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Landfill Site Selection Using Spatial Information Technologies A Case Study in Sanandaj Municipality, Western Iran

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Abstract

The appropriate site selection is an important issue for waste management activities in developing countries. An inappropriate landfill site may cause negative environmental, economic, and ecological impacts. Sanandaj city, western Iran, with a population of 370, 000 people faces daily production of 330 tons of solid wastes. Current landfill site of the city has caused environmental problems, while losing its capacity. This study attempted to determine appropriate landfill sites for municipal solid wastes in Sanandaj city through combination of Geographic Information System (GIS) and Multi-Criteria Decision Making (MCDM) techniques. For this purpose, nine information layers were weighted according to Analytic Hierarchy Process (AHP) and Inversion Hierarchical Weight Process (IHWP) methods. The final suitability maps for a landfill construction in both methods obtained by using overlay function and seven exclusionary criteria, which were used to prepare the restriction map. The result of this study showed that IHWP method increased the accuracy of the final decision for identifying best quality landfill sites and provided better results in comparison with AHP. Finally, an area with the extent of 87 ha, located approximately 5 km north-west of the Sanandaj, was identified as priority number one to establish a landfill site.

Key words: Site selection, Municipal solid wastes, Inversion Hierarchical Weight Process, Analytic Hierarchy Process, Geographic Information System

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INTRODUCTION

The increasing development of urban regions and the continued discharge of waste into the environment caused different health problems to human society (Abdoli, 1993). Municipal solid waste management is one of the major issues facing municipal authorities. Recycling, source reduction and waste transformation are methods used to manage solid wastes (Sener et al., 2006). Landfilling is the most common method for the disposal of solid wastes (Komilis et al., 1999). The term landfill is used to describe an operation for municipal solid waste disposal. The first important step in planning a landfill location, is the site selection according to different regulations and criteria (Waele et al., 2004). Landfill siting is a complex subject, because the site selection process depends on different factors and criteria, such as environmental (geology, hydrology and morphological properties) and socio-economics (price of the land, distance from the urban and rural areas) factors. To identify the best available disposal location, this location at the same time must minimize economic, health and social cost (Siddiqui et al., 1996) and must not cause damage to the ecology of the surrounding area (Erkut &Moran, 1991).

A number of methods for achieving optimal landfill sites have been improved and used in landfill site selection process to combine numerous criteria. Gorsevski et al (2012) used Spatial Multi-Criteria Decision Analysis (SMCDA) method for landfill site selection in Macedonia. They standardized environmental and economic factors by fuzzy membership functions and combined by AHP and Ordered Weighted Average (OWA) techniques for identifying landfill suitability. Sener et al (2006) implemented two different MCDA methods; Simple Additive Weighting (SWA) and AHP, for Ankara landfill siting. The principle of AHP method is dividing the decision problem into more smaller and intelligible parts, to analyze each part separately and then integrate the parts in a logical way (Malczewski, 1997). They declared that both methods yield conform better results according to field investigation. Mahini and Gholamifard (2006) combined GIS with SWA to evaluate the suitability of landfill sites in Iran. Leao et al (2001) used GIS and modeling techniques to determine the appropriate landfill size over the time. Afzali et al (2011) used AHP and fuzzy logic method for municipal landfill site selection. To do this, a complex problem is divided into a number of simpler problems in the form of hierarchy (Erkut &Moran, 1991). Khan and Faisal (2008) used Analysis Network Process (ANP) model as the most appropriate way to resolve complex issues. Because of its flexibility, this model helps decision makers in selecting the best solution. Isalou et al (2013) developed an integrated fuzzy logic and ANP to locate a suitable location for municipal solid wastes in Kahak Town, Iran. They clamied that integration of fuzzy logic and ANP can achieve better results in comparison with other models. Motlagh and Sayadi (2015) used environmental and socio-economic factors for siting MSW landfill of Birjand plain. They standardized criterion maps through fuzzy membership functions and for the weighting of layers the ANP algorithm was applied. Finally, they used OWA with linguistic quantifiers as decision rule. They claimed that OWA method had a great potential in the modeling of the complex decision-making problems. Several techniques for landfill site selection can be found in literatures (Charnpratheep et al., 1997; Higgs, 2006; Zamorano et al., 2008; Delgado et al., 2008; Moeinaddini et al., 2010; Chitsazan et al., 2013; Feo & Gisi, 2014).

According to the above-mentioned studies, it could be understood that the combination of GIS and SMCDA have been applied to accomplish potential landfill sites in different areas. In this study, IHWP, which includes both GIS and MCDA was used as the first time for landfill site selection process in Sanandaj city, Western Iran. Because of the kind of structural similarity between AHP and IHWP, we also used AHP model for comparing the results of both methods and their advantages and disadvantages for indentifying the best quality landfill sites.

Study area Sanandaj city as the capital of Kurdistan province with the extent of 3033 km^2 located in western part of the Iran, at the east longitude of 46° 26" to 47° 18" and north latitude of 35° 3" to 35° 38". The topographic map of the city shows that the elevation of the study area generally ranges between 1200 and 2900 m. The weather condition in the western edge of the Iran is characterized by a pronounced seasonal variation including a long freezing period in winter and mild summer (Sharifi et al., 2009). The annual average humidity is 51.2% and in the winter is more than the summer. The average annual precipitation is 491 mm. The major winds in city are the west and northwest winds. Fig. 1 shows the position of Sanandaj city in Iran.

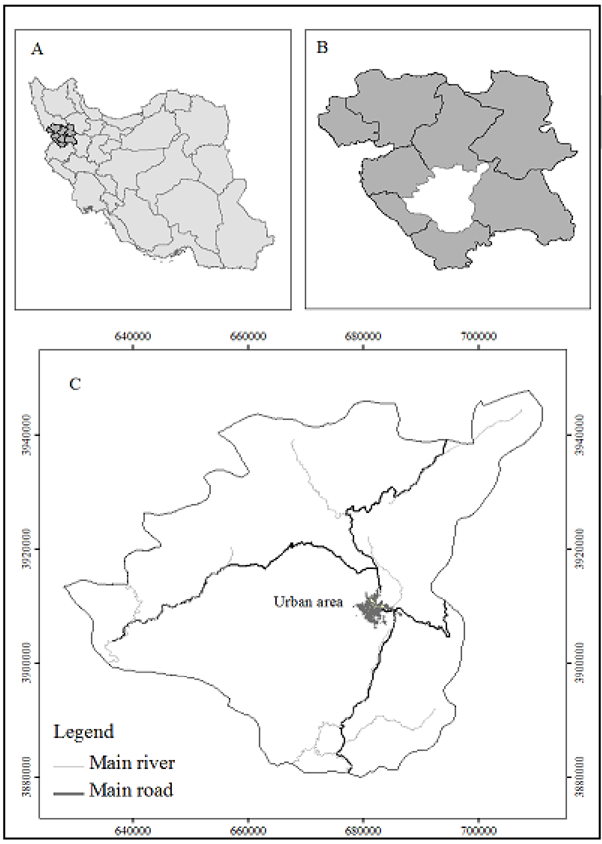

Fig. 1. Location of Sanandaj city in A: Iran and B: Kurdistan Province

Sanandaj city with a population of 370, 000 people faces daily production of 330 tons of solid wastes. The current landfill area of this city, with a distance of approximately 10 km from the urban area, for its vicinity to agricultural lands, causing ground water and surface water contamination and overloading. (Farhoudi et al., 2005). Therefore, in this study IHWP method, one of the decision-making techniques, which can be used to analyze and support multi objective decisions alongside with AHP model were used to select alternative landfill sites for the Sanandaj municipality in western Iran.

METHODS

Landfill site selection process requires consideration of comprehensive criteria and evaluation steps to identify the best available disposal locations and to eliminate subsequent nuisances (Abdolhadi et al., 2011). In current study nine attributes were involved in the computation process. These attributes were soil depth, main rivers, springs and wells, elevation, slope, urban areas, villages, road network and landuse. The landuse map was obtained from landcover map, with scale of 1:250, 000. The soil map was obtained from land capability map in scale of 1:250, 000. The other map layers were derived from the 1:25, 000 topographic maps. In the present study the overlaying method of information layers were used to achieve suitable landfill sites. The cell size of these layers was considered 25*25 m. The criteria analysis for landfill site selection according to IHWP and AHP methods in a GIS environment, is described in the following.

After the preparation of all input data layers, IHWP, a multi criteria evaluation method was used for ranking and weighting the information layers. This method was used by Shieh et al (2010) for investigating urban vulnerability to earthquake. We assumed that this model can be used for different site selection projects according to its ability for supporting decisions, which have multiple objectives like landfill site selection process. This method involves three steps. The first step is "setting the data matrix". In assessing a site as a possible location for solid waste landfilling many factors should be investigated. In this step, all these essential information should be taken into account. Available information were collected according to the Directions of Iran Environment Organization and municipality and other related previous studies (Afzali et al., 2011; Tavares et al., 2011; Moeinaddini et al., 2010). All the data layers were derived and prepared from maps by scanning, georeferencing and digitizing the relevant information.

The second step is "fuzzy modeling of the criteria". In this step fuzzy set membership functions are used for standardization of the different raster GIS-based criteria maps. Fuzzy set theory was introduced by Zadeh (1965) to manage decisional uncertainty (Gorsevski et al, 2012). Fuzzy membership functions are as linear, sigmoidal, j-shaped, or it is also possible to define the fuzzy membership function by the user (Afzali et al., 2011). In this study, the quantative map layers were standardized in the continous scale of [0-1] by using sigmoidal fuzzy membership function through Idrisi Klimanjaro software. For the "Distance from urban areas" criterion, we considered a distance of 4 to 20 km from Sanandaj city as acceptable for a landfill site and we utilized sigmoidal– decreasing fuzzy membership function for this purpose, while for omitting the areas of more than 20 km distance from the city, the map layer of this criterion was produced with two classes, 4 km and more than 20 km buffer zones were scored as 0 and remaining areas scored as 1. Finally, to obtain the suitability map for this criteria, the present Boolean map was multiplied by its fuzzy-based map. Qualitative criteria (soil depth and landuse) were standardized by assigning different membership values for classes of the each data layer. The selection of suitable fuzzy function control points, which regulate the shape of the fuzzy membership function, and membership values were obtained by the experts in agreement with geographical characteristics of the study area and literature review (Table 1). These fuzzy-based map layers are shown in Fig. 2

Table 1. Fuzzy set memberships and control points used for criteria in landfill site selection

Criterion	Control point a	Control point b	Control point c	Control point d	Fuzzy function type /membership
Soil depth					
Very deep soils					1
Deep and semi-deep soils					0.8
Shallow soils					0.2
Distance from main rivers (m)	600	2000			Increasing
Distance from springs and wells (m)	300	2000			Increasing
Elevation (m)			1300	2000	Decreasing
Slope (%)			5	40	Decreasing
Land use Thin grassland and Semi-dense grassland					0.8
Dense grassland and Thin forest					0.6
Semi-dense forest					0.4
Dry farming and Dense forest					0.2
Orchards and Irrigation farming					0.1
Distance from urban areas (km)			4	20	Decreasing
Distance from villages (km)	1	10			Increasing
Distance to road network (m)	400	600	800	1000	Symmetrical

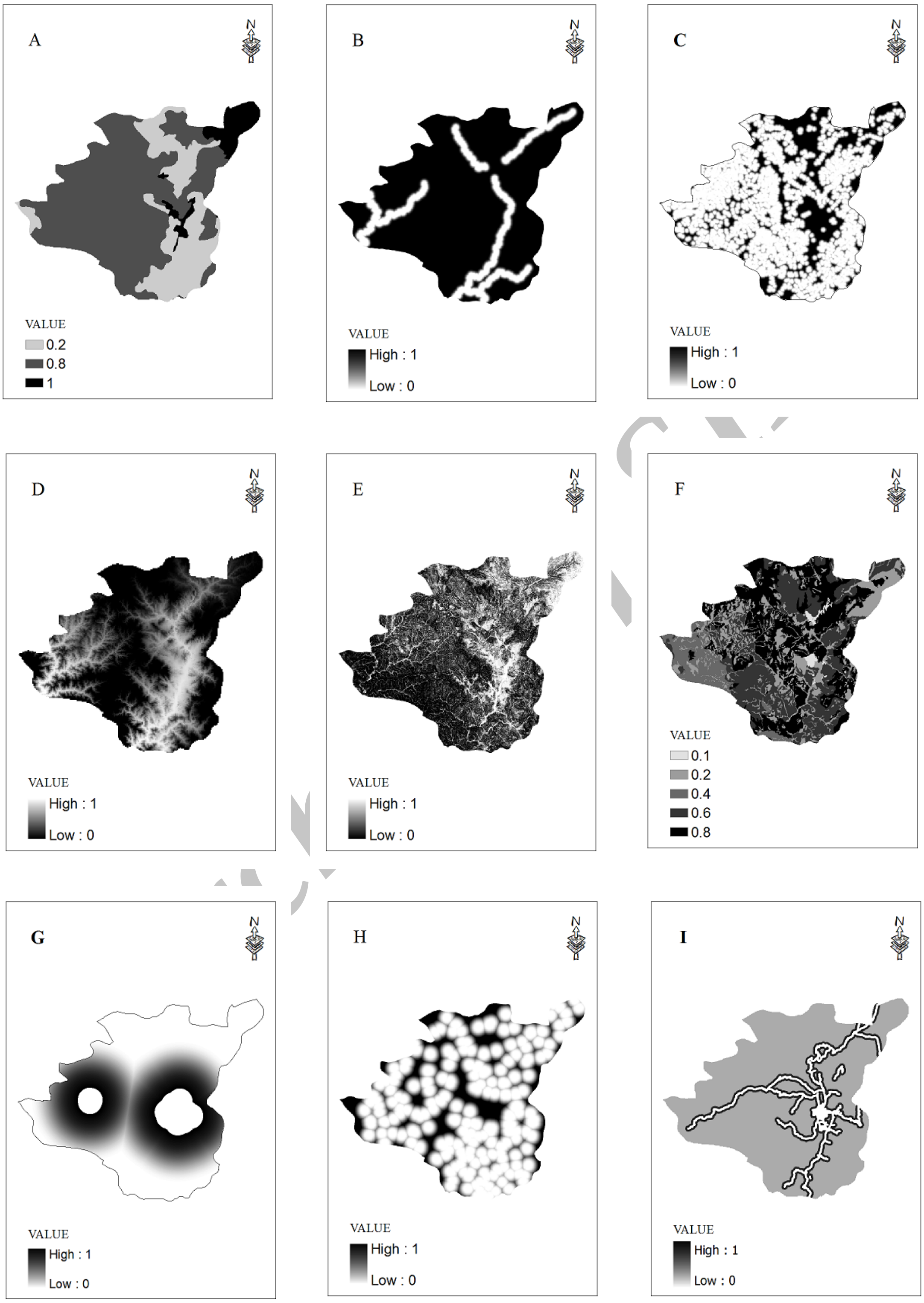

Fig. 2. Fuzzy-based map layers: (A) soil depth, (B) distance from main rivers, (C) distance to springs and wells, (D) elevation, (E) slope, (F) landuse, (G) distance to urban areas, (H) distance to villages, (I) distance to road network

At the third step, for weighting of criteria by IHWP (after fuzzy making the data layers), these criteria are ranked by Delphi method and the expert opinions according to their importance for related multi-criteria decisions. In Delphi method, after modification by repeating the process, the average of comments is used to make decisions (Malczewski, 1999). Number of experts in Delfhi method is 10 to 30. In this study, we used 12 for scoring the criteria.

In IHWP, all the criterion should be considered in classified form, because the weights are assigned for the inner classes of each criteria. For scoring the map layers and calculating the weight of their inner classes by current method, these formulas have been used (Shieh et al., 2010):

$$X = D/N$$

X= the initial score for each criterion

D= score from Delphi inventory

N= number of classes that each criterion stands for

$$j = D - (N - i)X$$

j= the obtained weight for each class of the criterion

i= dedicated number for classification of each criterion

Classifications and scores for each criterion and their interior wheights are shown in Table 2. In this table, classes with a score of zero were identified as unacceptable for being in a landfill area in fuzzy logic model (membership grade= 0). These classes are not considered in the calculation process of the initial score for each criterion (X). Numbers in the culomn "Score of the layer" are the scores from Delphi inventory (D). Numbers in parentheses in the culomn "Classification" are dedicated numbers for classification of each criterion (i). The final weights for classes of the each criterion are calculated in the last column (j). For example, in this study according to the experts, soil depth criterion was the first in priority to locate landfill site in comparison with the other criterion, so the layer score is 9, this criterion is contained of three classes, so the weight of classes are 3, 6 and 9. The more the weight, the more suitable it is. The production of weighted map layers was carried out in Arc.GIS software. Finally, for obtaining weighted standardized map layers, each IHWP weighted map multiplied by the standardized map of the factor and the final suitability map were produced by aggregation of resultant maps.

We also used AHP model (Saaty, 1980). It plays an important role in selecting optimized alternatives. In this method, the first step is establishing the hierarchy of complex decision into simpler decision problems. In current study, hierarchy model has three levels (Fig. 3), the first level represents the ultimate goal of the decision hierarchy (landfill site selection for Sanandaj city), the second level contains two main groups, ecological and socio-economic criteria, which include soil depth, distance from main rivers, distance to springs and wells, elevation and slope and four distance to urban areas, distance to villages, landuse and distance to road network, respectively. The alternatives for establishing the landfill site would be overlaying obtained by relative map layers.

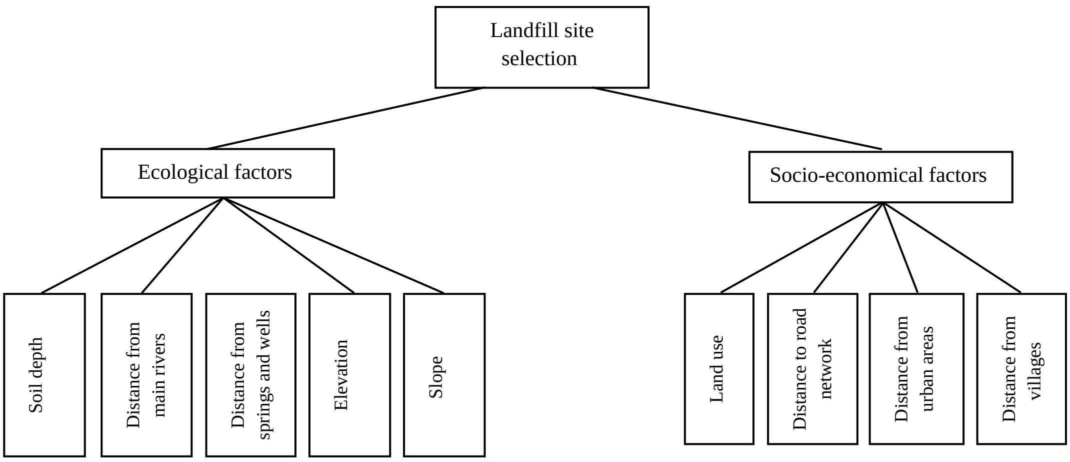

Fig. 3. Hierarchy model of landfill site selection

Table 2. Classes produced for each criterion according to IHWP method

Criterion	Score of the layer	Classification	Weight
Soil depth	9	Very deep soils (3)	9
		Deep and semi-deep soils (2)	6
		Shallow soils (1)	3
Distance to main rivers (m)	8	0-600	0
		600-1000 (1)	2
		1000-1500 (2)	4
		1500-2000 (3)	6
		>2000 (4)	8
Distance to urban areas (km)	7	< 4 and >20	0
		4-8 (4)	7
		8-12 (3)	5.25
		12-16 (2)	3.5
		16-20 (1)	1.75
Distance to springs and wells (m)	6	0-300	0
		300-1000 (1)	1.5
		1000-1500 (2)	3
		1500-2000 (3)	4.5
		>2000 (4)	6
Distance to villages (km)	5	0-1	0
		1-3 (1)	1.25
		3-5 (2)	2.5
		5-10 (3)	3.75
		>10 (4)	5
Elevation (m)	4	0-1300 (5)	4
		1300-1500 (4)	3.2
		1500-1700 (3)	2.4
		1700-1900 (2)	1.6
		1900-2000 (1)	0.8
		>2000	0
Slope (%)	4	0-5 (5)	4
		5-15 (4)	3.2
		15-25 (3)	2.4
		25-35 (2)	1.6
		35-40 (1)	0.8
		> 40	0
Landuse	3	Thin grassland and Semi-dense grassland (5)	3
		Dense grassland and Thin forest (4)	2.4
		Semi-dense forest (3)	1.8
		Dry farming and Dense forest (2)	1.2
		Orchards and Irrigation farming (1)	0.6
Distance to road network (m)	2	0-400	0
		400-600 (3)	2
		600-1000 (2)	1.32
		>1000 (1)	0.66

At the second step, pairwise comparisons were carried out at every level of the hierarchy to determine the relative importance of hierarchy elements. The method uses a scale with values range from 1 to 9 (Saaty, 1980)., 1= equally preferred, 3= moderately preferred, 5= strongly preferred, 7= very strongly preferred and 9= extremely preferred. The numbers 2, 4, 6 and 8 are used to recognizing similar alternatives (Brent et al., 2007). Reciprocals of these numbers are used to express the inverse relationship. The third step is computation of the weight of each factor in each hierarchy by their structural models. Finally, the weight of every lastest factor were calculated.

In AHP method pairwise comparison consistency, known as Consistency Ratio (CR), should be identified (Saaty, 2008). If CR< 0.10, this indicates a reasonable level of consistency in the pairwise comparison and the derived weights can be used (Eastman, 2003). Otherwise, it is necessary to reevaluate the relative importance. Pairwise comparisons of the elements in each hierarchy level and the weight of each factor in each hierarchy (W) are shown in Tables 3 to 5. The CR value for all of the comparisons were lower than 0.1, which indicated suitability. The final relative importance weights of ecological and socio-economic sub criteria (W_i) are shown in Table 6. We graded the classes of the criterion in the range of 0 to 5. The higher the score, the more suitable site for landfill is expected, while score 0 refers to the unacceptable zone of each criterion for a landfill site. Since the scores were qualified on different scales for each criterion, we standardized them by dividing the score of each class to the maximum score of related criterion map, so all the scores got the scale of 0 to 1. The classification range of each criteria is same as IHWP. The maps produced by AHP model for each criterion are illustrated in Fig. 4.

Table 3. The pairwise comparison matrix of socio- economic and ecological criteria

Landfill site selection	Socio- economic criteria	Ecological criteria	W
Socio- economic criteria	1		0.3333
Ecological criteria	2	1	0.6667

CR= 0

Table 4. The pairwise comparison matrix of socio- economic sub criteria

Socio economic criteria	Distance to urban areas	Distance to villages	Landuse	Distance to road network	W
Distance to urban areas	1				0.4673
Distance to villages	1/2	1			0.2772
Landuse	1/3	1/2	1		0.1601
Distance to roadnetwork	1/4	1/3	1/2	1	0.0954

CR= 0.0115

Table 5. The pairwise comparison matrix of ecological sub criteria

Ecological criteria	Soil depth	Distance to mainrivers	Distance to springs and wells	Elevation	Slope	W
Soil depth	1					0.4238
Distance to mainrivers	1/2	1				0.2898
Distance to springs and wells	1/3	1/3	1			0.1533
Elevation	1/5	1/4	1/3	1		0.0771
Slope	1/6	1/4	1/3	1/2	1	0.056

CR=0.0347

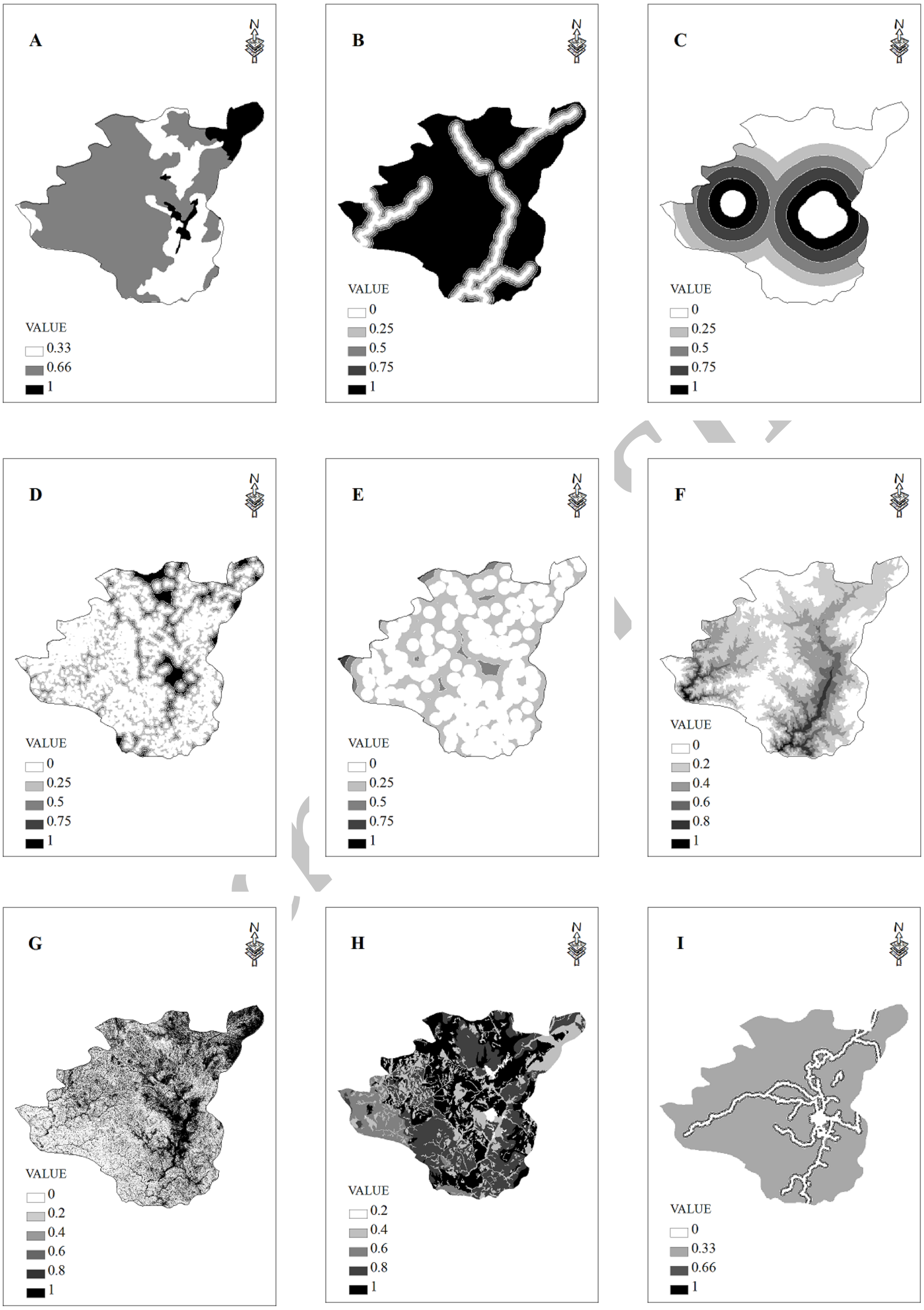

Fig. 4. AHP map layers: (A) soil depth, (B) distance from main rivers, (C) distance to urban areas, (D) distance to springs and wells, (E) distance to villages, (F) elevation, (G) slope, (H) landuse, (I) distance to road network

Table 6. Criteria weights for all factors. Wi is the the weight of every lastest factor

Goal	Criteria	Sub-Criteria	Wi
Landfill site selection	Ecological Criteria	Soil depth	0.2825
		Distance from main rivers	0.1932
		Distance from springs and wells	0.1022
		Elevation	0.0514
		Slope	0.0373
	Socio-economic Criteria	Landuse	0.1557
		Distance from urban areas	0.09239
		Distance from villages	0.05336
		Distance to road network	0.0318

RESULTS & DISCUSSION

Overlaying of weighted IHWP map layers was done through Raster Calculator tool in Arc.GIS software. It is possible that pixels with zero value from each layer that refers to unsuitable areas for landfill siting, could not be removed with overlaying, so making the constraint map becames necessary. For the production of exclusionary maps, that shows areas without capability for a landfill site, all the criterion maps are divided into two regions; the areas that defined as suitable area for a landfill site, and the remaining areas; classes with a score of zero for each criterion in IHWP (Table 2) as unsuitable, by assigning 1 and 0 respectively. In fact, this is the use of Boolean logic method, because the maps are produced with two classes 0 and 1 (Mahini and & Gholamalifard, 2006). In the present study the type of seven exclusionary criteria consisted of dual factors that were both criteria and restrictions for landfill siting, whereas soil depth and land use factors were considered as criteria, exclusively. The final restriction map was the result of multiplying all exclusionary maps. To obtain the suitable sites for landfilling, the final IHWP map multiplied by the final exclusionary map for ranking. So the exclusion of definitely unsuitable areas for landfilling was carried out at the end. The final resultant map of selected sites for Sanandaj solid wastes, was divided to three classes according to suitability. The map shows that about 92% of the study area was completely unsuitable for landfill siting, out of the remaining area, 4.4% had moderate suitability and only 3.6% was the most suitable.

The suitability map obtained from AHP model, was prepared by aggregation procedure based on the weight of each criteria and the weights of classes of the each map. For removing the existance of completely unsuitable areas for landfilling in overlayed map, it was multiplied by the final restriction map to obtain suitability map for landfilling. Classification of this final AHP map indicated that classes of the unsuitable, moderately suitable and most suitable for landfill installation occupied 92%, 2.7% and 5.3% of the study area, respectively. Fig. 5 shows the final IHWP and AHP suitability maps.

Due to the results of seven restriction map layers, 92% of the study area was identified as completely unsuitable for establishing a landfill site in both AHP and IHWP methods. Among these exclusionary criteria, villages with considering 1 km buffer zone had the most important role by omitting about 63% of the study area from more landfill sitting Whereas main rivers with 600 m buffer zone, by removing only 7% of the study area has a minor role in deletion of the suitable areas. In current study the highest score was assigned for soil depth and main rivers criterion in both AHP and IHWP methods, that shows the necessity of soil and rivers protection during the landfill site selection process. Identification of only 5.3% (161 km^2) and 3.6% (109 km^2) of the whole study area as the most suitable for landfill siting in final AHP and IHWP suitability maps, indicates the limitation of the whole area for landfill locating. These lands were mainly located 5 to 30 km north-west of the Sanandaj urban area, although they did not occupy an integrated area and were separated from each other. By considering the final AHP and IHWP resultant maps, we recognized that some areas which were identified as the most suitable in IHWP, belonged to the moderately suitable class in the final suitability AHP map. So it is expected that areas with the most suitability located in final IHWP map are more qualified and reliable for being selected as a final landfill site, in comparison with the equivalent areas in final AHP map.

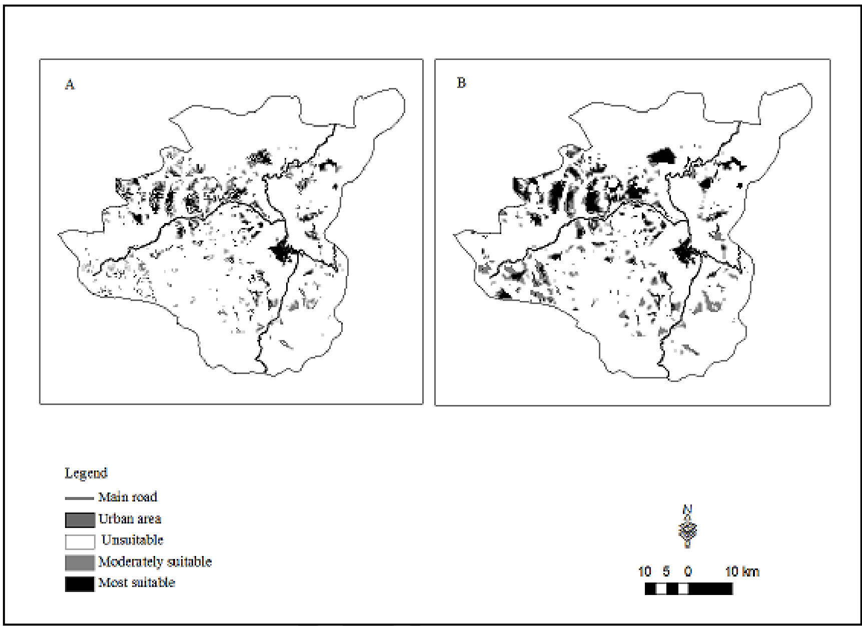

Fig. 5. Landfill suitability maps of Sanandaj city obtained from; (A) IHWP, (B) AHP model

By considering the average amount of daily wastes that are produced in Sanandaj city (330 ton), annual population growth and waste production rate (1.15%), and the compact solid waste density in the landfill site (500 kg/m^3), there is a need of at least 54 ha location for over the next 20 years for the city. So the areas with the extent of lower than 54 ha in vector suitability maps were ignored and finally, two regions with the extent of 310 and 87 ha through the most suitable class of the IHWP map, (which were the most appropriate with respect to all the criteria of the site selected model), (Fig. 6) were selected. Since the best landfill location should be located close to the waste source in order to decrease transportation costs (Isalou et al., 2013), the 87 ha area which is at a distance of approximately 5 km north-west from the city, is preferred for landfilling. The mean elevation of this area is about 1400 m and its mean slope is 23%, which is covered with thin and semi-dense grassland on the semi-deep soil. This areas' distance to the nearest main river (Gheshlagh), fault, well, major road and village is 4 km, 700 m, 500 m, 2/5 km and 3 km respectively.

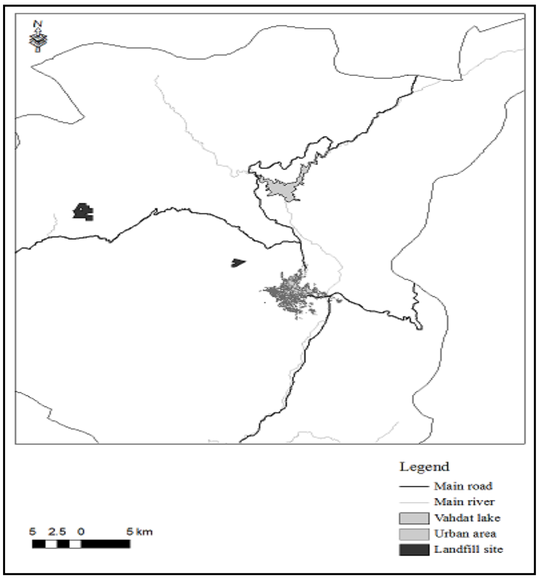

Fig. 6. Location of candidate landfills in the study area

CONCLUSION

The population growth in urban areas, followed by increasing consumption of products, as well as industrial development, has resulted in increasing waste. Selecting the optimal location for urban waste landfill is one of the most important issues in the management of wastes, specially in developing countries, like Iran. In current study nine criteria were used and classified in two ecological and socio-economic categories. By using fuzzy logic models, weighting through IHWP and AHP. IHWP method was introduced for the first time and applied to overlaying in raster GIS. This approach enables simultaneous consideration of both ecological and socio-economic factors, as well as combining both quantitative and qualitative criteria for a variety of site selection projects, like municipal landfill site selection. For each factor, the weights were assigned according to the importance each of factor. After overlaying the map layers, we used excluding criteria for selecting non-suitable areas, and the selection of the most suitable sites was performed by classification of the remained potentially suitable areas. In IHWP method the weight of interior classes of each map layer can be computed through the initial score that assigned for each criterion by experts, therefor the weighting process of interior layers of each criterion would be performed just in singular step. However, the AHP model uses pairwise comparisons for determining the weights of the criteria, end up in reduction of complexity. Comparing the results of IHWP and AHP in current study, showed that IHWP method increased the precision of the final decision for identifying best quality landfill sites and was useful to easier define the priorities of the evaluation criteria in comparison with AHP. The issue of evaluating suitable landfill sites has to be coupled with the issue of lowering environmental risk, which is achievable by doing Environmental Impact Assessment, so, if the likely effects of a landfill site is unacceptable, design measures or other relevant mitigation measures can be used to reduce or avoid those effects. Hence, by doing further field studies, multi-criteria decision analysis (MCDA) (Makhdoum et al., 2014) approach would be able to provide the best decision alternatives related to the main goal.

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