matrix and the amount of each element in the pair-wise comparison matrix divided to sum total of same column so that the pair-wise comparison matrix be normalized (Equation 1). The average of the elements in each row of the normalized matrix will be calculated and the weight vector of parameters is created. (Equation 2).

$$r_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \qquad (1)$$

$$W_i = \frac{\sum_{i=1}^{n} r_{ij}}{n} \qquad (2)$$

In this equations **m:** the number of matrix columns, **n:** number of matrix rows, $\mathbf{a_{ij}}$**:** pair-wise comparison matrix elements and $\mathbf{r_{ij}}$**:** normalized matrix elements for option i and j index and $\mathbf{W_i}$**:** Weight of option i is expressed.

Determine priorities and preferences

At this stage, with the integration of coefficients, is determined the final score of the each alternative. To do this step, is used hierarchical combination principle that leads to priorities vector by taking all judgments at all levels of the hierarchy. In other words, the final weight of the proposed alternatives is calculate based on Equation 3.

$$V_H = \sum_{k=1}^{n} W_k(g_{ij}) \qquad (3)$$

In this equation, $\mathbf{V_H}$**:** The final score of option j, $\mathbf{W_k}$**:** weight each criterion and $\mathbf{g_{ij}}$**:** weight of alternatives associated with criteria.

Calculating the compatibility or incompatibility of system

To calculate the compatibility rate, must be multiplied pair-wise matrix (A) in the weight vector (W) to obtain a good approximation of λmax W (ie A * W = λmax *W).

By dividing the value of λmax* W by W, is calculated the largest amount of special vector (λmax) (Equation 4) then the average λmax and inconsistency index value can be calculated through the following equation (Equation 5).

$$I.I. = \frac{\lambda max - n}{n-1} \qquad (4)$$

$$I.R. = \frac{I.I.}{I.I.R.} \qquad (5)$$

Which I.R. or C.I is the consistency index. I.I.R also will be extracted from Table 2:

Table 2 I.I.R value for calculation

N	1	2	3	4	5	6	7	8	9	10
I.I.R	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

If the inconsistency rate was less than or equal to 0.1, compatibility is acceptable and if it is greater than 0.1, it is better that decision maker reconsider in itself judgments. For these purposes, the Super Decisions software was used. Super Decisions is decision-making software which works based on two multi-criteria decision making methods. Super Decisions implements the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP). It has been used in many research and practical fields such as manufacturing, environmental management, aviation, small hydropower plants and agriculture. [5] Information needed to assess the environmental parameters were collected from Isfahan Industrial Estates Company.

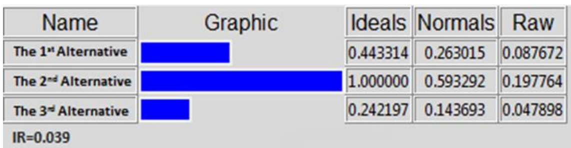
Results and Discussion

The results of the weighting factors, the pair-wise comparison matrix and the relative importance of the criteria, normalizing the factors affecting the location of landfill in the study area, the weight vector and the rate of incompatibility has been shown as Tables 3 , 4

Table 3 The pair-wise comparison matrix of indicators

Parameters	**The choices**			**Special Vector**
	The 1st Alternative	The 2nd Alternative	The 3rd Alternative	
1. Distance				
The 1st Alternative	1	1/9	3	0.129
The 2nd Alternative	9	1	9	0.808
The 3rd Alternative	1/3	1/9	1	0.062
2. Wind Direction				
The 1st Alternative	1	1/5	1/3	0.105
The 2nd Alternative	5	1	3	0.637
The 3rd Alternative	3	1/3	1	0.258
3.Preparation cost				
The 1st Alternative	1	1/7	5	0.173
The 2nd Alternative	7	1	9	0.772
The 3rd Alternative	1/5	1/9	1	0.054
4.Easy Availability				
The 1st Alternative	1	1/9	3	0.129
The 2nd Alternative	9	1	9	0.808
The 3rd Alternative	1/3	1/9	1	0.062
5.Access to the soil cover				
The 1st Alternative	1	1/7	5	0.173
The 2nd Alternative	7	1	9	0.772
The 3rd Alternative	1/5	1/9	1	0.054
6.Soil permeability				
The 1st Alternative	1	3	5	0.637
The 2nd Alternative	1/3	1	3	0.258
The 3rd Alternative	1/5	1/3	1	0.105
7.Direction of groundwater				
The 1st Alternative	1	7	1	0.487
The 2nd Alternative	1/7	1	1/5	0.078
The 3rd Alternative	1	5	1	0.435

According to inconsistency rate that was less than 0.1 as a result matrix compatibility of criteria is acceptable. Finally, based on Super Decisions output (Fig 4) the "2nd alternative" was chosen as the best place to landfilling of wastes.



Name	Graphic	Ideals	Normals	Raw
The 1st Alternative		0.443314	0.263015	0.087672
The 2nd Alternative		1.000000	0.593292	0.197764
The 3rd Alternative		0.242197	0.143693	0.047898

IR=0.039

Fig. 4 Super Decisions software output

Table 4 Weight vector and inconsistency rate

IR=0.039	Distance	Preparation cost	Easy Availability	Access to the soil cover	Wind Direction	Soil permeability	Direction of groundwater	weight vector
Distance	1	0.2	0.2	0.25	0.2	3	0.33	0.0616
Preparation cost		1	5	1	0.5	1	5	0.18
Easy Availability			1	0.33	0.2	0.143	2	0.0745
Access to the soil cover				1	5	5	7	0.314
Wind Direction					1	4	3	0.205
Soil permeability						1	1	0.107
Direction of groundwater							1	0.0575

According to field surveys, in the beginning year of the project (2015), total industrial waste of Razi town was 24452.7 tons per year. Considering the plan period of 20 years and activation of all industries located in the town at the end of the project (year 2035), the total the cumulative production of waste 872310.6 tons was calculated (table 5).
According to studies, we considered the specific gravity of compacted waste in the landfill to 933 Ib/ yd ^{3} (550.5 kg/m^3), as a result needed volume to landfill of 872310.6 tons of industrial solid wastes, 1584578.7 m^3 was calculated. If the soil cover to volume of waste ratio be considered amount of industrial solid waste production 157785.4 tons was calculated. If industries located in Razi town launch based on annual increase as a result, solid waste production rate is calculated increase cumulatively .As a result,

1/5, as a result, the final volume of landfill equal to 1901494.4m^3 was estimated. Depth of compacted waste in the landfill was considered 6 m, therefore, 32 hectare land required at the end of the project.
According to existing standards as well as the type and amount of waste generated in the town, it necessary designing a suitable place for

Table 5 Total waste production

Year	2015	2017	2019	2021	2023	2025	2027	2029	2031	2033	2035	Cumulatively
Waste amount	24452.7	37786	51119.3	64452.6	77785.9	91119.2	104452.5	117785.7	131119	144452.3	157785.4	872310.6

landfilling of waste from Razi industrial zone. Because of the high altitude points in the eastern parts of town as well as the proximity to places such as residential areas; access roads and agricultural areas, must be selected a suitable place. The three points selected as proposed sites for landfilling of industrial waste generated in the Razi industrial zone. It should be noted that, based on Olecno and Drastic methods, all three options were considered as a desirable option, as a result, using hierarchical analysis the best alternative (2nd alternative) was selected as the preferred choice.
Different studies have used different parameters in AHP. Wang et al. in 2003, used of the analytic hierarchy process to landfill site selection of Beijing in China and considered environmental (such as distance from residential areas, away from surface water and groundwater, etc.) and economic factors (cost of land and transport distance) in their decision-making.[12] Sener *et al* in 2011, used AHP and GIS methods to locate waste landfill sites in Turkey and to develop a hierarchical model used criteria such as geology, hydrology, hydrogeology and morphology of proposed sites.[15] Madadi et al in 2012 to locate the landfill of the Mahalat city in Iran by using AHP, considered different criteria such as distance from the main roads, away from streams; faults, slope percent and the land uses. The incompatibility index was calculated 0.004 in their study that matched with the findings

from this study. The results showed that, the analytic hierarchy process according to its specific characteristics can be used to urban and regional planning with the aims of locating .[16] Taghvaee et al in 2011 using analytical hierarchy rocess (AHP) attempted to locate of landfill in the Marvdasht city (in Iran). [8] Ghobadi et al. were investigated siting MSW landfills by combining AHP with GIS in Hamedan province, western Iran. The results indicate that 60.4 % of the area in the Hamedan province (11,631 km^2) is unsuitable, 33 % (6,257.7 km^2) moderately suitable and 6.6 % (1,344 km^2) most suitable for construction of landfill.[17] .In this study also hydrological and topographical parameters involved in the decision-making process and ultimately the optimal site was selected based on expert analysises.

Conclusion

Alternatives comparison and selection of the preferred alternative

The 1st alternative: the most important disadvantages of this region is increase the transportation distance from waste production places at the initial phases of project, compared to the 2nd alternative. Another disadvantage is east-west winds that predominantly blow toward the Razi industrial area. These winds can lead to increased emissions of air pollutants in the area. The cost of site preparation is also high (score=0.263).

The 2nd alternative: Due to its proximity to Razi town, the low level of groundwaters, availability of soil cover (lower operating costs), suitable direction of dominant winds, suitable slope of area, the availability of needed communication paths, away the main roads, lack of stream flow and flood pathway, this alternative was considered the most appropriate choice (score=0.593). However, because this place is used as the current landfill site, thus greatly reduced the cost of site preparation. Based on the weight vector of accessibility soil cover and the dominant wind direction had the greatest impact on the decision making process.

The 3rd alternative: Because of the remoteness of the location of waste production, and cost more than other alternatives and high porosity of the soil due to the sand bed is not a good option (score=0.143).

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