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Locating industrial landfill using analytical hierarchy process (AHP)(Case study: Natanz-Isfahan industrial suburbs)

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Original Article

Abstract

Locating landfills in urban areas is one of the most important issues in urban planning because of the effect on economy, ecology, and environment, therefore the right management and principled landfilling of solid waste is the major concern all over the world especially in the developed countries. In locating landfills, different criteria should be considered. In the present study, locating sites for solid landfill of two industrial suburbs in Natanz using Analytic Hierarchy Process (AHP) was investigated so as to present optimal solutions. Three places were investigated as suggested sites and seven factors like distance from the industrial suburb, ease of access, cost of site preparation, access to covering soil, wind direction, soil penetration, and groundwater direction were considered in the decision-making process. Super Decisions software was employed to create hierarchy network, compare criteria and sub criteria, and finally choose better choice. Based on the results, the third choice located in northeast of Shojaabad suburb and southeast of Ooreh suburb (almost between two suburbs) was selected as the best choice to bury the industrial wastes of these suburbs with score of 0.618 based on the software results. The incompatibility rate was 0.069.

KEYWORDS: Landfill siting, Analytical Hierarchy Process, Industrial Waste.

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Introduction

Population explosion, city dwelling growth, new technology and changes in consumption pattern in one hand and limitation in the use of natural sources not only cause complicated problems in humans' quality of life, but lead to social, economical, and environmental incompatibility. One of the main issues is producing a variety of solid waste with different quality and quantity and disposing them.[1] One of the main solutions in solid waste management is landfilling based on technical and environmental principles. Sanitary landfilling plays a major role in increasing environmental health of every region but in the case of deviating technical principles and environmental and hygienic and hygienic

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standards in the time of locating landfills, there is a possibility of environmental, cultural, and social damages for the region. So, to minimize the damages and maximize the benefits, selecting the appropriate site is one of the main stages in sanitary landfilling.[2-3]

The sanitary landfilling is inevitable part of wastes management system and requires precision, specialized studies and designing in the stage of locating, preparing and efficient management in the landfill operation. All harmful effects appearing during the environmental impact assessment should be considered in the time of locating process. It can be said that the correct locating can eliminate half of the concerns regaring landfill.[4] To locate the landfill, factors such as topography , geology, hydrology, climatic condition, the required surface area, the covering soil, the level of ground water, the urban development, the properties of the solid waste, the usage of neighboring land, the distance of surface water from the landfill site, the price of site, and site lifetime should be considered.[3-5] Like other engineering projects, the landfilling requires the basic information and precise planning. The selection of several factors creates multiplicity of information layers and attempt to find a solution for analysis of several information layers and achieving accurate results lead decision makers to a system which has high precision, speed, and facilitation.[6] Multiple-criteria decision-making (MCDM) or multiple-criteria decision analysis (MCDA) is a sub-discipline of operations research that explicitly evaluates multiple conflicting criteria in decision-making. Approaches to MCDA, which include Analytic Hierarchical Process (AHP), Analytic Network Process (ANP), Weighted Linear Combination (WLC) or Simple Additive Method (SAM) and Fuzzy Logic, have been widely used in the identification of potential landfill sites. Among decision-making models, Analytical Hierarchy rocess (AHP) has been used by different experts.[7]

AHP is based on paired comparison which is utilized to determine relative importance of each criterion. This method, using systematic network, uses different indices and multiple criteria with prioritized multi-surface structures to rank the importance of different choices of a complex decision making process. The capability of analysis of a decision-making issue with ranked structure is the main foundation in using AHP.[5-8]

Ramshet et al. investigated locating landfill in Kouhdasht town applying AHP model and geographical information system (GIS).[1] Goyna et al. (2009) identified and presented sites as landfill in Pekan in relation to environmental and economical factors applying AHP and GIS.[9] Rashed Hasan et al. investigated locating solid waste landfill in Dhaka city, Bangladesh from 2007 to2015 applying AHP.[10] Sener et al. investigated locating landfills for Senir Kent catchment basin in Turkey using AHP considering different human and natural indices.[11]

The goal of the present study is to determine the appropriate site for burying solid wastes of two suburbs namely Shojaabad and Ooreh in Natanz, Isfahan based on decision-making processes and AHP.

Materials and Methods

Shojaabad and Ooreh suburbs's geographical situation

Natanz town's geographical coordinates are51.5° 22.5' N and 33° 36' E. Figure 1 shows the geographical situation of the industrial suburbs namely Shojaabad and

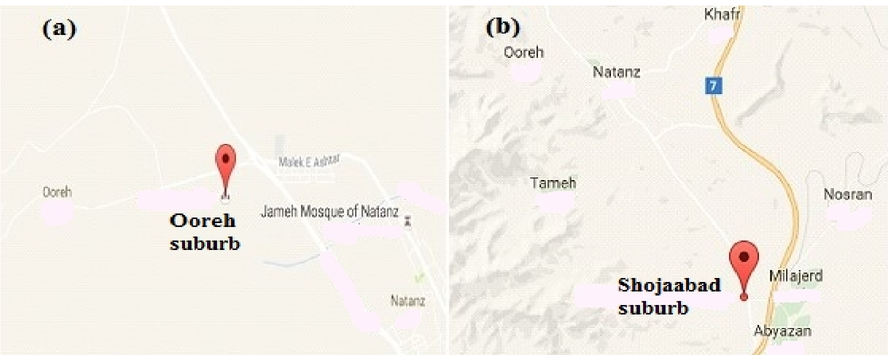

Figure 1. Ooreh (a) and Shojaabad (b) suburbs's geographical situation

Ooreh with distance of 5 and 3 km, respectively from Natanz.

Based on the field survey method, three sites were presented as the suggested choices to bury the solid wastes belonging to Shojaabad suburb and Ooreh suburb. Figure 2 shows the satellite image of the suggested choices.

The first choice's geographical coordinates

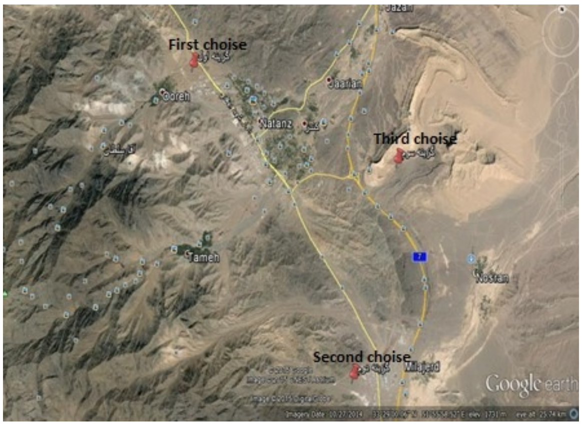

Figure 2. The suggested choices to bury the solid wastes belonging to Shojaabad suburb and Ooreh suburb

are 33° 31' 45 N and 51° 52' 52 E situated near Ooreh suburb. The second choice's geographical coordinates are 32° 25' 34 N and 51° 57' 55.5 E situated close to Shojaabad suburb. The third choice's geographical coordinates are 33° 29' 57 N and 51° 59' 12 E which is located in northeast of Shojaabad suburb and southeast of Ooreh suburb (almost between two suburbs with distance of 9 km).

Establishment of hierarchy structure for locating landfill

In this study, factors such as distance from the industrial suburb, ease of access, cost of site preparation, access to covering soil, wind direction, soil penetration, and groundwater direction were considered in the decision-making process. This stage is the most important stage in the hierarchy analysis because in this part, the complex issues can be analyzed and converted to a simple form which conforms to human mind. The hierarchy structure is a graphical presentation of a real complex problem where the general goal is at the top while the criteria, sub criteria, and choices are in the next levels. The investigated hierarchy structure, criteria, and sub criteria for selecting the best choice as the landfill are shown in Figure 3.

Weighing factors affecting landfill locating

In AHP, the highest weight belongs to the layer that has the highest effect on goal determination. In other words, the weighing criterion for each information unit is based on the role played by that factor inside the layer. Table 1 shows the weighing criteria and factors based on preference in the form of paired comparison.

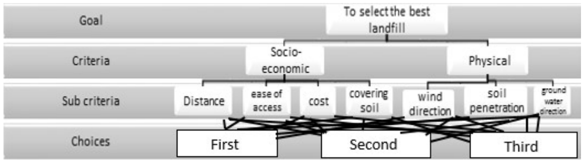

Figure 3. The investigated hierarchy structure and criteria for selecting the best choice of landfill

Table 1. Weighing factors based on preference as paired comparison[5]

AHP scale of importance for comparison pair	Score
equal importance	1
moderate importance	3
strong importance	5
very strong importance	7
extreme importance	9
Intermediate values	2, 4, 6, 8

The creation of normalized matrix (R) and weight vector calculation (W) for criteria and choices

To this end, the numbers of each column of paired comparison matrix should be sum and each element number is divided into the total number of each column to normalize matrix of paired comparison (Equation 1), then the mean of elements in each row of normalized matrix is calculated to create the vector of parameters' weight (Equation 2).

$$r_i = \frac{a_i}{\sum_{i=1}^{m} a_i} \quad (1)$$

$$W_i = \frac{\sum_{i=1}^{n} r_i}{n} \quad (2)$$

Where m is the number of columns, n, number of row, a_{ij}, elements of paired comparison matrix and r_{ij}, elements of normalized matrix for i^{th} choice and j^{th} index, and W_i, the weight of i^{th} choice.

Determination of priorities and preferences

At this stage, the final score for each choice is determined from incorporating the given coefficients. To do this, the hierarchy combination principle which leads to priority vector considering all judgments in all levels of hierarchy is applied. In other words, the final weight of the suggested arenas (choices) is obtained through multiplying criteria by their weight and adding them up, whereas the weight of criteria layer is obtained through multiplying criteria by their weight and summing them up (Equation 3).[12]

$$V_H = \sum_{k=1}^{n} W_k(g_i) \quad (3)$$

Where V_H is the final score of choice j, W_K: weight of each criterion, g_{ij}, the weight of choices related to criteria.

The calculation of system's compatibility and incompatibility

To calculate the incompatibility rate, paired matrix (A) is multiplied by weight vector (W) to estimate $\lambda_{max}\times W$, that is $A\times W = \lambda_{max}\times W$. when $\lambda_{max}\times W$ is divided into given W, the largest Priority vector (λ_{max}) is calculated (Equation 4). Then the mean of λmax is computed and the incompatibility index is obtained through following equation (Equation 5).

$$I.I. = \frac{\lambda_m \;\; - n}{n-1} \quad (4)$$

The incompatibility rate (I.R) is computed using equation 5:

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

Where the amount of incompatibility index rate (I.I.R) is taken from Table 2:

Table 2. Amount of I.I.R based on index number (N).[5]

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 incompatibility rate is 0.1 or less, the compatibility of the system is acceptable. If it is more than 0.1, the decision maker should revise his judgments.

Results and Discussion

The results related to factors weighing, the matrices of paired comparison, the relative importance of subcriteria, the normalization of factors affecting locating landfill in the studied area, weight vector, and incompatibility rate are presented in Tables 3 to 5.

Table 3. paired comparison matrix of parameters

Parameters		The choices		Priority
1. Distance	First choice	Second choice	Third choice	vector
First choice	1	1/3	1/7	0.076
Second choice	3	1	1/7	0.158
Third choice	7	7	1	0.766
2. Wind direction				
First choice	1	3	1/3	0.258
Second choice	1/3	1	1/5	0.105
Third choice	3	5	1	0.637
3. Preparation cost				
First choice	1	1/3	1/5	0.105
Second choice	3	1	1/3	0.258
Third choice	5	3	1	0.637
4. ease of access				
First choice	1	1/2	1/9	0.072
Second choice	2	1	1/9	0.114
Third choice	9	9	1	0.814
5. Access to covering soil				
First choice	1	1/3	1/7	0.081
Second choice	3	1	1/5	0.188
Third choice	7	5	1	0.73
6. Soil penetration				
First choice	1	1/3	1/3	0.143
Second choice	3	1	1	0.428
Third choice	3	1	1	0.428
7. Ground water direction				
First choice	1	3	1/2	0.332
Second choice	1/3	1	1/3	0.14
Third choice	2	3	1	0.528

Table 4. Relative importance of subcriteria in the different choices

	Distance	Preparation cost	Wind direction	ease of access	Access to covering soil	Soil penetration	Groundwater direction
First choice	0.076	0.105	0.258	0.072	0.081	0.143	0.332
Second choice	0.158	0.258	0.105	0.114	0.188	0.428	0.14
Third choice	0.766	0.637	0.637	0.814	0.73	0.428	0.528

Regarding this point that the incompatibility rate is less than 0.1, the compatibility of criteria matrix is acceptable. According to table 5, Groundwater direction with score 0.322 had the greatest impact on decision-making process. The figure 4(a,b) are presented numbers of active and passive industries in Ooreh and Shojaabad suburb respectively. Based on fig 4a, non metallic minerials, textile and chemical industries produce more waste in this suburb. In the fig 4b, non metallic industries have more number of active industries.

Table 5. Weight vector and incompatibility rate

I.R=0.068	Distance	Preparation cost	ease of access	Access to covering soil	Wind direction	Soil penetration	Groundwater direction	weight vector
Distance	1	0.2	0.33	0.2	0.2	0.33	0.33	0.029
Preparation cost		1	5	0.33	0.33	0.33	0.2	0.084
ease of access			1	0.33	0.33	0.25	0.2	0.047
Access to covering soil				1	3	0.33	0.33	0.157
Wind direction					1	0.33	0.25	0.111
Soil penetration						1	1	0.247
Groundwater direction							1	0.322

With respect to the20-year planning horizon, it can be estimated that during this time, all the inactive licensed industries located in the suburbs will start working by this year. Presently, the total amount of solid wastes produced in relation to Shojaabad suburb and Ooreh suburb in Natanz is 63893.7 tons.

If the inactive industries started working till horizon year, 2035, and increase in the industrial solid waste was calculated cumulatively in the form of annual increase, the cumulative amount of solid waste would be 1110133.23 ton according to table 6 Landfill is divided into industrial solid wastes and stone and construction wastes. Cumulative industrial solid waste was estimated to be 35115 tons till 2035, whereas stone waste and wastes from nonmetallic mineral industries were estimated to be 1075018.23 tons. Based on the studies, stone wastes, solid wastes of stone cutting, and other wastes from nonmetallic mineral industries have density equal to 826 kg/m^3, so occupy 1301474.8 cm^3 spaces.

Table 6. The total cumulative amount of the solid wastes produced.

Year	The cumulated amount of solid wastes
2015	63893.7
2017	71299.2
2019	78704.7
2021	86110.2
2023	93515.7
2025	100921.2
2027	108326.7
2029	115732.2
2031	123137.7
2033	130543.2
2035	137949
Total	1110133.23

The needed volume in planning horizon year $= \frac{1 \quad .2}{8} = 1301474.8\, m^3$

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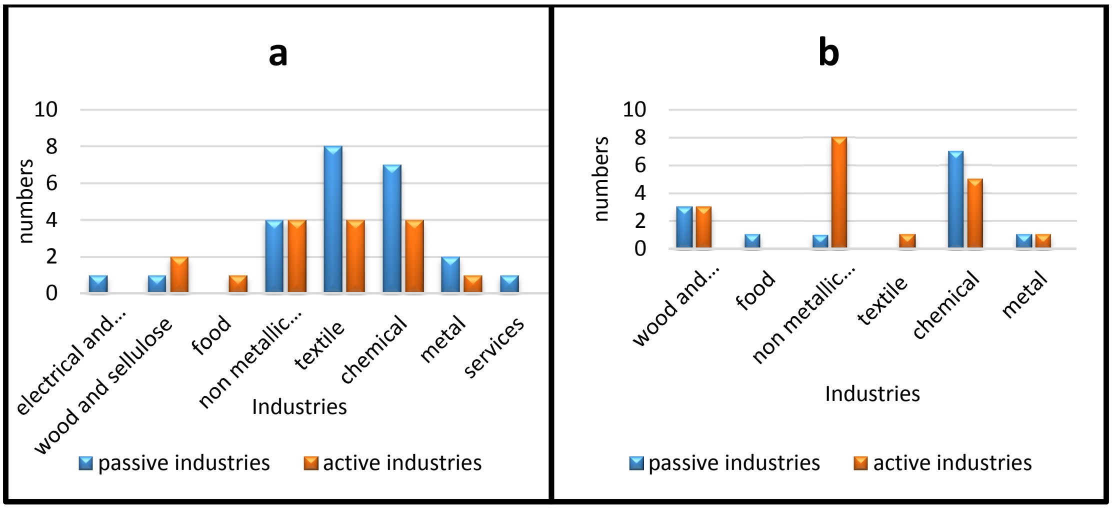

Figure 4. The numbers of active and passive industries in Ooreh(a) and Shojaabad(b) suburb

Considering 6 m depth for landfill, the required area for construction wastes is almost 22 hectares.

The needed area in planning horizon year

$$= \frac{1301474.8}{6} = 216912.4\ m^2 \cong 22\ ha$$

If specific weight of condensed industrialsolid waste is considered to be 413 kg /m^3, the required volume to bury industrial solid waste belongs to the mentioned suburbs which will be 85000 m^3.In case the covering soil volume and solid wastes volume is in the proportion of 1:5, the final volume of solid wastes including covering soil equals to:

$$V_f = \left(85000 \times \frac{1}{5}\right) + 85000 = 102000\ m^3$$

In case the depth of the site is 4.5 m, the required area to bury industrial solid wastes in planning horizon is obtained in the following way:

The needed area in planning horizon year

$$= \frac{102000}{4.5} = 22666.7\ m^2 \cong 2.5\ ha$$

Therefore, about 25 hectare is required to bury industrial wastes and wastes of non-metallic mineral industries (stone cutting, etc) belonging to Shojaabad suburb and Ooreh suburb in Natanz.

Regarding the standards, kind and amount of wastes produced in the suburbs, a site should be selected as landfill for disposal of wastes from Shojaabad suburb and Ooreh suburb in Natanz. Therefore, three sites were selected. Since all three sites were appropriate based on Olekno and DRASTIC indices, the best choice was selected by AHP.

Different studies have applied a variety of parameters in AHP. Zyari et al. (2012) used AHP for landfill selection in Jolfa and considered factors like distance with residential area and main roads, distance with conservation areas, geological structures, faults, dry rivers, vegetation, slopes, etc.[12] Sener et al. (2011) applied AHP and GIS for landfill selection in Turkey and investigated criteria like geology, hydrology, hydrogeology, morphology of suggested sites to create AHP.[11] Samari Jahromi and Hoseinzadeh Asl (2012) utilized AHP for landfill selection in Bandar Abbas considering parameters such as distance with river, residential area, vegetation, and main road and the favored site was selected.[4] Salari et al. (2012) applied FUZZY Logic - AHP model in GIS for finding waste disposal site regarding a variety of parameters such as hydrology, hydrogeology, economical-social issues, geology, and climate.[13] Gbanie et al. have presented a methodological framework for identifying municipal landfill sites in urban areas in Sierra Leone using Bo in Southern Sierra Leone as a case study. This framework involves a multi-criteria GIS approach that combines two aggregation techniques: Weighted Linear Combination and Ordered Weighted Averaging.[7] Wang et al based on actual conditions of the study area, considering economic factors, calculated criteria weights using the analytical hierarchy process (AHP), and built a hierarchy model for process (AHP), and built a hierarchy model for solving the solid waste landfill site selection problem in Beijing, China. In this study, they used criteria such as: Residential areas; Surface water bodies; Ground water; Airport areas; Slope of the land surface; Price of land; Roads; Proximity to waste production centers; for decision process. Each grade was assigned a different score (1–5). So the higher the score was, the more suitable the area was for landfill siting. Based on this study, the economic factors are very important for developing countries and districts. Landfill sites are selected not only according to environmental factors but also according to economic factors[14].

Finally based on results and Super Decisions output (Fig. 5), the third choice was selected as the best site for landfilling solid wastes of Shojaabad and Ooreh suburbs.

Name	Graphic	Ideals	Normals	Raw
First choice		0.259129	0.160354	0.053451
Second choice		0.356848	0.220825	0.073608
Third choice		1.000000	0.618821	0.206274

IR=0.068

Figure 5. Output of Super Decisions software

The advantages of the first choice are being close to Ooreh suburb, appropriate ground water direction. On the other hand, this site has high preparation cost due to long distance with Shojaabad suburb and there are road dangers due to the transportation of wastes. Also, easterly and westerly winds toward Ooreh village increase the pollutants in this area. This site cannot be an appropriate place to bury wastes from Shojaabad and Ooreh suburbs (0.16 score). The second choice is close to Shojaabad suburb. The characteristics of this site are proximity to Shojaabad suburb (cheaper transportation), access to road, and far from wells. On the other hand, there are some disadvantages like inappropriate direction of ground water, and northerly and easterly winds which can transfer the pollutants to Natanz town. Moreover, like the first choice, this site may create high transportation expenses and traffic jam for Ooreh suburb. Another negative point is proximity to the main road which is not aesthetically pleasing. Therefore, this site is not considered a suitable choice (0.22 Score). The third choice is almost between two suburbs with distance of 9 km leading to less transportation cost and traffic jam. This site is in the vicinity of municipal landfill. Some studies have been carried out regarding this site which indicate that this site has less environmental effects. Since the studied suburbs don't produce hazardous waste or leachate, they have less undesirable environmental effects in comparison to above-mentioned sites. Distance with main road is longer in this site (about 2 km) which is considered as a positive point aesthetically. Groundwater direction and wind direction are also appropriate. Consequently, this choice is suggested as the best choice to bury wastes produced in Shochaabad and Ooreh suburbs in Natanz based on AHP (0.618 Score).

Conclusion

The third choice is located in northeast of Shojaabad suburb and southeast of Ooreh suburb (almost between two suburbs) and it has less transportation cost and environmental effects. In addition, this site is in the vicinity of municipal landfill and is appropriate in terms of distance with main road, groundwater direction and wind direction. Based on the results, the third choice was selected as the best choice to bury industrial wastes of these suburbs with score of 0.618 based on the software results. Moreover, scores were 0.16 and 0.22 for the first and second choices, respectively. The incompatibility rate was 0.069.

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