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Integrating GIS and Fuzzy Logic for Urban Solid Waste Management (A Case Study of Sanandaj City, Iran)

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Abstract: The city of Sanandaj with population of 340000 in 2003 produces 714 tons of solid waste per day. Waste dumping is the main method of solid waste disposal during the thirty past years. The conditions show that the present site is quite unsuitable because many principles and criteria for site selection are not considered. So in the near future, the severe environmental impacts will threats the health of Sanandaj's inhabitants. The research attempts to integrate fuzzy logic and GIS with the help of Remote Sensing in selecting the most suitable area for the waste disposal. In this study we georeferenced many data which ranges from physical to socio-economic to monitor the impacts of all different factors. Some of these factors are; distance from the legal limits of the city, distance from main road, airport, main urban utilities, other human settlements, surface water resources, wind direction, population density, gradient, fault line, vegetation cover and geology. The data and information has been integrated and then by using satellite images, three areas in the 20 km of north east of Sanandaj city were identified for the solid waste disposal.

Key words: Site selecting, GIS, fuzzy logic, geometric correction of images, waste disposal

INTRODUCTION

The unprecedented urban population growth and the extensive use of technology has changed the living styles of people worldwide in one hand and the scarcity of natural resources in the other led to many socio-economic problems which ultimately endanger our living environment. In lower-income countries the main problems are related to collection, with between one-third and half of all solid waste generated in Third World cities remaining uncollected (Pacione, 2001). Iran like other developing country has experienced a high urban population growth. Today, the country is faced an environmental crises as there is not a comprehensive plan in the field of solid waste management. The only way to dispose the waste is to find a place for dumping regardless to its ecological and socio-economic potentials (Abdoli, 2000). The economic boom of 1970 due to oil export has changed the feature of many Iranian cities such as Sanandaj. The invasion of Iraqi troops to Iran has pushed much population from the border contact zones toward the city as the number of population increased from 95000 in 1976 to 340000 in 2003. The most obvious resultant of such events was the extensive growth of the city. This Study is based on two assumptions that the present waste landfill is not suitable and created many socio-economic and environmental problems and the second that selecting a new appropriate site is impossible without using new techniques such as GIS and integrated models. The capability of GIS as a set of soft and hardware has proved to be suitable world-wide to site selection for solid waste management as Al-Jarreh and Abu-Qdais (2004) addressed the problem of sitting a new landfill using an intelligent system based on fuzzy inference. They considered several factors in the sitting process including topography and geology, natural resources, socio-cultural aspects and economy and safety. A weighting system is used for all of the considered factors. The results from testing the system using different sites show the effectiveness of the system in the selection process. Partovi (2000) presented a strategic solution to the facility location problem which incorporates both external and internal criteria in the decision-making process by using AHP with ANP and QFP (Partovi, 2006). Svoray *et al.* (2005) applied multi-criteria and GIS techniques to investigate the suitability of different land uses for residential, industrial, forest and natural conservation (Svoray *et al.*, 2005). Higgs (2006) integrated multi-criteria and GIS to investigate the possibility of public participation in the solid waste management (Higges, 2006). Chang *et al.* (2007) used multi-criteria and fuzzy model with the help of GIS to find

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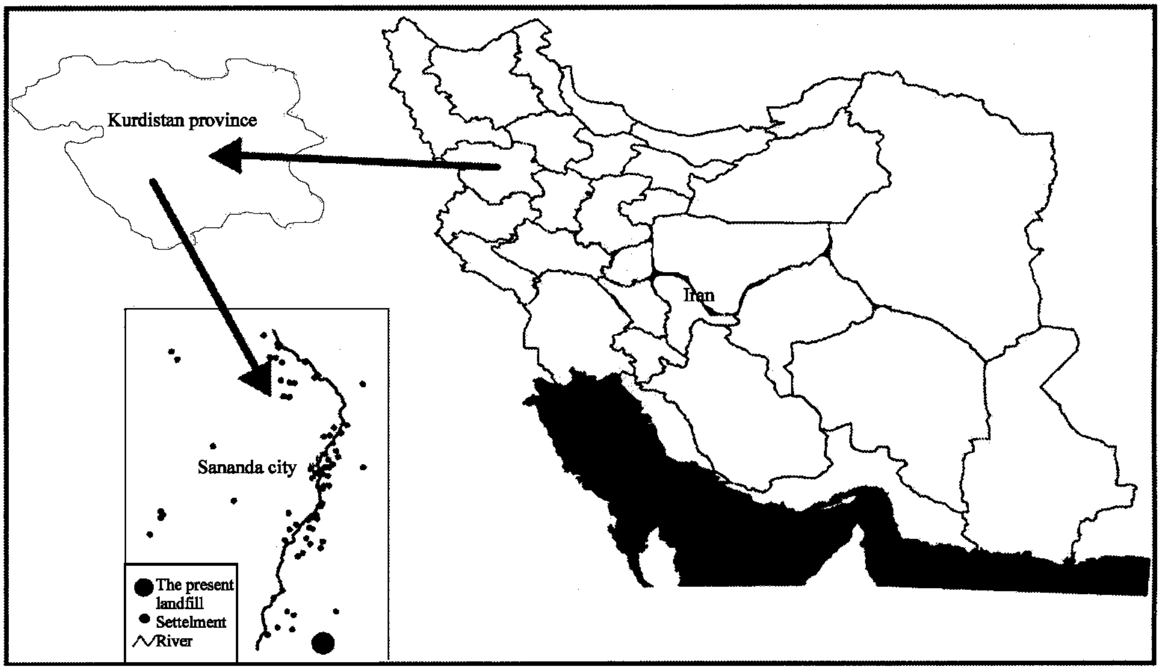

Fig. 1: The position of Sanandaj in Iran

a site for the southern Texas waste disposal, they persuaded the procedure in two stages (Chang *et al*., 2007). Rashed assessed the vulnerability of earthquake hazards through spatial analysis of urban areas in Bangladesh, he by integrating fuzzy logic and AHP classified three area of high, medium and low risk (Rashed, 2003). A study by Vastava and Nathawat through using GIS and Remote Sensing showed that the pairwise comparison of different indicators is quite useful to determine an appropriate site for waste disposal (Vastava and Nathawat, 2002; Eldin and Eldrandaly, 2004). Today, the management of urban waste is the main challenge of most of the urban authorities and planners. The main aim of this study is to find a place for the waste disposal which has the least negative environmental impact. Sanandaj city is the political center of Kurdistan province in the western border of Iran (Fig. 1).

MATERIALS AND METHODS

The original study of the present research was carried out in 2005. The study has been organized in four stages as follow. In the first step the city of Sannadaj was studied with regard to its spatial-physical characteristics in the context of its master plan. Also the socio-economic features of the city were carefully investigated. In the second stage the basic maps were used to update the recent different urban land use changes. This stage was followed by regular field observation to complete some possible shortcomings. In the third stage the main works have been done in labs. The satellite images of TM land sat of 1990 and 1998 with aerial photos of 1956 and 1994 were analyzed and interpreted to provide the different layers by extensive application of Arc/info, Arc/view and Edrisi-3 for geometric correction and digitization. And finally the results of the three first stages were coordinated and corresponded for site selection. All the descriptive and spatial data were incorporated using the fuzzy logic for obtaining membership degree of all data. In the process of the finding the optimum site, the conceptual model and effective indicators for waste disposal were defined and introduced in the eight stages (Fig. 2). Twenty different layers were prepared such as topography, gradient, geology, land use, soil, incompatible uses and transport network and etc. The preparations of these layers were done in the form of topology, correction and editing, geometric correction of images and maps. After defining the appropriate method of incorporating, the recognition of the integrated functions of the layers were done in the frame of union, intersection, clipping, buffering, merge, updating and then after the table analysis of integrated information banks the appropriate site was identified and investigated.

Different types of integrated information models for site selections: One of the main capability of GIS as an

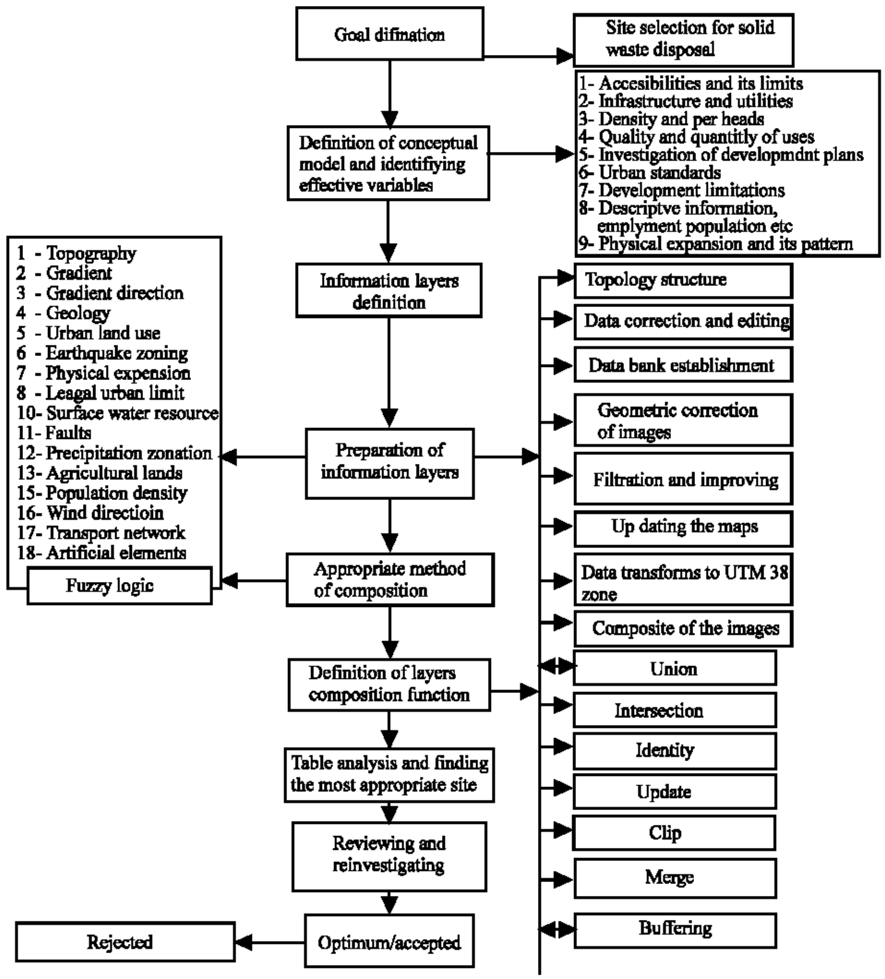

Fig. 2: The conceptual flow of the research

exclusive system is its potential of integration, modeling and site selecting through land valuation. By integrating and compositing the different criteria the most appropriated location can be selected. There are different methods for criteria composition which some of them include as follow:

Boolean Logic: This logic originated from the name of an English mathematician Gorge Boolean who by valuating each unit in information layer on the base zero and one value. The logical composite of values is in two ways; yes or no. Each place examined by valuating as true or false and so there is not another option. In the end the model introduces a location which is appropriated or inappropriate for a given activity. The main shortcomings of the model are. It can not be applied to the real world because the results of the model are 100% true or false. If a criteria become inappropriate in the process of sitting, that location will be omitted. Also when the criteria are many, the model has no capability to find an appropriate location for location.

Index overlay: In this model the different factors and classes has different values and then a set of flexible maps will be provide which has a range of numbers. For example, gradient has different degrees for different purposes which may change from 3 to 10% or more. Here, an appropriate gradient for urban development is between 3 to 8%. The process of weighting will be done for fault line, gradient direction, soil and etc. Then by two variable analyses the layers composite and each location with higher values would be selected.

Probability logic: In this model by using coincident coefficient model, Kappa indicator, entropy, Moran indicator and Cramer and so on the different information layers would be integrated and then analyzed in two or multi layers.

Coefficient correlation: Two layers will be analyzed on the base of their relationship. For instance the relationship between height and temperature, disease distribution and population density, the aim is to find the degree of association which may be high or low. The weighting of the layers is on the base of highest correlation coefficient.

Artificial neural networks: This is a kind of modeling on the nature of human mind, which is simulated by using mathematical models. Application of this model for integrating layers and variables is in its initial stage.

Fuzzy logic or the logic of black and uncertainty: Fuzzy logic was first developed by Lotfi A. Zadeh an Iranian-American scholar in the 1960s in order to provide mathematical rules and functions which permitted natural language queries. Fuzzy logic provides a means of calculating. It enabled many concepts, variables and systems to be illustrated mathematically and provided a background for reasoning, control and decision making in the uncertain conditions. Membership degree, combination, joint, similarity, complement, multiple, plus, gamma are the basic powers of this integrated model. For creating layers and fuzzy set the mathematical functions of linear threshold, sigmoidal, S shape, hyperbolic and etc can be applied. For example, sitting for urban utilities such as power station several variables like distance from transport network or a fault line must be studied. Membership degree would be determined as follow:

$$f(x)=\begin{cases} \text{If } x<1000\,\text{m} \\ \dfrac{X\max-X}{\Delta x}=\text{value} \text{if } 4000<\times<1000\,\text{m} \\ \text{Ifx}>4000 \end{cases}$$

Here, the fuzzy amount of a 1000 point from transport network equals 1 and the fuzzy amount for 4000 points from even transport network is 0 and this amount would be 0.46 for 1600 point from transport net work which all have been resulted from linear threshold function. For all of the other layers these procedures could be set up and the space of the area would be weighted. The only weakness of the model is the substandard weighting in connection with different attitudes of users. Nonetheless this model is one of the most applied integrated models in urban planning.

The main criteria of site selection for urban solid waste disposal: However there is not a standard definition of factors for site selection of solid waste disposal but four important variations consists from:

Gradient: In this model gradient is a physical parameter, in high slop waste disposal is impossible as in the rainy season the waste leakage pollute the area and the establishment of needed utilities like road is too costly. So the best degree of the gradient is 3-6%.

Precipitation: Rain with soil erosion accelerates the leakage of the waste and transfers the chemical and organic pollutants into main water channels. This condition leads to diffusion of insects and other animals which can threat the nearby communities.

Wind direction: One of the obvious problem with waste minefield is the bad smell which causes discomfort for the near settlements. Clearly wind direction can make the condition worst.

The average disposal duration: Waste disposal land usually should cover a time range of 20 to 40 years due to population growth. According to the American Planning Association (APA) research the area of land can be obtained by using following formula (Kizek and Power, 1996):

$$V = R/D\ (1-P/100)+CV$$

Where:

V	=	Needed space for a year
R	=	Per capita production
VC	=	The needed cover soil
P	=	The percent of decreased waste volume due to compression
D	=	The average density of waste

The Municipality Organization of the Interior Ministry of Iran has recommended some criteria in 2000 which seems inappropriate to be generalized to all parts of the country (Anonymous, 2001a). In this research the following criteria were evaluated for selecting a new site.

- Three hundred meter from drinking water well
- Hundred meter from ground r resources
- Displacing from the heavy rain area
- At least 10 m clay soil under the surface.
- Away from dominated wind direction.
- At least 80 to 100 m from fault line.
- At least 100 years of return flooding period.
- Silt clay of surface soil and sand silt in next stage.
- Less than 40% gradient.
- Three hundred meter from population center like schools and public parks.

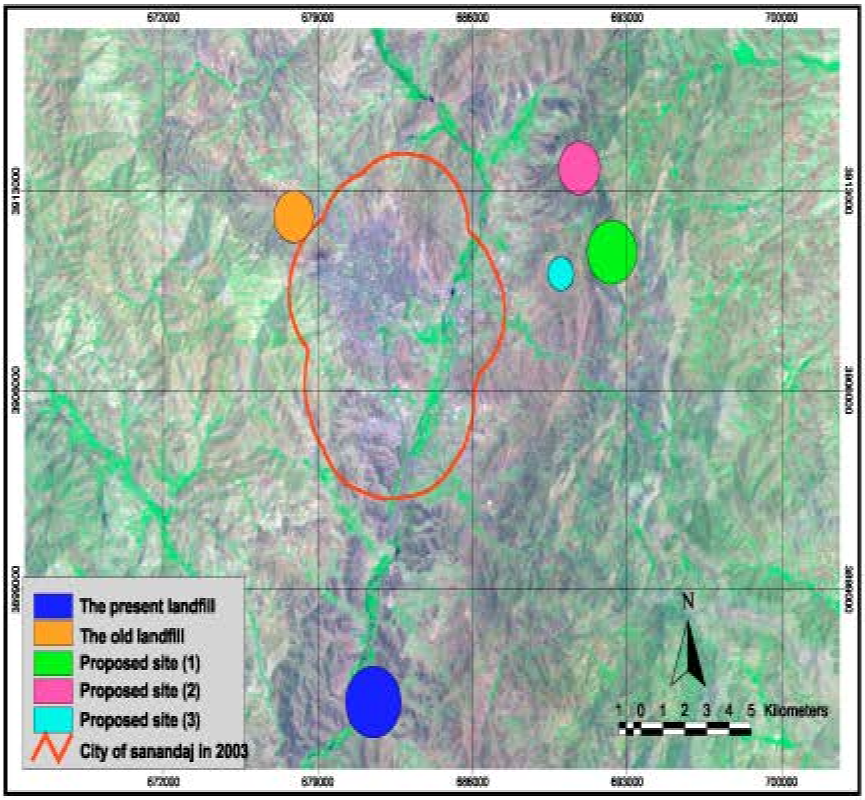

Fig. 3: A 3D map of three proposed sites on the satellite images (land sat)

- At least 2 to 3 and maximum 20 km from cities.
- Six to seven width for adjacent transport lines.
- Away from agricultural, forest, wetland and rangeland.
- At least 8 km from airport.
- At least 700 m from historical sites.
- Land price should be 50% lesser then the most expensive land in the area.

It is clear that the above criteria need to be altered with respect to each region for more accuracy and generalization. The study has chosen an area in the radius of 20 km from the city in its legal limit. By using fuzzy logic and index overlay 18 natural and physical factors were integrated and weighted. Three appropriated location were selected as new sits for urban solid waste disposal. These new sites are located in a close distance to each other which can be used for establishing new recycling and compost plant. The recommended sites were the result of 178 thousand polygons of information layers, maps and satellite images (Fig. 3).

RESULTS

Population and domestic waste: According to the result of fifth national census the city of Sanandaj had 277000 residents in 1996 and it increased to 300000 in 1998. The official source announced that 100% of population is under the solid waste collecting services in 1998 (Table 1). The seasonal division of solid waste shows that the average weight of daily solid waste of the city is 170 tons in spring, 170 in summer, 150 tons in autumn and 140 tons in winter, which the annual prediction is about 630 tons. That is, the annual waste production is 511000 cubic meter. A detail study shows the solid waste loses its volume about 20% and each cubic meter with 450 kg weight decreases to 0.2% cubic meter. If 6500 tons of waste disposed in a layer of 2 m thick, there needs about 1500 m^2 per day which would be 54 ha in a year (Hamshahri, 2004). With regard to this situation the following hypotheses is true about Sannadaj solid waste production:

- With 630 tons waste in each day, the total produced waste is 229950 tons.

Table 1: Population under the waste collection services

City and province	Population 1996	Population 1999	Population 2000	Population under waste collecting services (%)
Sanandaj	277808	300000	325000	100
Urban areas	705715	778000	800000	98.3
Location coefficient	39.29	38.5	40	-

Table 2: The daily waste production in different seasons

	The average produced waste in 1999 (tons per day)						
City/province	Spring	Summer	Autumn	Winter	Total	Waste per person	Predicted waste for 2002
Sanandaj	170.00	170.00	150.00	140.00	630.00	2.1	682.00
Urban areas	647.00	642.00	639.50	564.00	2492.00	3.2	2560.00
Location coefficient	26.27	26.47	23.45	24.82	25.28	-	26.64

- If each cubic meter of waste equals 450 kg, the daily produce wait will be 1400 m^3 and about 511000 m^3 annually.
- If the total waste is disposed in 3 m of the ground the required areas is 17 ha and if the waste disposed in a depth of 5 m this figure decreases to 10.2 ha.

The socio-economic comprehensive study of Kurdistan province in 1994 estimated that the produced waste of the city is 0.9 kg per day (219 tons) and 1.2 kg for 2011 (Hamoon, 1996). But this figure only after 5 years later, i.e., 1999 increased to 2.1 kg (Table 2).

Industrial and medical wastes: As we know the industrial and medical wastes are more dangerous to home-generated wastes. A report shows that in industrial and medical sites 630 different kinds of chemical materials are used which 300 of them are poisonous and 330 are non poisonous and harmless (Anonymous, 2001b). The city of Sanandaj generates about 1 tons industrial and 3.5 tons medical waste per day. These figures are 4.6 and 13 tons in other urban places of the province, respectively. That is the location coefficient of the industrial and medical wastes of the city compared to other urban places is 25.16 and 21.73%.

The collecting methods: The semi-mechanized waste collection is used in the new and geometric made parts and in the high gradient and organic layout sections with their narrow lanes traditional methods is applied where the vehicles can not enter. So, as the Table 1 shows 70% of the Sanandaj city waste is collecting by semi-mechanized method. The concentration of this indicator is about 82% compared to the city. In other words the other urban places of the province have 12% more than the Sanandaj which the main problem to using traditional method is related to the organic layout of the old parts of the city.

The collecting machineries: The most of the wastes are collecting by municipal machineries in the different areas of the city between 21 to 5 and the deliver to dumping field in Sanandaj-Kermanshah road about 10 km from the city. All of the waste collecting services are done by the municipality without private sector participation. The garbage first are collected by the formal iterant of the municipality in a main neighborhood container and then delivered to the main dumping filed for disposal by small lorries, handy carriage and garbage trucks. The location coefficient in the city for container is 69.5% compared to 26.9% of garbage trucks.

The collecting costs: The average collecting and delivering cost of each urban solid waste was 42.8 Rials in the city of Sanandaj. So the cost of collecting of each ton of waste was 42000 Rials which makes 15 million Rials annually according to the 1999 price. With regard to this situation the total costs of waste collection and delivery was 945 milliard Rials for the city. The proportion of this cost is 10% of total current and development costs of the city which is quiet high for the city expenditures. So it seems establishing compost plants and recycling process is a crucial need for the solid waste management of the Sanandaj city.

The dumping field of the city: Waste disposal is different which all of the methods aim to reduce the dangers of the waste in human and natural environment. The main methods of the waste disposal include incineration, disposing in the ground, pouring in the oceans. The hygienic disposal is a method which refers to an engineering operation to dispose the waste in the deep layers of the ground which has no harm to the ecological sustainability of the area. In this method the volume of waste reduces to least and in the end of each day is disposed in the layers of the ground by covering with soil and lime. The present dumping field of the city is located in the legal limits of the city about 10 km in a distance of 400 m to the main transit road of Sanandaj-Kermanshah which connects the North West part of the country to the South West. The waste dumping area is bounded by three villages of Chenareh, Cheno and Kilac and about

600 m from the river Gheshlaq. The different maps and satellite images of the region indicates that the present dumping field is quite inappropriate and created many problems such as surface and underground water and air pollution. In addition it has land use contradiction and is uneconomic with regard to the delivery cost, land value and ownership.

DISCUSSION

The urban physical growth of Sanandaj city has been resulted from two main reasons. The first one is related to the high rural-urban migration and the second due to high natural population growth. The population of the city has increased from 95000 in 1976 to 340000 in 2003. The major consequences of urban growth have been the intensive use of natural and urban utilities and mainly the production of solid waste in different quantity and quality. Disposing 714 tons of waste in the outskirt of the city created many environmental problems and degraded human health. So, the present disposal place of the city in position of x = 681385 and y = 3894891 in UTM is not appropriated. The major problems could be discussed as follow.

- With regard to the fact that the province of Kurdistan is a less developed region compared to the other parts of the country. So risking the natural resources of the area is not justifiable. For instance the province has the first rank of strawberry production in the country by annual production of 22000 tons (Aeoso, 2003) while the dumping field of the city is only in 5 radius of the main farm of the strawberry. Also the area is located among the tree villages.
- The wind direction of 5 recent year shows that the dominant winds come from the south region along the river Gheshlaq towards the city. So many residents suffer from the problem of stink smell. Air pollution and the bad smell have limited the tourism potential of river Gheshlaq.
- The distance from the surface water is less than 100 m in some areas. Moreover the site is located in 500 m from the main river and tens of semi-depth wells which are the main source of irrigation for agricultural lands. While the average depth of the groundwater is 114, 108 and 126.9 m in the neighboring provinces like Ilam, Zanjan and Kermanshah respectively. This figure decreases to 25 m in the area. Also the normal average depth of underground water is about 68.9 meter in the country. Therefore the underground water contamination is a serious problem.
- The site situated in the vicinity of the city airport which according to the Interior Ministry is 8 km less than the standard level.
- The gradient of area in the most of the parts is more than 40% (the standard gradient is below 40%). The new sites have an average gradient less than 25-30%.
- The trend of physical growth of the Sanandaj shows more than 90% of the growth has been towards the south and south east. So in the near future the present site of waste disposal will situate in the service zone of the municipality.
- From economical point of view the site should be sufficient for waste disposal in long-term periods at least 20 years, but the present location has a limited extension and roughly is sufficient for only 9 years.
- The findings of the research are significant as the model used here is generalized and applied to the socio-economic and natural characteristics of the region. In other words the technique has been localized and the new sites were prioritized. It needs to be mentioned that a few study have been done in the country in the field of site selection but as almost all of them concentrated only on a few factors, the results never practiced by the urban authorities. The present research ends with following conclusion. The study revealed selecting a new site for the near future to dispose the waste is quite crucial. So this study tried to investigate many socio-economic and physical criteria by using GIS and fuzzy logic to evaluate different sites for selecting an appropriate dumping field. The city of Sanandaj is growing very fast and the residents need green space for their leisure times and also the agricultural land of the city periphery has important role for the city and rural household's economy. Therefore the new sites recommended by the present study consider these prospects. This model can be applied to the other regions of the country which have almost similar natural and physical characteristics with the study area. In the end we suggest along with environmental assessment there are a crucial need for cultural activity to increase the public knowledge about origin separation and recycling to lesser the amount of the urban solid waste.

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