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Integrating GIS and AHP for Municipal Solid Waste Landfill Site Selection

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ABSTRACT

Landfill siting is one of the most important concerns for city planners particularly in regions with intensive land uses. This paper addresses a landfill site selection methodology that integrates GIS and AHP with expert opinion analysis. It employs two stages to select most suitable landfill site for Ramjerd city, Fars province, Iran. First, the desired thematic maps of the study areas were prepared to establish a GIS database for municipal landfill site selection. Thereafter, unsuitable areas were masked based on Iran environmental protection organization legislations. The obtained Boolean map shows almost 99 percent of the study region is unsuitable for landfill construction due to shallow groundwater and intensive land use. At the second stage, the obtained nine candidate sites at preliminary siting stage were ranked by AHP method. The evaluation criteria were derived by face-to-face interviews of several experts. Subsequently, three factors including potential of surface water contamination, land use and wind direction that had spatial variability among alternatives, were selected. Ranking of alternatives with respect to these factors was performed by Ramjerd municipality stakeholders opinion. The reliability of the results was examined by applying sensitivity analysis. The results obtained based on proposed method were verified by comprehensive field visit of three top ranked alternatives. This field visit confirmed that combination of GIS and AHP can make the best time-saving and flexible method to support decision makers in solving complicated landfill site selection problem. The main objective of this study was to find a best location for municipal solid waste disposal by integrating GIS and AHP features.
KEYWORDS: AHP; GIS; landfill siting; municipal solid waste.

1. INTRODUCTION

Municipal solid waste (MSW) management is one of the major problems facing city planners worldwide. The problem is especially severe in developing countries where urbanization, poor planning, and lack of adequate resources contribute to the poor state of solid waste management practices [1]. For successful managing of MSW, a guide called waste hierarchy is built up which was first seen in the European Union's Waste Framework Directive of 1975 and improved in following years. The waste hierarchy implies a fixed order of waste management options, from most to least preferable: reduce, re-use, recycle, recovery and dispose [2].

In spite of increasing stress towards the waste reduction at the source, as well as recovery and recycling, disposal of solid wastes by landfilling remains the most commonly used method. Landfill incorporates an engineered method of disposal of solid waste on land in a manner that minimizes environmental hazards by spreading the solid waste in thin layers, compacting the solid waste to the smallest practical volume and applying a cover at the end of the operating day [3].

There are two main reasons for rapid solid waste increasing in Iran, accelerated population growth rate and changing in life style [4]. Most MSW in Iran are disposed to open sites, causing several adverse effects on the environment and public health. Consequently, constructing sanitary landfills that meet the environmental legislations and reduce the undesired impacts of current practices is the main priority for MSW management in Iran. Undoubtedly, precise landfill site selection can mitigate various issues concern with waste disposal [4]. But landfill site selection is a complex land use planning problem involving the collection and processing of information that relates to environmental, socioeconomic, as well as operational aspects [5]. To make the task more convenient, researchers tend to use Multi-Criteria Decision Analysis (MCDA) methods that take several individuals and often conflict criteria into account [4].

Many of the attributes involved in the process of selection of sanitary landfill sites have a spatial representation, which in the last few years has motivated the predominance of geographical approaches that allow for the integration of multiple attributes using Geographic Information Systems (GIS) [6]. The different techniques of GIS and MCDA in landfill site selection have been widely addressed in previous investigations [e.g. 3, 6, 7, 8, 9, 10, 11, 12, 13].

Several approaches have been proposed for MCDA and the relevant methods were developed and applied with more or less success depending on the specific problem. In the past, analytic hierarchy process (AHP) introduced by Saaty (1980) [15], was one of the useful methodologies, which plays an important role in

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selecting alternatives. AHP is an analytical tool enables people to explicitly rank tangible and intangible criteria against each other for the purpose of selecting priorities [14].

This research presents a methodology to select and rank MSW landfill site using AHP and GIS with combination of expert opinion analysis. The methodology was then verified for Ramjerd city, Fars province, Iran. The intensive agricultural land use in the region, shallow groundwater and spread residential areas are the furthermost challenges faced by Ramjerd municipality to select a new landfill site.

Background information

Ramjerd city is located at 30°07′58″ N latitude and 52°36′38″ E longitude on a fertile agricultural plain of Doroodzan region at center of Fars province, Iran. The average annual temperature of the region is 17.6 °C and the annual average rainfall is recorded to be 478 mm, mostly falling in winter. The significant predominant wind directions in the area are northwest and west. Other wind directions are negligible. The region is drained by Kor river. Geologically, the area is dominated by thick Quaternary alluvium deposits consisting of clay and sand but in a few places with salts [4].

The dominant type of land use in the area is agriculture. Based on Iranian land classification scheme for irrigation, the prevailing land units in the region belonged to class II and III. Based on this scheme, according to 18 different soil and land characteristics, the land units are classified into six classes. Class I, II and III are considered as suitable classes for irrigation designated as the best, good and relatively good ranks, Class IV is not suitable for irrigation except under especial circumstances, class V has undetermined suitability for irrigation and class VI is permanently non-irrigable (such as mountains). Since the study area is located in a semi arid region, agricultural fields are irrigated with continues consumption of considerable amount of both groundwater and river water. Accordingly, the new landfill site should not impose any undesirable impacts on these water resources. The local map of the study area as well as its agricultural classes is demonstrated in Fig. 1.

Ramjerd has a population of about 2,258 [16]. A recent estimation indicates a solid waste generation of approximately 1.27 tons per day in Ramjerd with average per capita of almost 562 g/day. Currently, there is no waste separation in source or gas or leachate utilization. The current landfill of Ramjerd is located at 30º3′33″ N latitude and 53º37′47″ E longitude with 1,641 m elevation from sea level. This site located on fan physiography with high infiltration rate which is a zone of groundwater recharge. The distance of this site is less than 400 m from wells and agricultural farms. It should be noted that the capacity of current landfill site is almost full. Due to environmental hazards, this site must be displaced to another location. According to stakeholders opinion of Ramjerd municipality, the new landfill site should cover an area of almost two hectares.

Site selection methodology

The GIS-based landfill siting methodology used in this study was consisted of several stages as follow:

- Scanning and georeferencing of the available paper maps.
- Digitizing primary paper maps and generating digital thematic maps from the collected data.
- Using SMCE tool of ILWIS software to exclude unsuitable areas for landfill.
- Determining evaluation criteria for alternatives ranking.
- Using AHP to specify the most preferred alternative.

Establishing GIS database

The primary data sources for this study include topography map (1/25,000) which shows the elevation contour lines, roads, rivers and residential areas, soil map (1/50,000) indicating soil depth, subsurface hydraulic conductivity and frequency of floods in each unit map, geology map (1/100,000) demonstrating the position of faults, agricultural land classification map (1/50,000) representing the suitability class for irrigation, groundwater depth, water bodies and position of wells, dams, springs and qanats.

After scanning and georeferencing, all primary paper maps were digitized. A 50 m cell size thematic map was then constructed for each designated criteria. Consequently, a GIS database for municipal landfill site selection was established.

Preliminary landfill siting

Based on legislations of Iran's environmental protection organization (IEPO), MSW landfill must have a distance of at least 400 m from qanats, wells and springs, 300 m from highways and main roads, 200 m from fault lines, 1000 m from residential areas, rivers, wetlands, dams and water bodies. Also, landfill sites must not be located in areas with shallow groundwater depth (< 5 m), flooding and landslide proneness areas [17]. Because of financial deficit of Ramjerd municipality, the transportation of waste to landfill is possible only up to 10 km far from the city. According to these constraints, the Boolean map of the study area was obtained using SMCE tool of ILWIS 3.3 software [18].

Evaluation criteria

After preliminary landfill siting step, a number of 27 experts with most related experience and publications were consulted to determine which factors should be considered for alternative ranking. This was accomplished by face-to-face interviews with well oriented individuals. Each individual requested to supply a list of most important factors for the dominant situation in the study area. Thereafter, these factors were used for alternative ranking.

Alternative ranking

The last step was to rank the alternatives that were remained from preliminary step by using AHP method as proposed by Saaty (1980).

The AHP has seen extensive use in a number of decision making scenarios. The AHP uses a four step approach to solve a decision making problem. A decision hierarchy is created by breaking down the decision problem into a hierarchy of interrelated decision elements. Input data is then collected by pair wise comparisons of decision elements [19]. Paired elements are verbally judged against each other in terms of their importance for the objective they are contributing to and the 9-point scale of Saaty (1994) [20] is used to quantify the procedure [21]. The nine point scale includes: [9, 8, 7, ..., 1/7, 1/8, 1/9], where 9 means extreme preference, 7 means very strong preference, 5 means strong preference, and so on down to 1, which means no preference [12]. The "eigenvalue" method is used to estimate the relative weights of decision elements. The relative weights of decision elements are then aggregated to arrive at a set of ratings for the decision alternatives [19]. The pairwise comparison matrix (PCM) formed by the decision makers must obey the following attributes, aii = 1 and aij = 1/aji. The AHP method allows slightly non-consistent pairwise comparisons. If the PCM is perfectly consistent, then aij = aik*akj for all possible combinations of comparisons in the PCM. It is rare to have a perfectly consistent PCM. The AHP method includes an index called inconsistency ratio that indicates the overall consistency of the PCM. According to Saaty (1980), the inconsistency ratio should have a value of less than 10%, indicating consistency of the matrix [7].

RESULT AND DISCUSSION

The obtained Boolean map of the study area based on IEPO legislations is presented in Fig. 2a. According to this figure, a large portion of the region that covers almost 99% of the region dose not suit for landfill construction due to one or more constraints. The most limiting factor was shallow groundwater as shown in Fig. 2b. Based on this figure, about 43% of the region contains less than 5 m groundwater depth and cannot be considered for landfill site.

The possible landfill areas obtained in preliminary landfill siting are consisted of nine discrete alternatives (Fig. 2a) that were ranked in next step. Sites 1 and 2 located at north, site 3 at northwest and the remaining sites located at south of Ramjerd. A list of evaluation criteria obtained from experts interviews were consisted of potential of groundwater and surface water contamination, land use, soil permeability, wind direction, accessibility and visibility of the sites. Based on the soil map, all nine alternatives include deep fine alluvial soil with slow permeability. The average groundwater depth of all selected sites was 5-6 m. Therefore, soil permeability and potential of groundwater contamination were not suitable factors for differentiating the performances of the alternatives.

According to viewshed analysis of the sites, all alternatives were visible from population areas or roads. Furthermore, all selected sites were accessible by roads. Consequently, both the visibility and accessibility were not suitable criteria to compare the sites. Although expert's interviews aimed to select all evaluation criteria, but it is also necessary to be sure that any selected factor is varies spatially. Accordingly, potential of surface water contamination, wind direction and land use were used to rank alternatives.

Potential of surface water contamination was considered based on detail computation of sites aspect and distance towards rivers, creeks, wetlands, dams and water reservoirs. As previously mentioned, the only land use in the region is agriculture. Therefore, land use of selected sites was compared based on Iranian land classification scheme. This scheme shows the potential of sites for sustainable usage in agriculture, their limitation and indirectly their cost. Sites 1, 2, 4, 5, 6, 8 and 9 were classified as class III, but with different soil and land limitations and sites 3 and 7 were categorized as class IV.

In the study area, wind direction should be considered to hinder residential areas from dust and particularly odor of landfill site. Therefore, this factor was used to rank alternatives by considering aspect of the sites, prevailing wind directions and position of residential areas.

Figure 3 presents the hierarchical structure used for landfill site selection by AHP using Expert Choice software [22]. Pairwise judgment of all related hierarchy elements were done by consulting Ramjerd municipality stakeholders. The data provided by participants were used as inputs for Expert Choice software and the priority ranking were then derived. The pairwise comparison matrixes of nine alternatives with respect to potential of surface water contamination, land use and wind direction criteria are presented in Tables 1, 2 and 3, respectively. The local weights of the sites derived from each matrix are presented in right the columns. The inconsistency ratio for all matrixes is within the tolerable limits of about 0.1 or less in the AHP method.

According to stakeholders opinion, land use was moderately more important than wind direction and equally to moderate more important than surface water. The relative importance of surface water was equally to moderate more than wind direction. The rational was the detrimental effects of landfill site to its surrounding that considered by wind direction and surface water factors were reduced due to perform constraints in preliminary siting step. Although high potential agricultural lands should not be considered as landfill sites, but this factor was not regarded in preliminary site selection. Consequently, the weights assigned to land use, wind direction and surface water factors from this scheme were 0.540, 0.163 and 0.297, respectively.

The result of alternatives priorities using AHP is presented in Fig. 4 together with the weights assigned to each factor. As shown in this figure, the best site for landfill construction is alternative 7 with overall weight of 0.223. Alternatives 1 and 3 were the second and third best alternatives, respectively.

Sensitivity analysis was conducted to evaluate the reliability of the results. The outcome of alteration in alternatives priorities with changes in factors weights is presented in Fig. 5. The linear presentation of the alternatives against a single criterion in gradient sensitivity emphasizes how the alternatives relate to any priority assigned to the criterion shown on the x-axis. In this figure, the vertical line represents the priority of the criterion selected for the x-axis, and the slanting lines represent the linear relationships among the alternatives with regard to the priority selected for the x-axis. The current priority for the criterion is where the vertical line intersects the x-axis. The priorities for the alternatives are the y-axis readings where the vertical line intersects the slanting alternative lines. The crucial analyses to be gained from the gradient sensitivity are the points at which the alternative lines cross one-another. These are the “tradeoff points” where the preferred alternative with respect to the selected criterion changes [22]. According to this figure, there is no reversal point between site 7 and the other sites by ±20% changes in all factor weights. This means that by considering ±20% uncertainty range for all factor weights, the rank of this site remains at top first. The priority of sites 1 and 3 were sensitive to -20% changes in surface water weight (Fig. 5a). Furthermore, their ranks would remain equal if considering +20% alterations in land use weight (Fig. 5b). Consequently, based on this sensitivity analysis site 7 obtained the first rank and it can be used as Ramjerd new landfill site.

Ultimately, subsequent screening and refinement based on detail field inspections was performed for three top ranked alternatives. Their characteristics that were obtained from the field inspection are summarized as follow:

Site 7 located at southeast nearly 5,600 m far from Ramjerd. The average groundwater depth of the site is about 5.5 m. The nearest well distance that located downward of the site according to groundwater flow direction is 910 m. There is no current land use within this site due to salinity (EC_e=16-32 dS/m) and sodicity (SAR=13-30%) of the soils and. The site has an area of about 10 hectares. The nearest residential area locates at 1,100 m of the site but it is not downward according to prevailing wind directions.

Site 1 located at north nearly 5,900 m far from Ramjerd with current agricultural land use. The nearest residential area is located at about 1,790 m downward the site according to prevailing wind directions. The distance from adjacent well is almost 800 m. The site has an area of approximately 58 hectares.

Site 3 located at northwest of Ramjerd with 3,110 m distance from the city. Its current land use is dry farming. Irrigation of the site is limited due to its slope of 2-5%. The nearest well to the site is located at about 620 m far considering groundwater flow direction. There is no residential area downward the site with respect to prevailing wind direction and the nearest has located at 2,200 m far from the site.

Table 1
The pairwise comparison matrix of nine alternatives with respect to potential of surface water contamination*

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	local weights
Site 1	1	5	4	2	3	1	1	3	1	0.182
Site 2		1	1	1/2	1/2	1/5	1/3	1/2	1/5	0.039
Site 3			1	1/2	1/2	1/4	1/2	1/2	1/2	0.044
Site 4				1	1	1/2	1	1/2	1/2	0.096
Site 5					1	1/3	1/2	1	1/3	0.071
Site 6						1	1	3	1	0.182
Site 7							1	1/2	1	0.138
Site 8								1	1/3	0.066
Site 9									1	0.182

***Inconsistency ratio = 0.01**

Table 2
The pairwise comparison matrix of nine alternatives with respect to land use*

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	local weights
Site 1	1	2	1/2	4	4	3	1/3	3	3	0.155
Site 2		1	1/3	2	2	2	1/4	2	2	0.092
Site 3			1	4	4	3	1/2	3	3	0.197
Site 4				1	1	1/2	1/4	1/2	1/2	0.041
Site 5					1	1/2	1/4	1/2	1/2	0.041
Site 6						1	1/4	1	1	0.064
Site 7							1	4	4	0.281
Site 8								1	1	0.064
Site 9									1	0.064

*Inconsistency ratio = 0.02

Table 3
The pairwise comparison matrix of nine alternatives with respect to wind direction*

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	local weights
Site 1	1	1/3	1/4	2	2	2	1/5	1/2	1	0.065
Site 2		1	1/2	4	4	4	1/2	1	1/2	0.145
Site 3			1	5	5	5	1	2	2	0.220
Site 4				1	1	1	1/6	1/2	1/2	0.040
Site 5					1	1	1/6	1/2	1/2	0.040
Site 6						1	1/6	1/2	1/2	0.040
Site 7							1	3	4	0.268
Site 8								1	2	0.106
Site 9									1	0.075

*Inconsistency ratio = 0.01

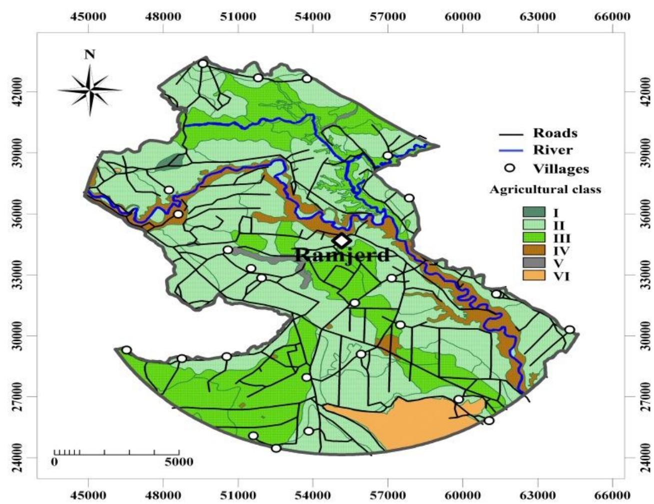

Fig. 1. The study area map

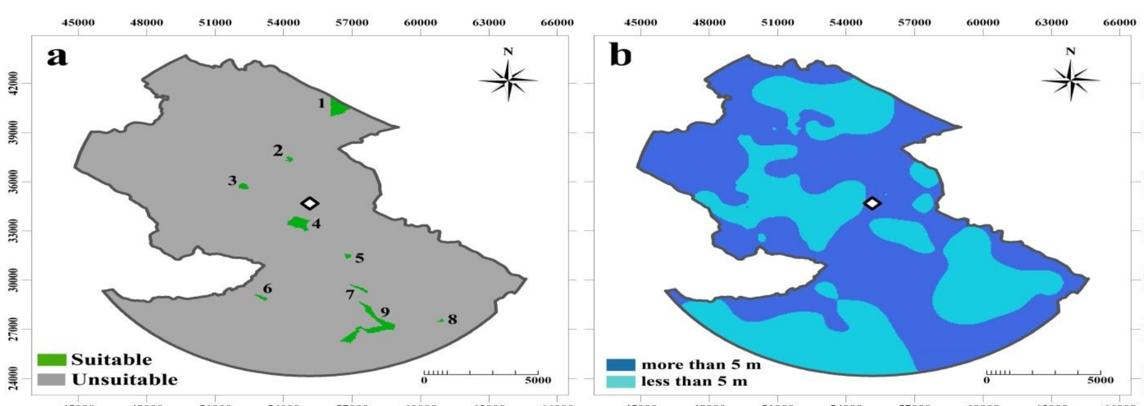

Fig. 2. The Boolean map and nine obtained candidate alternatives (a) and groundwater map of the study area (b)

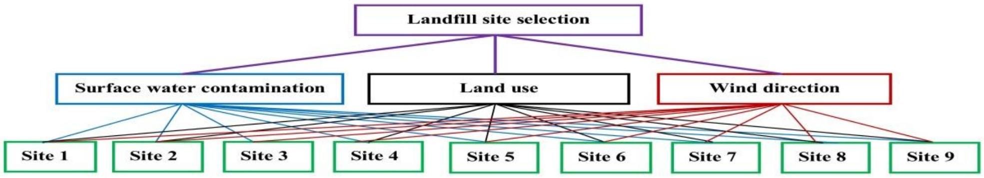

Fig. 3. Landfill site selection decision making hierarchy

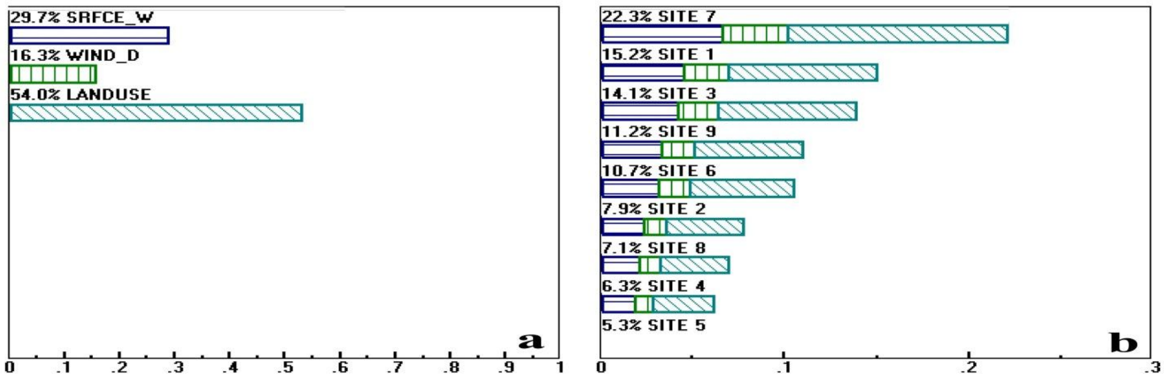

Fig. 4. The factors weights (a) and the result of alternatives priorities using AHP method (b)

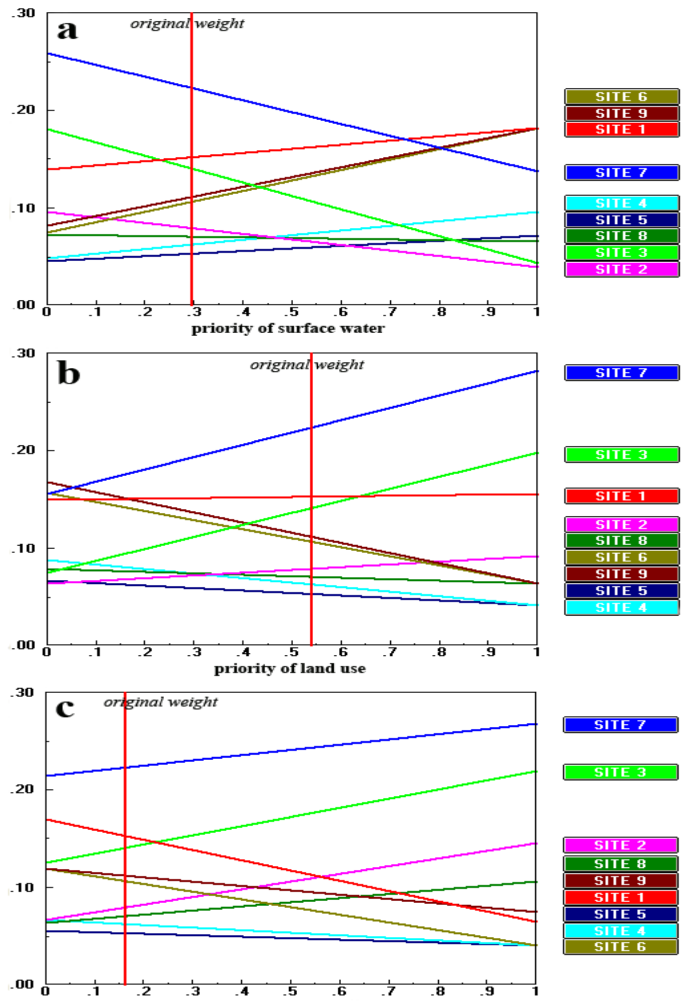

Fig. 5. Sensitivity of the alternatives priorities with respect to changes in the weight assigned to surface water (a), land use (b) and wind direction (c).

Conclusion

This paper introduces a MSW landfill siting methodology that integrates GIS and MCDA technique, AHP, with stakeholder analysis. GIS feathers were used to masked unsuitable areas based on IEPO legislations. To comply these legislations many criteria were considered with detailed investigation. This process makes landfill site selection as a complicated and time-consuming procedure. Using GIS to handle this candidate waste disposal site selection has shown accurate and time-saving process. If the desired primary data were available, GIS can help to move from large geographic areas to target areas. At the second stage, the most suitable alternative was extracted by using AHP method. The evaluation criteria were derived by face-to-face individual interviews with several experts. This way, the interviews can be organized easily in time-saving manner without suffering from irresponsibility of some questionnaire interviews. Although expertise analysis clarify all the criteria that should be considered in site selection procedure, but final factors depend upon particular region under consideration. Consequently, some criteria with negligible spatial variability among candidate sites were not useful to differentiate performances of the alternatives. Finally, potential of surface water contamination, land use and wind direction were used to rank the alternatives. This procedure was performed based on Ramjerd municipality stakeholders opinion. The reliability of the ranking procedure was examined by applying sensitivity analysis. The result showed that combination of GIS and AHP can make very time-saving and flexible method to support decision makers in solving complicated landfill site selection problem.

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