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Selection of Suitable Site for Municipal Solid Waste Disposal Sites for the Aksaray (Turkey) using AHP and GIS Methods

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Abstract The municipal solid waste generation is among the most threatening the global environmental health hazards. The problem of environmental pollution due to waste disposal can be overcome by selecting suitable sites. Commonly, because of simultaneous effects of social, environmental, and technical parameters on suitability of a landfill site, landfill site selection is a complex process and depends on several criteria and regulations. The municipal solid waste disposal site (MSWDS) selection process is a complex multi-criteria decision-making problem. This study deals with determination of suitable sites for the disposal of waste generated from Aksaray city surrounding areas. Analytic Hierarchy Process (AHP) technique which is extremely useful for pairwise comparison of multi criterion layers and Geographic Information System (GIS) techniques is used to identify suitable MSWDSs. In this study, ten data layers are exploited to detect the most susceptible areas. These factors are as elevation, slope, aspect, lithology, soil map, proximity to the settlement areas, proximity to the road, proximity to the river, proximity to the water surfaces and land use. The relative weights of defined criteria and sub-criteria are also determined applying AHP technique. Next, by overlaying these criteria layers, final map is produced. The produced map shows areas that are suitable for MSWDS. Based on the analysis several sites are identified as highly suitable. Finally, the best site is chosen. The results showed the efficacy of GIS and multi-criteria decision making method in decision making.

Keywords Geographic information system (GIS), Multi-criteria decision analysis (MCDA), Analytic hierarchy process (AHP), Municipal Solid Waste Disposal Site

1. Introduction

One of the important problems in developed countries is the inadequate municipal solid waste management (MSWM) systems that not satisfy the expectation due to rapid population growth and lack of appropriate infrastructures [1]. Municipal and industrial solid waste disposal sites have been an important issue for local community because they are directly related to soil, water and air pollution. However, many Municipal Solid Waste Disposal Sites (MSWDS) are uncontrolled; appropriate disposal site management rules and severe constraints determinate by environmental organizations are not taken into consideration [2]. Inadequate MSWDS get together with hot climatic conditions results in increasing environmental problems [3]. Unregulated MSWDS are directly affect in a negative way all components of environmental and human health [4-5]. So MSWDS selection is a crucial municipal planning procedure which affects different regions in the economic, the ecological, and the environmental health sectors [6-8].

The selection of a waste disposal site is a complex procedure as well as crucial. Because, it needs significant expertise in many social and environmental domains, for instance soil science, engineering, hydro-geology, topography, land use, sociology, and economics. Methods of selection new waste disposal site take into consideration parameters such as distance to roads, residential area, key infrastructure elements and the soil density maps to leach contaminants. Therefore, spatial data, regulations and acceptance criteria are extremely important in the selection of a solid waste disposal site together with must be an effective correlation between them [3].

Obviously there are many factors in the selection of solid waste disposal site and geographic information systems (GIS) are ideal for this type of complex work because of their ability to manage spatial data which obtain from different data source. Gets, keep, analyzes and efficiently shows information according to user-defined properties. Multifarious and complex data in spatial planning can become meaningful through the Multi-Criteria Decision Analysis (MCDA) [9]. MCDA is used for cope with the challenges that decision-makers confronted in handling vast amount of complex data. The logic of this method is to divide the problems into smaller and comprehensible parts so analyze each part separately and then defragment the parts in a logical manner [10].

Analytical Hierarchy Process (AHP) is improved by Saaty [11] as a systematic decision approach [12]. In detection of criteria weights process usually AHP is implemented. By this way AHP supplies a hierarchical structure by decreasing multiple criteria into a pairwise comparison method for singular or group decision-making and provide an opportunity to the use of quantitative and qualitative information [10, 11, 13]. So, under the landfill site selection circumstances integration of GIS and AHP is a significant tool for solve problem [14-17].

2. Study Area

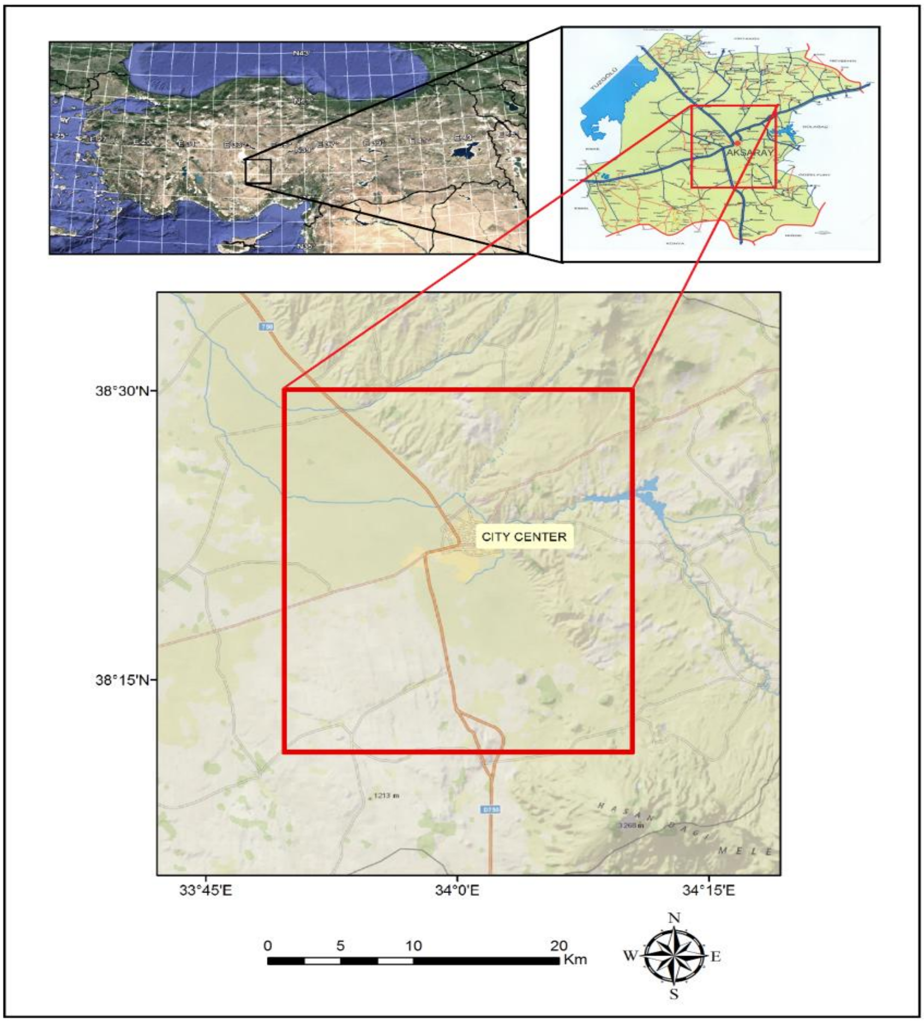

Figure 1: Study Area

The study area comprises the city center of Aksaray province and surrounding areas in the Central Anatolian region of Turkey, lies between 33-35 degrees east meridians and 38-39 degrees north parallels. According to the 2016 census, the population of the district is 396,673 of whom 293,631 live in the city center Aksaray. The average altitude of the region is 980 m. Aksaray is located on the highway of Samsun, Kayseri, Konya and Antalya via the Edirne, Istanbul, Ankara, Adana and Iskenderun highways. It lies between 33-35 degrees east meridians and 38-39 degrees north parallels. It is surrounded by Nevşehir in the east, Niğde in the South East, Konya in the west, Ankara in the North and Kırşehir in the North East. The surface area of the province of Aksaray is approximately 7700 km².

3. Production of the data

In this study 1:25000 scale standard topographic maps (STM) are used for creating Digital Elevation Model (DEM). Counter lines on STM had been digitized and TIN (Triangulated Irregular Network) is created and divided five elevation categories (Fig. 2A).

The main parameter of the MSWDS selection analysis is the slope degree. Therefore, the slope degree map is prepared from the digital elevation model (DEM) and divided into six categories (Fig. 2B).

Aspect is also a factor for MSWDS selection analysis, and in various study this parameter is used. In this study, aspect map is created from DEM (Fig. 2C). Aspects are grouped into 9 groups such as Flat (-1), North (337.5–360, 0–22.5), Northeast (22.5–67.5), East (67.5–112.5), Southeast (112.5–157.5), South (157.5–202.5), Southwest (202.5–247.5), West (247.5–292.5) and Northwest (292.5–337.5).

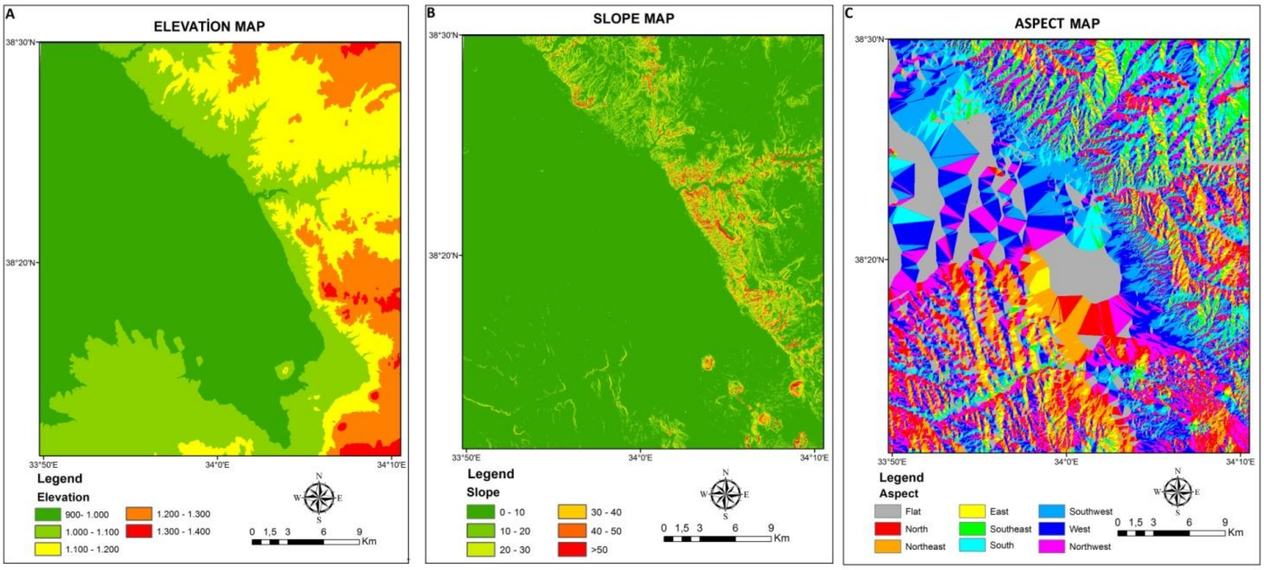

Figure 2: Elevation, Slope and Aspect Map

The geological map of the study area which had been prepared by the Mineral Research & Exploration General Directorate at 1:25,000 scale and had been digitized. The study area is covered with various types of lithological units. The general geological setting of the area is shown in Fig. 3A,

Sentinel-2 satellite images which having 10 m spatial resolution (band 2, band 3, band 4 and band 8) were used in the study to generate the land use types. To implement the aims of this research, recently acquired dated 26/09/2017 Sentinel-2 images of study area were obtained and image pre-processing steps such as atmospheric and geometric correction were employed. Maximum Likelihood (MLC) supervised classification method were applied to data sets for identify seven land use classes (Fig. 3B) and is mostly consist of agriculture and deciduous areas.

The soil map was derived from a regional soil map at a 1:100,000 scale. The study area was divided into seven soil classes according to land use capability classification (LCC). The study supported the soil classification as shown on Fig. 3C.

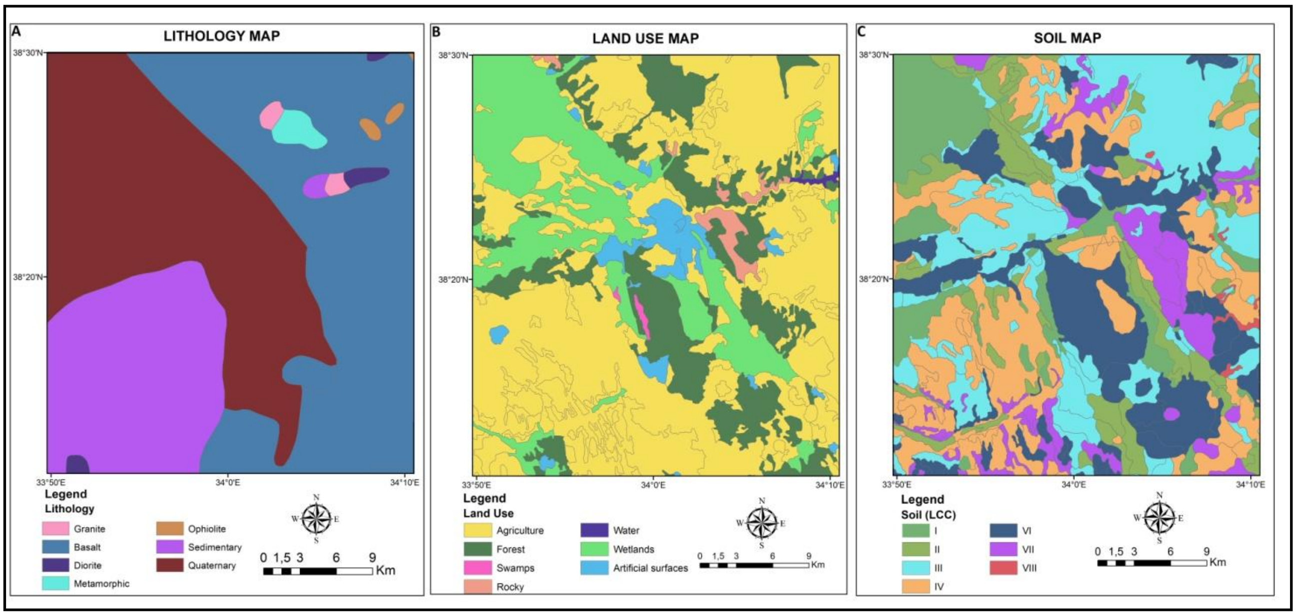

Figure 3: Lithology, Land Use and Soil Map

The study area was divided into five different buffers (0–250, 250–500, 500–750, 750-1000 and bigger than 1000) categorized to designate the influence of both road (Fig. 4A) and settlement areas (Fig. 4B) .

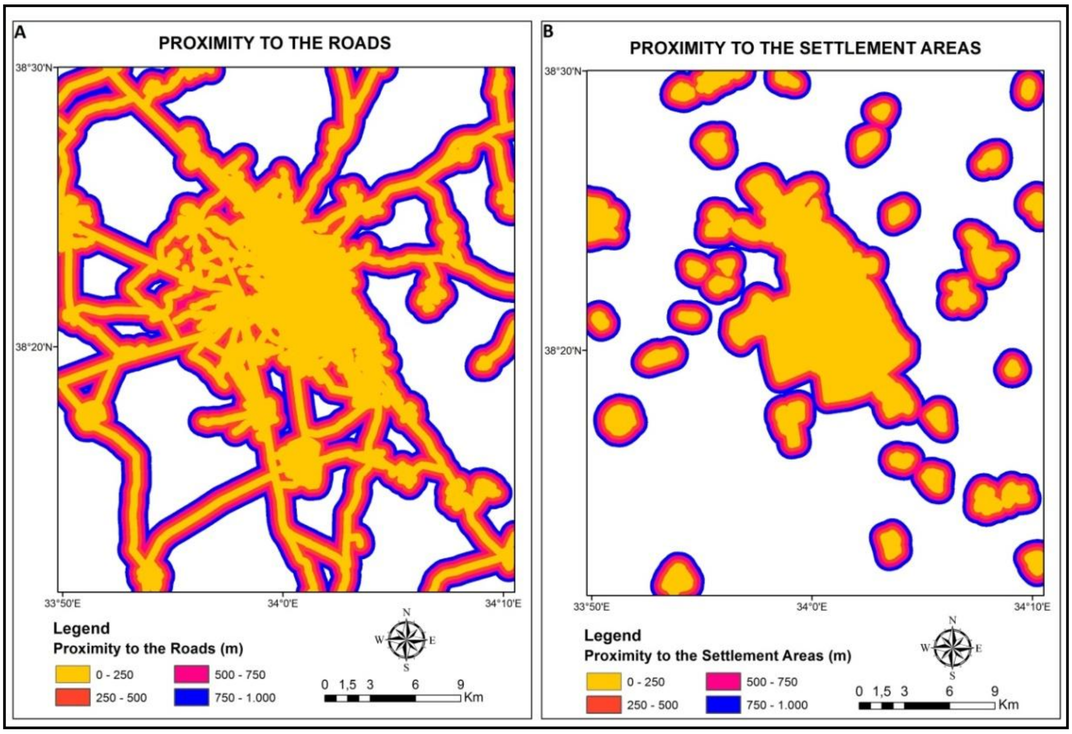

Figure 4: Proximity to the Road and Settlement Areas Map

The study area was divided into five different buffers (0–500, 500–1000, 1000–1500, 1500-2000 and bigger than 2000) categorized to designate the influence of both river (Fig. 5A) and water surfaces (Fig. 5B).

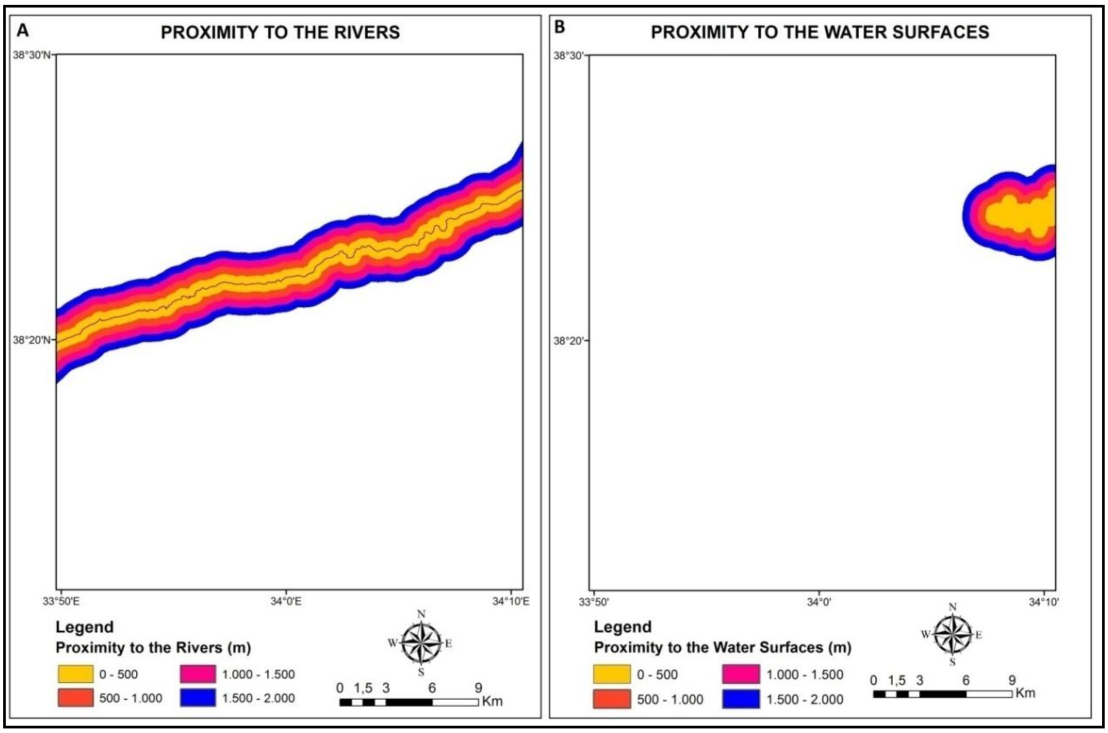

Figure 5: Proximity to the River and Water Surfaces Map

4. Selection of Suitable Site For Municipal Solid Waste Disposal Sites by Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a semi-qualitative method, which involves a matrix-based pair-wise comparison of the contribution of different factors for site selection. AHP is a multi-objective, multi-criteria decision-making approach, which enables the user to arrive at a scale of preference drawn from a set of alternatives [11]. It helps decision makers find out the best suits their goal and their understanding of the problem. This mathematical method widely used in site selection, suitability analysis, regional planning, routing modeling, and landslide susceptibility analysis [18]. The process includes four steps. First, break a complex unstructured problem down into its component factors. Second, arrange these factors in a hierarchic order. Third, assign numerical values according to their subjective relevance to determine the relative importance of each factor. Forth and finally synthesize the rating to determine the priorities to be assigned to these factors [19]. When arranging the factors in a hierarchic order, there should be relative importance of one factor over another forming a pair-wise comparison matrix [20]. When creating pair- wise comparison matrix, each factor is rated against every other factor by assigning a relative dominant value between 1 and 9 to the intersecting cell (Table 1).

Table 1: Pair-wise comparison matrix, weights and consistency ratio of the data layers

Factors	1	2	3	4	5	6	7	8	9	Weights
Elevation (m)										
(1) 900-1000	1									0,488
(2) 1000-1100	1/3	1								0,241
(3) 1100-1200	1/4	1/2	1							0,166
(4) 1200-1300	1/7	1/5	1/4	1						0,072
(5) 1300-1400	1/9	1/7	1/6	1/4	1					0,033
Consistency Ratio:	0,066									
Slope (%)										
(1) 0-10	1									0,440
(2) 10-20	1/2	1								0,257
(3) 20-30	1/4	1/2	1							0,136

(4) 30-40	1/6	1/4	1/2	1						0,081
(5) 40-50	1/8	1/5	1/3	1/2	1					0,052
(6) >50	1/9	1/7	1/4	1/3	1/2	1				0,034
Consistency Ratio:	0,010									
Aspect										
(1) Flat	1									0,308
(2) South	1/2	1								0,219
(3) South East	1/3	1/2	1							0,154
(4) East	1/4	1/3	1/2	1						0,109
(5) South West	1/5	1/4	1/3	1/2	1					0,076
(6) West	1/6	1/5	1/4	1/3	1/2	1				0,053
(7) North East	1/7	1/6	1/5	1/4	1/3	1/2	1			0,037
(8) North West	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1		0,026
(9) North	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	0,019
Consistency Ratio:	0,031									
Proximity to the Settlement Areas										
(1) 0-250	1									0,075
(2) 250-500	4	1								0,171
(3) 500-750	3	1	1							0,159
(4) 750-1000	2	2	2	1						0,269
(5) >1000	1	4	3	1	1					0,326
Consistency Ratio:	0,032									

Table 1 (Continued): Pair-wise comparison matrix, weights and consistency ratio of the data layers

Lithology								
(1) Granite	1							0,160
(2) Basalt	1/3	1						0,079
(3) Diorite	3	5	1					0,227
(4) Metamorphic	1/5	1/2	1/5	1				0,056
(5) Ophiolite	5	7	5	5	1			0,418
(6) Sedimentary	1/6	1/3	1/6	1/2	1/7	1		0,036
(7) Quaternary	1/7	1/5	1/9	1/3	1/9	1/2	1	0,023
Consistency Ratio:	0,083							
Soil (LCC)								
(1) 1. Class	1							0,024
(2) 2. Class	9	1						0,324
(3) 3. Class	7	1/3	1					0,168
(4) 4. Class	7	1	2	1				0,296
(5) 6. Class	5	1/5	1/2	1/5	1			0,099
(6) 7. Class	5	1/7	1/5	1/7	1/3	1		0,055
(7) 8. Class	3	1/9	1/7	1/9	1/5	1/2	1	0,034
Consistency Ratio:	0,064							
Proximity to the Roads (m)								
(1) 0-250	1							0,329
(2) 250-500	1	1						0,266
(3) 500-750	1/2	1	1					0,218
(4) 750-1000	1/3	1/2	1/2	1				0,106
(5) >1000	1/4	1/4	1/3	1	1			0,081
Consistency Ratio:	0,014							
Proximity to the Rivers (m)								
(1) 0-500	1							0,091

(2) 500-1000	1	1						0,115
(3) 1000-1500	2	1	1					0,139
(4) 1500-2000	3	2	2	1				0,283
(5) >2000	4	4	3	1	1			0,372
Consistency Ratio:	0,015							
Proximity to the Water Surfaces (m)								
(1) 0-500	1							0,091
(2) 500-1000	1	1						0,115
(3) 1000-1500	2	1	1					0,139
(4) 1500-2000	3	2	2	1				0,283
(5) >2000	4	4	3	1	1			0,372
Consistency Ratio:	0,015							
Land Use								
(1) Agriculture	1							0,188
(2) Forest	2	1						0,203
(3) Swamps	1/7	1/3	1					0,037
(4) Rocky	5	5	7	1				0,405
(5) Water	1/9	1/7	1	1/9	1			0,030
(6) Wetlands	1/7	1/7	1	1/9	1	1		0,030
(7) Artificial surfaces	1/3	1/5	3	1/3	5	5	1	0,107
Consistency Ratio:	0,088							

When the factor on the vertical axis is more important than the factor on the horizontal axis, this value varies between 1 and 9. Contrary to the above the value varies between the reciprocals 1/2 and 1/9. In these techniques, firstly, the effects of each parameter to the best MSWDS relative to each other were determined by dual evaluation in determining the preferences in the effects of the criteria to suitability map. Normally, the determination of the values of the parameters relative to each other is a situation that depends on the choices of the decision maker.

The final result includes the weights of the criteria as seen in Table 2.

Table 2: Pair-wise comparison matrix and weights of the criteria

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**Weights**
(A) Elevation	1										0,0443
(B) Slope	3	1									0,0966
(C)Aspect	1/7	1/9	1								0,0172
(D) Lithology	4	1	8	1							0,1280
(E) Soil Map	3	1/2	5	1/3	1						0,0678
(F) Prox. to Sett. Areas	1	1/2	7	1/3	1	1					0,0608
(G) Prox. to Roads	1	1/3	2	1/5	1/5	1/3	1				0,0334
(H) Prox. to River	4	2	5	3	5	3	3	1			0,1814
(I) Prox. to Water Surface	6	4	7	3	5	4	5	2	1		0,2717
(J) Land Use	3	1	7	1/2	3	3	3	1/3	1/5	1	0,0988

In the AHP method, an index of consistency, known as the consistency ratio (CR), is used to indicate the probability that the matrix judgments were randomly generated [11].

$$CR = (CI/RI)$$

where RI is the average of the resulting consistency index depending on the order of the matrix and CI is the consistency index and can be expressed as:

$$CI = ((\lambda_{max} - n)/(n-1)$$

Where λ_{max} is the largest or principal eigenvalue of the matrix and can be easily calculated from the matrix and n is the order of the matrix [11].

The consistency ratio is a ratio between the matrix's consistency index and random index and in general ranges from 0 to 1. A CR of 0.1 or less is a reasonable level of consistency [21]. A CR above 0.1 requires revision of the judgment in the matrix due to an inconsistent treatment for particular factor ratings.

In this study, the CR is 0.067; the ratio indicates a reasonable level of consistency in the pair-wise comparison that is good enough to recognize the factor weights. Consequently, the weight corresponding to proximity to the water surface is large, however aspect is the lowest (Table 2).

For all cases of the gained class weights, the CRs are less than 0.1, the ratio indicates a reasonable level of consistency in the pair-wise comparison that was good enough to recognize the class weights.

MSWDS selection model using AHP model was constructed using the following equation:

$$\text{LSM} = \sum_{i=1}^{n} (Ri \times Wi)$$

In equation, R_i is the rating classes each layer and W_i is the weights for the each of criteria. The pixel values obtained are then classified into 5 classes (very low, low, moderate, high, and very high). Classification in the suitable MSWDS map is made by natural break method (Fig. 6).

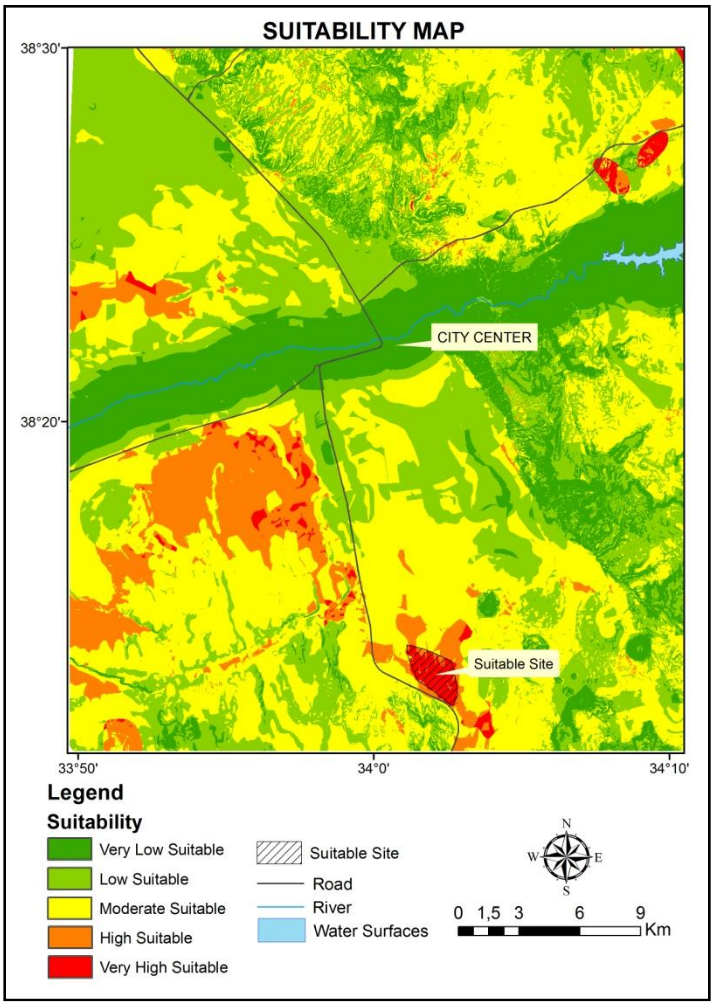

Figure 6: Suitability Map

5. Conclusion

This paper presented a methodology integrating AHP and GIS techniques to identify suitable MSWDSs for the Aksaray (Turkey). In order to tackle this complex decision-making problem, 10 site selection criteria were identified and GIS tools were used for creating, analyzing, digitizing and displaying. In the present work, AHP technique was employed to assign weights to decision criteria and classes within each criterion. Weighted Linear Combination (WLC) method was used to create the final suitability map. In this map, one candidate site were identified which satisfy the minimum requirements for MSWDSs. It has to be emphasized that GIS-based MCDA analyses provide a regional scale suitability assessment aiming to identify the best locations for MSWDSs, where further field investigations need to be conducted before the final decision is made. In addition, such suitability assessments can be improved by revising the data and methodology when more detailed and reliable data and more robust and powerful methods become available in the future.

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