Iran. J. Environ. Health. Sci. Eng., 2011, Vol. 8, No. 3, pp. 273-284

MUNICIPAL LANDFILL SITE SELECTION FOR ISFAHAN CITY BY USE OF FUZZY LOGIC AND ANALYTIC HIERARCHY PROCESS

[1]A. Afzali, *[2]J. M. V. Samani, [3]M. Rashid

[1]Department of Chemical Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, Skudai, Malaysia
[2] Department of Water Structures Engineering, Faculty of Agriculture, Tarbiat Modarres University, Tehran, Iran
[3]Malaysia-Japan International Institute of Technology, UTM International Campus Jalan Semarak, Kuala Lumpur, Malaysia

Received 12 June 2010; revised 12 April 2011; accepted 14 August 2011

ABSTRACT
Selecting the most suitable site for landfill can avoid any ecological and socio-economical effects. The increase in industrial and economical development along with the increase of population growth in Isfahan city generates tremendous amount of solid waste within the region. Factors such as the scarcity of land, life span of landfill, and environmental considerations warrant that the scientific and fundamental studies are carried in selecting the suitability of a landfill site. The analysis of spatial data and consideration of regulations, and accepted criteria are part of the important elements in the site selection. The present study presents a multi criteria evaluation method using GIS technique for landfill suitability site evaluation. The Analytic Hierarchy Process (AHP) was used for weighing the information layers. By using the fuzzy logic method (classification of suitable areas in the range of 0 to 255 byte scale) the superposing of the information layers related to topography, soil, water table, sensitive ecosystems, land use and geology maps was performed in the study. Only after omission of inappropriate areas, the suitability examination of the residue areas was accomplished. The application of the present method in Isfahan city shows approximately 5% of the south east and north east parts of the study area with the value of more than 220 byte scale, which are suitable for landfill establishment.

Key words: Landfill site selection; Solid waste; GIS; Analytic Hierarchy Process; Fuzzy logic

INTRODUCTION
The increasing development of urban areas and population growth caused a tremendous amount of municipal solid wastes generation, presenting a problem in urban environment (Kontos *et al*., 2005). Although there is a tendency toward solid waste reduction at source through reuse and recycle of solid waste, landfill is still the final disposal method (Sumathi *et al*., 2007). Landfill technique consists of loading, scattering, and covering of waste material with soil in a sanitary manner. In addition, the landfill should minimize adverse environmental impacts and expenses due to distance. Thus, the safety, sanitary aspects, natural environmental and socio-economic conditions of any proposed site for landfill should be investigated and the best site be selected among various options (yaghmayian, 2003). Therefore as many criteria must be incorporated into landfill site selection, the use of GIS is ideal due to its ability in handling a large volume of special data management. GIS enables information storage, analysis and display according to the applicant defined specifications (Sener *et al.,* 2006). However, due to the vagueness associated with specifying various criteria in landfill site selection, fuzzy logic approach is included in

*Corresponding author: E-mail: samani_j@modares.ac.ir
Tel/Fax: +98 21 82 88 31 48

the decision making approach to handle the existence uncertainty (Chang *et al*., 2008; Singh and Vidyarthi, 2008). Many landfill site selection studies have been conducted within the GIS environment (Sumathi *et al.,* 2007; Chang *et al*., 2008; Cheng *et al*., 2003; Delgado *et al*., 2008) where in some of them the AHP method is used (Sener *et al.,* 2006; Siddiqui *et al*., 1996; Kontos *et al*., 2005; Gemitzi *et al*., 2007). Similarly, in Iran different criteria was applied in some studies for municipal solid waste landfill site selection (Khorasani and Nejadkorki, 2000; Javaheri *et al*., 2006). Khorasani *et al* (2004) used the Boolean and fuzzy methods for landfill site selection in Sari city (Khorasani *et al*., 2004). Farhoodi *et al* (2005) investigated the previous and existing landfill site of Sanandaj city by employing the fuzzy logic and confirmed the suitability of the previous site against the existing site where the later was not corresponding with many principals, criteria and special legislations. Then, the suitable landfill sites location was identified after defining the criteria and incorporating the information layers and maps (Farhoodi *et al*., 2005). Poorahmad *et al* (2007) considered the limit of 20 kilometer radius around the legal restrict of Babolsar city and incorporated 14 natural and artificial layers by using different integrated methods such as overlaying index and fuzzy logic. Finally, the authors prioritized the three considered most suitable sites by defining some conditions to fulfill the requirements of 20 future years of the city (Poorahmad *et al*., 2007). Although landfill site selection has been carried out since the last century, the problem is still being addressed in literature related to waste management. The existing landfill site capacity in Isfahan city is limited and this approves the necessity of siting a new sanitary landfill. In this study the selection of the most suitable municipal solid waste landfill of Isfahan city was carried out by considering site selection effective criteria (constraints and factors) by incorporating GIS, and weighing factors according to AHP method. The applied criteria (constraints and factors) are site specific. The factors criteria are weighted mainly on the basis of expert's knowledge therefore the decision made about the suitable landfill site would be justified.

MATERIALS AND METHODS

Study area

Isfahan city is located approximately at 32º 38´ northern latitude and 51º 38´ eastern longitude (figure 1). Its elevation is varied from the minimum of 1550 m around Zayanderood to the maximum of 2230 m in Soffe Mountain. Annual average precipitation and temperature are 121.1 millimeters and 16.2ºC, respectively. Isfahan city, the capital of Isfahan province, with the area of 18200 ha and 1583600 people is the third populated city in the country. Increase in economy and industrial development resulted in the increase in generation of solid waste in the city. It is estimated that solid waste production of the city is 900 ton/day. The existing solid waste landfill site has been used for approximately 20 years and will soon be abandoned. In this regard, a study to investigate the suitability of landfill to be site within 40 kilometers of the Isfahan city has been carried out and is reported in this paper.

Analysis method

Landfill site selection requires effective criteria assessment according to the governmental legislations to reduce social, economic, environmental and health costs (Siddiqui *et al*., 1996). In the present study, by taking into account these criteria the overlaying method of information layers were used to achieve suitable landfill site selection. The cell size of these layers was considered 100*100m. In the multi criteria evaluation method, an integration of criteria is used for accessing a single combination in decision making. The criteria are divided into two categories of constraints and factors (Gemitzi *et al*., 2007). The criteria analysis for landfill site selection is described in the following sections.

Constraint analysis

Constraints are criteria which cause the limitation of decision alternatives and omit some location from more investigations. The Boolean method is employed for constraints. By applying the Boolean method the study area is classified into two classes of suitable (1) and unsuitable (0) (Mahini and Gholamalifard, 2006). The mathematical formulation in area selection by using constraint criteria is expressed as (Gemitzi *et al.,* 2007):

$$SI = \prod_{j=1}^{K} b_j \quad (1)$$

Where: SI= total suitability index value (0 or 1); b_j= suitability index value for each constraint criterion (0 or 1) and K= total number of constraint criteria.

Factor analysis

Factors are naturally continuous and are representative of rational suitability of an area. In fact factor is a criterion which causes the suitability of an alternative increase or decrease for a specific application (Mahini and Gholamalifard, 2006). In this study the specific factors were quantified in the byte scale of 0-255 on the basis of Idrisi 256-level color palette by using the fuzzy membership functions where it is introduced into Idrisi Klimanjaro software in the form of map layers. The existence of such an extensive scale provides the most possible difference while analyzing data. Zero (0) denotes the least suitable area for landfill while 255 shows the most optimum site for landfill.

Fuzzy sets are defined according to the fuzzy membership functions. On the basis of fuzzy set A in the society of X (equation 2), μ_A (x) represents consistency of x element in X fuzzy set which can get complete membership, partial membership or no membership.

$$A= \{x, \mu_A (x) | x \varepsilon X\} \quad (2)$$

Fuzzy membership functions are as linear, S (sigmoid) shape and J shape ones. It is also possible to define the fuzzy membership function by the user. S shape membership function is perhaps the most common used function in fuzzy set theory which shows the gradual changes from no-membership to complete membership (Gemitzi *et al*., 2007). So the S shape fuzzy membership functions such as monotonically increasing, monotonically decreasing and symmetrical were generally used due to the presenting gradual membership variations. After standardization of all the factors by the use of fuzzy membership functions in the byte scale of 0 to 255, a weight was assigned to each factor. This weight is the representative of one factor importance against the other factors. Each factor weight is multiplied by the standardized map (being scaled) of that factor and the produced results are added with each other. This method is called as the weighted linear combination. In fact weighted linear combination is a kind of evaluation that shows cell suitability via weighing and combining of factor map layers (Malczewski, 1999). The mathematical formulation of this method is described as fallows (Kontos *et al*., 2005):

$$SI = \sum_{i=1}^{N} w_i x_i \quad (3)$$

Where: SI= total suitability index value (0-255); w_i= weigh of factor i; x_i= criterion score of factor i and N= the total number of factor criteria.

There are different ways for factor weighing. The method that is used in this work is the pair-wise comparison which was proposed by Saaty as Analytic Hierarchy Process in the decision making process concept. Landfill site selection problem is composed of a hierarchical structure with constraint and factor criteria that its level is shown in figure 2.

Constraint criteria are consisted of fault, sensitive habitats and airport. Factor criteria are consisted of slope, soil permeability, surface water, groundwater, landuse, road network and residential areas. In addition surface water, groundwater and residential areas criteria were also considered as constraint.

Criteria (factors) are compared reciprocally in each level in pair-wise comparison and the numerical priority is allocated according to Saaty standardized table (table 1) (Saaty, 2008). In this method weights are obtained by considering eigenvector produced from pair-wise comparison between the criteria of square reciprocal matrix. In the square reciprocal matrix by completing the lower-left triangular half, the upper-right triangular half is completed because the latter half is equal to the reciprocal of the corresponding entries in the lower-left (Gemitzi *et al*., 2007). Tables 2, 3 and 4

Table 1: AHP pair wise comparison scale for 9 importances

Intensity of importance	Definition
9	Absolute importance
7	Very strong or demonstrated importance
5	Strong importance
3	Week importance
1	Equal importance between the elements
8,6,4,2	For comprise between values

show the pair wise comparison matrix of physical and socio economic criteria, physical sub criteria and socio economic sub criteria respectively. After sub criteria accounting (factors) in each 2 physical and socio economic groups, their final weight is computed via multiplying obtained sub criteria weight by the related criteria weight in the upper level (table 5).

As the environmental criterion works as constraint in this study it does not participate in the weighing process. By paying attention to this issue that physical and socio economical criteria have equal importance, identical weight is allocated to them.

After extracting matrix relative importance and criteria weights, pair-wise comparison consistency should be identified (Saaty, 2008). Saaty declares this process by consistency index known as consistency ratio (CR). Consistency ratio shows the probability of matrix ratio random producing. The consistency ratio should be lower than 0.1. Otherwise there is a need in reevaluating the relative importance. In the case that the consistency ratio is lower than threshold limit, accounted weights are affected on the criteria (factors) map layers.

Table 2: Comparison matrix of physical and socio economic criteria

Landfill site selection	Physical criterion	Socio economic criterion	Relative importance weight or weight value
Physical criterion	1	1	0.5
Socio economic criterion	1	1	0.5

Table 3: Comparison matrix of physical sub criteria

Physical criterion	Slope	Soil permeability	Surface water	Ground water	Relative importance weight
Slope	1	1/2	1/2	2	0.195
Soil permeability	2	1	1/2	2	0.138
Surface water	2	2	1	2	0.391
Ground water	1/2	1/2	1/2	1	0.276

Table 4: Comparison matrix of socio economic sub criteria

Socio economic criterion	Road network	Residential areas	Landuse	Relative importance weight
Road network	1	1/3	1/2	0.163
Residential areas	3	1	2	0.540
Landuse	2	1/2	1	0.297

Table 5: Final Weights assigned to physical and socio economic sub criteria in the evaluation phase

Criterion	Physical criteria				Socio economic criteria		
Criterion weight	0.5				0.5		
Sub criterion	Slope	Soil permeability	Surface water	Ground water	Road network	Residential areas	Landuse
Sub criterion weight	0.195	0.138	0.391	0.276	0.163	0.540	0.297
Final weight	0.0975	0.069	0.1955	0.138	0.0815	0.27	0.1485

Final landfill map identification

For identification of suitable final landfill site, the criteria map layers that included constraints and factors should be combined with each other. This process is accomplished according to the below formula in which the suitability is calculated from multiplying the factors and the constraints.

$$\mathrm{SI} = \sum_{i=1}^{N} w_i x_i \times \prod_{j=1}^{K} b_j \qquad (4)$$

Evaluated criteria

Landfill site selection studies are dependant on the natural and legal condition of an area. In this regard the criteria and principles that should be considered in this study are divided into three classes namely, physical, environmental and socio economic criteria. These criteria have been selected according to the guide directions and legislations of Iran environment organization and municipality.

Physical criteria

Physical criteria are consisted of slope, surface water, groundwater, soil permeability and faults.

Slope: Land morphology is a fundamental factor in landfill establishment. Land morphology is evaluated by slope gradation that is defined in percent or degrees (Kontos *et al*., 2005). Steep slopes are not suitable for landfill establishment where the construction costs of excavation increases in higher slopes (Gemitzi *et al*., 2007). Also, the suitable slope of land surface is important in preventing the leachate flowing (Khorasani and Nejadkorki, 2000). The slope layer map was obtained from the study area DEM map on the basis of pixel size in percentage. The lands with the slope of more than 20 percent with 0 value were considered unsuitable. In the slope layer by increasing the slope from 0 to 20 percent, the site suitability decreases from 255 to 0 and the selected fuzzy membership function type is S shape (Fig. 3a).

Surface water: This criterion is important from the point view of both environmental and economic concerns because in addition to causing pollution problems, it may require an efficient drainage system with high expenses (Gemitzi *et al*., 2007). Areas located within distances less than 100 m from permanent and seasonal rivers are excluded due to the possible interaction between the landfill and the rivers and according to the Boolean logic were given 0 value. For the rest distances a monotonically increasing S shape fuzzy membership function was considered. The suitability increases from 0 to 255 as the distance increases from rivers. Therefore, for distances more than 100m from the rivers towards values of 255, the areas are considered more suitable (Fig. 3b).

Groundwater: In areas where solid wastes are put directly on groundwater table, groundwater will be polluted strictly (Omrani, 2004). This pollution is caused basically from contact with water and leachate (Soupios, 2007). For the preparation of groundwater table map, data statistics analysis of observed wells obtained from Isfahan water organization was conducted and the interpolation was performed by Idrisi Klimanjaro software.

Fig.1: The location map of the study area

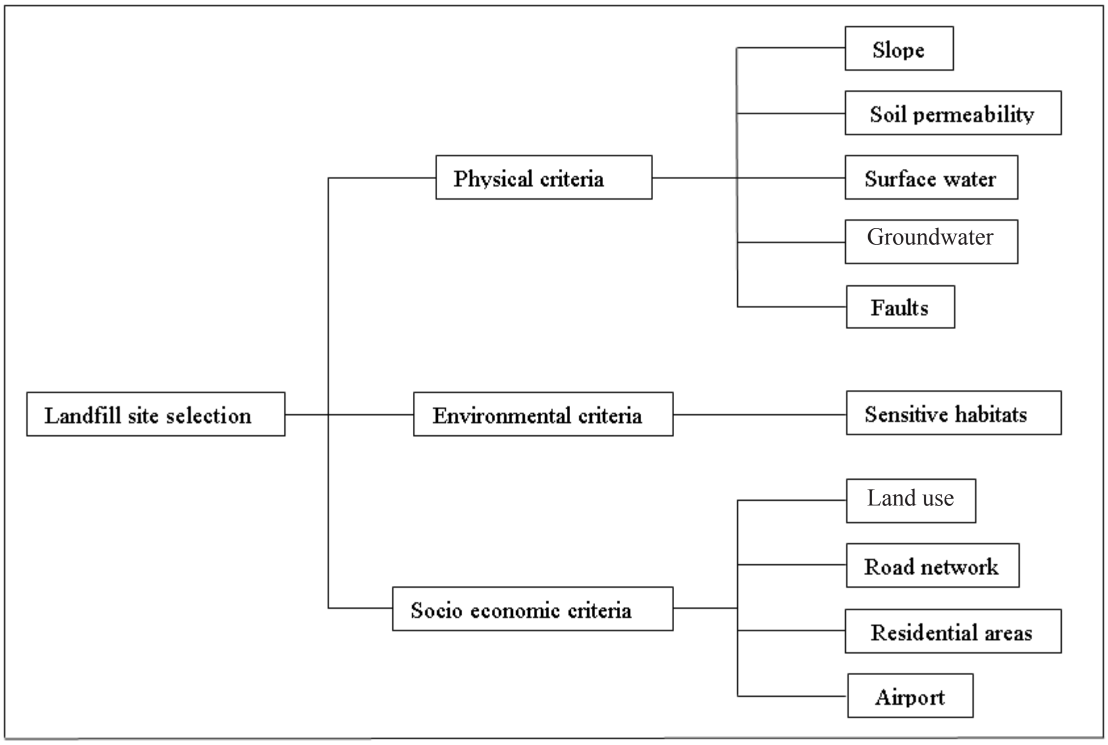

Fig.2: hierarchical structure of landfill site selection problem

Areas with groundwater depth less than 10 m from the land surface were considered unsuitable and according to the Boolean logic were given 0 value. By increasing groundwater depth from 10 to 50 m, the suitability increases from 0 to 255 and the areas with depths of more than 50 m were considered more suitable. The selected fuzzy membership function is an S shape with monotonically increasing (Fig. 3c).

Soil permeability: The most the amount of soil permeability, the most probable the entrance of leachate into groundwater and their pollution. In soils with low permeability, the productive leachate may stay within landfill area (Abdoli, 1993). The soil texture characteristics are considered for classifying the study area according to user defined membership. Rocks were considered unsuitable with 0 value. Soils with light to moderate, moderate to light, moderate and moderate to heavy textures were assigned 100, 150, 180 and 230 values respectively. Soils with heavy and heavy to very heavy texture were preferred for landfill establishment with value of 255 (Fig. 3d).

Faults: Faults are geological conditions that cause limitation for sitting a landfill (Gemitzi *et al*., 2007). As there are not complete and exact

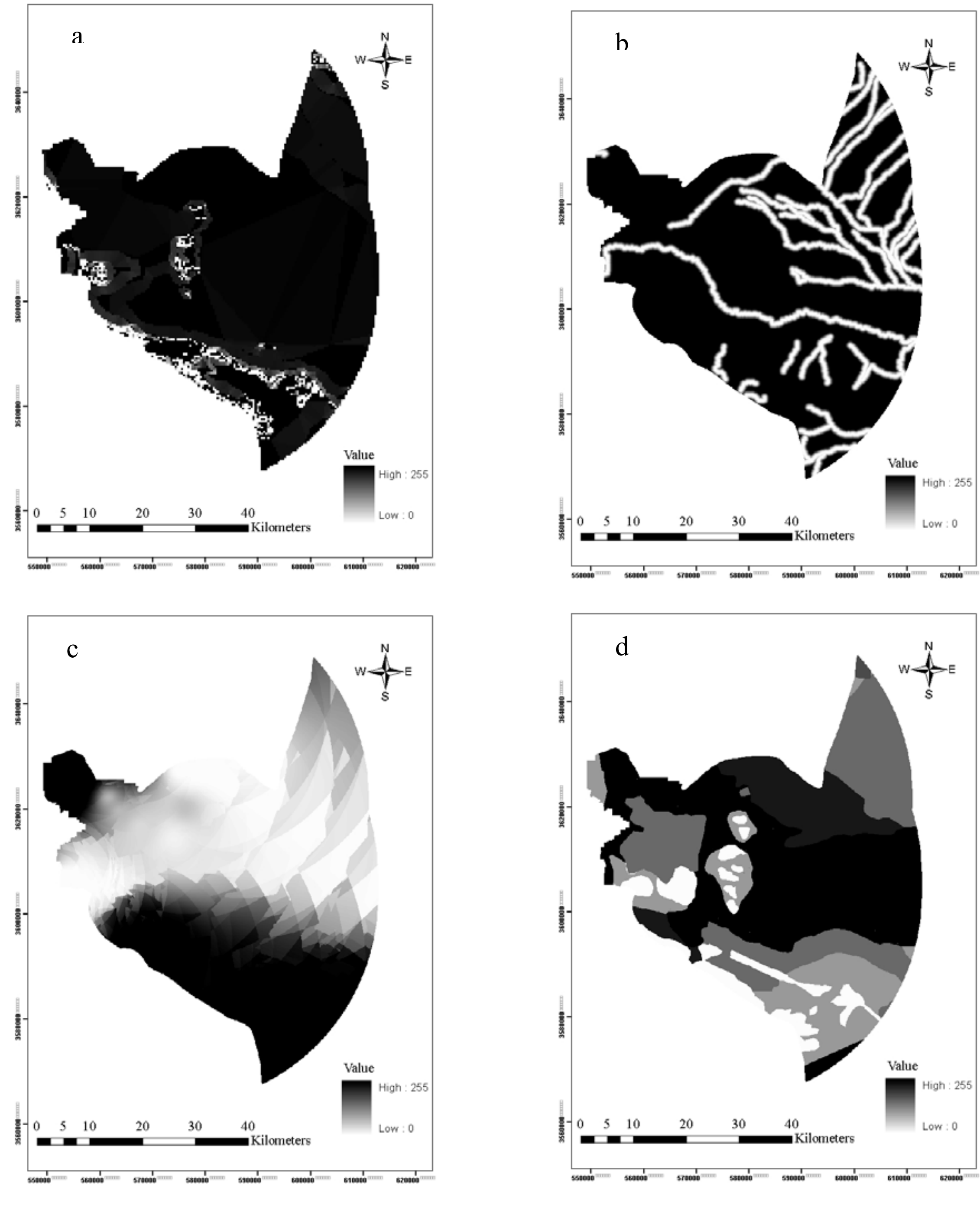

Fig. 3: a) Slope; b) Surface water; c) Ground water and d) Soil permeability

information about all faults in the country the preliminary background is that all the faults in geology map are active (Fathi, 2007). This criterion is considered as constraint and fuzzy logic method is not applied for it. Faults and their 100 m buffer were considered unsuitable with value 0 and the other areas were considered suitable with value 1.

Environmental criteria

In the present study only the sensitive habitats sub criterion is included in this category.

Sensitive habitats: This criterion is important because it causes degradation and potential pollution to sensitive ecosystems. In Iran it has been attempted to conserve the nature of the areas which are under the management of the environment department. These areas are national parks, protected areas, wildlife refuges and national monuments (Fathi, 2007). In the study area, Kolahghazi national park is as a sensitive habitat that causes constraint for landfill establishment and therefore the fuzzy logic is not applied for it. So this area and its 500 m buffer were considered unsuitable with 0 value and the other areas were considered suitable with 1 value.

Socio economic criteria

Socio economic criteria are composed of residential areas, road network, landuse and airport.

Residential areas: Landfill site should be located away and far from populated centers of the city. Otherwise it causes aesthetic, bad odors and land value of the surrounding area (Chang *et al*, 2008). By considering sufficient landfill capacity for the city long term requirements, landfill site should not be affected by the development plans of the city (Abdoli, 1993). Due to its negative effects the areas of 2 kilometers distance around the residential areas are omitted from the potential areas and according to the Boolean logic were given 0 value. The greater the distance from residential areas the more suitable the area is for landfill site selection. The suitability of the selected site is referred by a value from 0 to 255 and the applied fuzzy membership function is considered as S shape one (Fig. 4a).

Road network: Building roads for landfill access especially in long distances requires huge preliminary expenses. So the selected site should be close to the highways and main roads (Abdoli, 1993). For the connection road map, to prevent the interference of solid waste transferring vehicles with the main traffic, the lowest pixel value allocated to 100 m distance from existed roads. In addition, by increasing distance from roads, the suitability decreases from 255 to 0 and the distances of more than 1000 m were considered unsuitable due to the more transportation expenses. The used fuzzy function in this criterion is considered to be symmetric S shape one (Fig. 4b).

Landuse: This criterion is not on the basis of specific directions and may alter according to the study area (Kontos *et al*., 2005). From the stand point of economy it is better to choose bare lands which can be used after landfill site completion or can be sold (Abdoli, 1993). The identified uses in the study area are consisted of residential areas, artificial forests, semi compact and low compact pastures, agricultural lands and orchards, kavir, sand dunes, bare lands and rocks. In the study area, different landuses were categorized on the suitability basis in the range of 0 to 255 according to user defined membership. In the related map, residential areas and rocks were given value of 0, sand dunes value of 20, agricultural lands and orchards value of 25, artificial forests value of 120, semi compact pastures value of 180, low compact pastures value of 225 and bare lands and kavir value of 255 (Fig. 4c).

Airport: Landfill sites attract variety of birds to be accumulated around. This issue may interfere with the operation of airplanes. So it is essential to consider suitable distance from landfill site according to airport and airplane types (Daneshvar, 2004). By considering this criterion as a constraint, for safety matters, 3 kilometer buffer around airport was omitted from the next investigation.

RESULTS

The results from information layers probe related to evaluated criteria showed that about 16% of the study area was omitted from more landfill sitting investigations because of the limitations

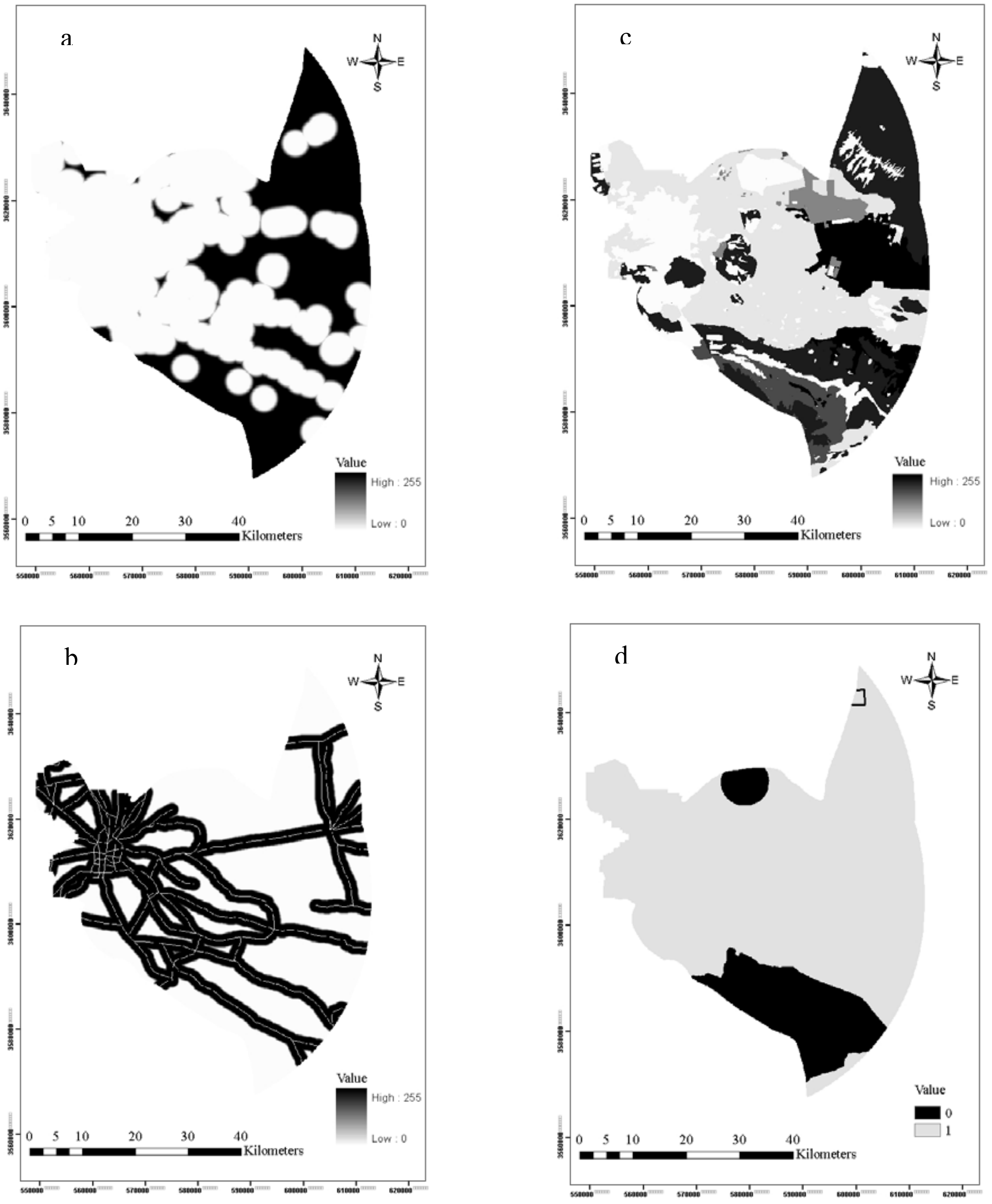

Fig. 4: a) Residential areas; b) Road network; c) Land use and d) Fault, national park and airport constraints

of Kolahghazi national park in south, airport in north and fault in northeast of the study area (Fig. 4d). Among them Kolahghazi national park with the area of about 38600 ha has caused the elimination of 14% of the study area and the existence of fault has a minor role in the deletion of the suitable areas. Residential areas in the west also have caused the limitation of approximately 55% from the study area. In addition, agricultural lands and orchards in the center and the existence of light to moderate texture in south, west and north east parts of the study area have made these parts unsuitable for landfill siting. Slope factor has a minor role in the omission of suitable areas

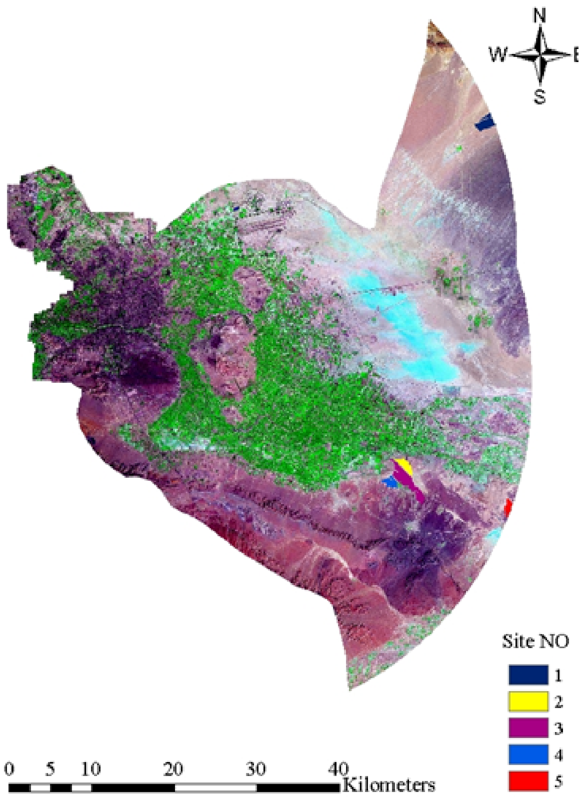

Fig.5: Suitable landfill sites

Table 6: Average value and areas of the suitable landfill sites

Site No.	Average value (0-255)	Area (ha)
1	221	271
2	222	191
3	224	573
4	223	167
5	226	140

and only a small part of the south has the slope of more than 20% because of rocks. Small parts of the west were also sloppy. The areas with permanent and seasonal rivers and the level of water table under 10 m have a minor role in the omission of the suitable areas and road network is approximately scattered in the most parts of the study area.

By overlaying information layers, the study area is shown in the value range of 0 to 255 that 5 areas with the suitability of more than 220 were selected as the most suitable areas for landfill site selection. In fact, because of the high structure and operation expenses of landfill, it is preferred that the landfill establishment site responds to the next 20 years needs of the city. By considering solid waste production rate, population, cover matter amount and compact solid waste density in the landfill site there is a need of at least 135 ha land for the requirements of 20 years of the area. So the areas with the extent of lower than 135 ha for landfill site selection were ignored and 5 regions from the study area were considered suitable for landfill site as given in Table 6, and shown in Fig. 5.

DISCUSSION

The present study shows the combination of GIS, fuzzy logic and multi criteria evaluation techniques in identifying solid waste landfill site suitability and selection. The site suitability was provided by considering 10 criteria. The gained results from expert opinions shows that among physical sub criteria, surface water, groundwater, slope and Soil permeability and among socio economic sub criteria, residential areas, landuse, and access roads are important in order respectively. The extension of some suitable areas is more than required landfill site, so it is possible to arrange the related equipments of bio compost and recycling beside it to manage solid waste better in addition to reducing transition expenses.

Applying of GIS and multi criteria decision analysis is desired in site selection problems. GIS is flexible in considering criteria and it is possible to develop this method by taking into account other effective criteria. In addition, the possibility of GIS usage in fuzzy method and its extensive value ranges of each option (0 to 255) and having cell information permits that the characteristics of the study area be investigated precisely at small regions of cell size. Fuzzy logic which considers different levels of membership is more flexible than Boolean logic (0 and 1). Multi criteria decision analysis is also providing necessary conditions to consider different criteria within the site selection evaluation problem and therefore helps decision makers towards correct option selection. GIS combination with decision analysis as decision supporting system can assist decision makers in each site selection problem as an effective tool. AHP method facilitates decision making by broking a complicated decision problem into easier ones. In addition, decision elements are compared by the use of pair-wise comparison for weight identification which helps in reducing the complexity of the decision problem. It is important to add that due to different criteria prioritization assigned by different experts, the final results may also be different for various areas. For taking final decision, field investigation of the proposed landfill sites should be proposed in addition to the other expenses and political aspects considerations. The proposed method can help managers in the disposal and solid waste management activities.

ACKNOWLEDGEMENTS

The authors are thankful to the assistance of staff of Isfahan Natural Resources Ministration for their cooperation in providing necessary information. The authors also appreciate the help and suggestions provided by anonymous reviewers of IJEHSE.

REFERENCES

Abdoli, M.A., (1993). Municipal solid waste management system and its control methods. Metropolitan recyclying organization publication, 142-154.

Chang, N. B., Parvathinathan, G., Breeden, J. B., (2008). Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. Journal of Environmental Management, **87**: 139-153.

Cheng, S., Chan, C. W., Huang, G. H., (2003). An integrated multi-criteria decision analysis and inexact mixed integer linear programming approach for solid waste management. Engineering Applications of Artificial Intelligence, **16**: 543-554.

Daneshvar, R., (2004). Customizing Arcmap Interface to Generate a User- Friendly Landfill Site Selection GIS Tool. Department of Civil Engineering. University of Ottawa Canada, 7-13.

Delgado, O. B., Mendoza, M., Granados, E. L., (2008). Analysis of land suitability for the siting of inter-municipal landfills in the Cuitzeo Lake Basin, Mexico. Waste Management, **28**: 1137-1146.

Farhoodi, R., Habibi, K., Zandi Bakhtiyari, P., (2005). Municipal solid waste landfill selection by using fuzzy logic in GIS environment (case study: Sanandaj City). Qualified Art (in Persian), **23**: 15-24.

Fathi, T., (2007). Environmental site selection criteria of hazardous waste landfill sites. Waste Management (in Persian), **8**: 236-243.

Gemitzi, A., Tsihrintzis, V.A., Voudrias, E., Petalas, C., Stravodimos, G., (2007). Combining geographic information system, multicriteria evaluation techniques and fuzzy logic in siting MSW landfills. Environ Geol, **51**: 797-811.

Javaheri, H., Nasrabadi, T., Jafarian, M. H., Rowshan, G. R., Khoshnam, H., (2006). Site selection of municipal solid waste landfills using analytical hierarchy process method in a geographical information technology environment in Giroft. Iran. J. Environ. Health. Sci. Eng., **3**(3): 177-184.

Khorasani, N., and Nejadkorki. F., (2000). Site selection for urban waste in arid lands by the application of GIS: a case study for the city of Kerman, Central Iran. BIABAN (in Persian), **5**(1): 59-66.

Khorasani, N., Shokraie, A., Mehrdadi, N., Darvishsefat, A.A., (2004). An environmental study toward site selection of landfill for the city of sari. Iranian J. Natural Res. (in Persian), **57**(2): 275-284.

Kontos, T. D., Komilis, D. P., Halvadakis, C. P., (2005). Siting MSW landfills with a spatial multiple criteria analysis methodology. Waste Management, **25**: 818-832.

Loken, E., (2007). Use of multicriteria decision analysis methods for energy planning problems. Renewable and Sustainable Energy Reviews, **11**: 1584-1595.

Mahini, A. S., and Gholamalifard, M., (2006). Siting MSW landfills with a weighted linear combination methodology in a GIS environment. Int. J. Environ. Sci. Tech, **3**(4): 435-445.

Malczewski, J., (1999). GIS and multi criteria decision analysis. samt Inc (in Persian), 336-339.

Omrani, G.A., (2004). Solid waste, management, collection, transportation, sanitary landfill and composting. 3rd Ed. Azad University- Scientific Inc (in Persian), 178-185-189.

Poorahmad, A., Habibi, K., Zahrayi, S.M., Nazari Adli , S., (2007). Using of fuzzy algorithm and GIS for municipal equipment site selection (case study: landfill site of Babolsar City). Environmental Science (in Persian), **42**: 31-42.

Saaty, T. L., (2008). Decision making with the analytic hierarchy process. Int. J. Services Sciences, **1**(1): 83-98.

Sener, B., Suzen, M. L., Doyuran, V., (2006). Landfill site selection by using geographic information systems. Environ Geol, **49**: 376-388.

Siddiqui, M., Everett, J. W., Vieux, B. E., (1996). Landfill siting using geographic information systems: a demonstration. Journal of Environmental Engineering, **122**(6): 515-523.

Singh, A. P., and Vidyarthi, A. K., (2008). Optimal allocation of landfill disposal site: a fuzzy multi-criteria approach. Iran. J. Environ. Health. Sci. Eng., **5**(1): 25-34.
Soupios, p., Papadopoulos, N., Papadopoulos, I., Kouli, M., Vallianatos, F., Sarris, A., Manios, T., (2007). Application of integrated methods in mapping waste disposal areas. Environ Geol, **53**: 61-675.
Sumathi, V. R., Natesan, U., Sarkar, C., (2007). GIS-based approach for optimized siting of municipal solid waste landfill. Waste Management, **28**: 2146-2160.
Yaghmayian, K., (2003). Material decomposition. Waste Management (in Persian), **1**: 4-10.