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Evaluation of AHP and Frequency Ratio Methods in Landslide Hazard Zoning (Case Study: Bojnord Urban Watershed, Iran)

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Abstract

Natural and anthropogenic factors increased the damages resulted from landslides in the last years. One of the main solutions for decreasing the landslide hazards is keeping distance from higher danger areas. For this purpose, it is necessary to prepare the landslide susceptibility map. In this research, after field studies in the Bojnord Urban Watershed, nine factors distinguished including slope gradient, aspect, elevation, precipitation, distance from road, distance from fault, distance from drainage, land use and lithology as effective factors in landslides occurrence of the studied area. After preparing the information of these nine factors in GIS environment, every layer has been crossed with the landslide layer to find the role of corresponding layer in the formation of landslide. Then hazard zoning was performed with two methods including Analytical Hierarchy Process and frequency ratio methods. Finally, in order to evaluate the verification of the hazard zoning, the obtained weights from the mentioned watershed using the above two methods were used for the adjacent basin (Chamanbid Watershed), which has similar characteristics to the urban watershed. Results showed that the AHP model give better results for landslide hazard zoning of the area.

Keywords: GIS, Landslide, Map classification, Susceptibility, Urban Watershed

Introduction

Every year landslides impose great damages that can not compensate easily or need much expenses and time for compensation; therefore, planning for damage prevention is very important. Landslide susceptibility mapping provide information to relevant executive administrations to know the susceptible area to landslide and make decision about considering plans (Mahdavifar et al.,1997). Widespread studies were carried out about landslides in the last years. 1990 decade was introduced as repel against natural hazards by UNESCO organization and Different research centers carried out extensive studies about landslides as a natural hazard. Faiznia et al. (2003) evaluated the landslide causing parameters in Shirinrud watershed in Iran using four methods and presented a landslide susceptibility mapping. They found that the information value and overlap index are suitable methods for mapping and changing in the landuse is the main agent in the landslide occurrence. Komac (2006) prepared landslide susceptibility map using AHP and multivariable statistic methods in Slovenia. He reported that AHP is much better than multivariable regression and susceptible area are closely related to the road paths. Fanyu Lu (2007) prepared the landslide susceptibility map using information value in GIS environment for the Langen area in Ganso provine, China. His results showed that information value gives active landslides fairly. Yalcin (2008) prepared the landslide susceptibility map for Ardesen basin (Turkey) using AHP, weight factor and statistical index methods. In order to verify the above three models, he applied them for the active landslides of the area. Results demonstrated that AHP method classifies 81.3% of the active landslides in the very high and high hazard classes. Statistical and weight factor methods classified only 62.5% and 68.8% of the active landslides respectively. Therefore the AHP method gives confident results for landslide recognition in the area.

Materials and Methods

Characteristics of the study area

Bojnord urban watershed is situated in center of Bojnord city in northeast of Iran. The study area is located between longitude 37° 14' to 37° 39' N and latitude 56° 23' to 56° 57' E, having 1240 km^2 area. Mean annual precipitation of 30 years (1977-2006) in the area is 276 mm and the mean annual temperature in the same period is 13.7° C. The land cover is mainly range. Geologically, Most of the watershed landslides happened in Tirgan formations, in which they are sensitive to erosion. Figure 1 shows the location of the watershed in north khorasan province and Iran.

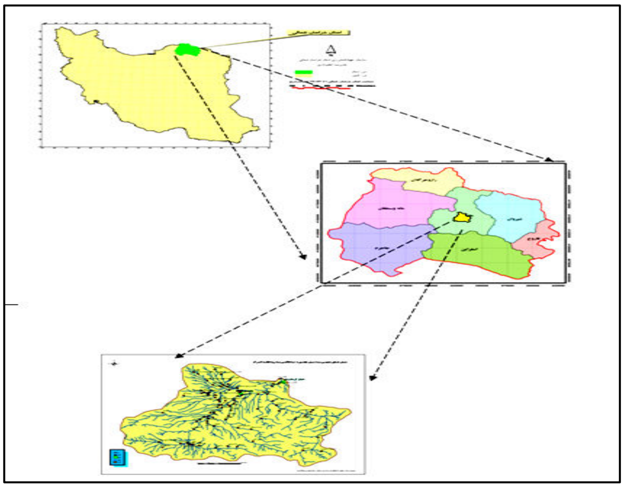

Figure 1. Location of watershed in Iran and north khorasan province.

Method of study

The characteristics of watershed landslides were collected during field surveys. Totally 84 landslides were recognized and their locations were determined by GPS. The geographic coordinates of landslides entered the geographic information system (GIS) environment using DNR Garmin and Arc View software programs.

By inspection of landslides characteristics forms, the results of other studies with similar conditions and experiences of dwelling people, nine parameters including slope gradient, elevation, aspect, geology, land use, precipitation, distance from road network, distance from faults and distance from drainage network were considered roughly as effective factors in the formation of landslides. After preparing the above rough effective parameters, they classified in GIS environment. In some of the classes like elevation and slope gradient, cumulative frequency of pixels was drawn against the pixel value in a diagram. This is a rational method for map classification and minimizes the role of user; in fact, it takes into account the land conditions (Ayalew & Yamagishi, 2005). The changes in the slope of diagram are considered as the boundary of classes.

In the next stage, in order to determine the rate of classes; in which is very important in mapping, the landslide distribution is crossed with each of information layers. Finally using the following two methods, the mapping was performed.

AHP mapping method

This method was proposed by Saaty for the first time and is based on comparison of pairs of different parameters (Faraji Sabokbar, 2005). In order to determine the priority of different parameters and convert to quantitative values, the oral description (user judge) of parameters is used (Table 1). The outcome of these comparisons is a matrix. According to table 1, the range of values in the matrix varies from 1 to 9. After formation of matrix, the sum of each column for all of parameters is written below the matrix. Then in order to calculate the weight of each parameter, the value of each parameter of matrix is divided by the sum of columns of the same layer and put in the other table. In the resulted table, the average of rows is considered as the weight of each layer. The rate of each class of parameters will be determined in the next stage. To do this, the distribution map of landslides overlays on different layers and the percent of slide area calculated in each class.

Table 1. Oral judgment of pair comparison in AHP method

Preferences (oral judgment)	Numerical amount
Completely desired	9
Very strength desired	7
Strength desired	5
Little desired	3
Little important	1
Preferences between spaces	2, 4, 6, 8

Considering 100 score for the class with highest percentage of slided surface, the score of other classes will be given.

After scoring to classes of parameters of the area (a), the score of considered parameters will be multiplied by the weight coefficient (x) and add together. Finally the following model is produced:

$$M=a_1x_1+a_2x_2+a_3x_3+\ldots \quad \text{(Equation 1)}$$

In the above equation "M" is sensitivity agent, "x" related to different parameters and "a" is the weight of each class of different layers. The final susceptibility map is prepared based on the resulted model. In order to determine different classes of sensitivity, the "M" is divided to four equal distance classes of sensitivity based on Table 2.

Table 2. Classification of mass movement hazard based on AHP method

Degree of class (M)	Score	Landslide Susceptibility
1	0-25	Low
2	25-50	Moderate
3	50-75	High
4	75-100	Very high

Mapping using frequency ratio method

The information of different layers was prepared and classified. These layers were combined with the information of landslide distribution layer and the number of landslides determined in each classes of parameters. Using the frequency ratio (equation 2) the weight of classes was determined:

Frequency ratio=percent of landslides in each class of parameter ÷ percent of pixels of the related class (Equation 2)

The obtained weights were added together in GIS environment and the resulted map was classified to four classes.

Results and Discussion

The effective parameters in occurrence of mentioned watershed's landslides were determined and they presented with suitable codes (Table 3). Then the susceptibility map of landslides was prepared based on the two above mentioned methods.

Table 3. The classes' codes of different parameters

Factor / Code	Geology	Slope (%)	Distance from road (m)	Land use	Precipitation (mm)	Distance from fault (km)	Elevation (m)	Aspect	Distance from river (m)
1	Limestone	0-12	0-500	Forest	230-280	0-1	920-1085	North	0-200
2	Tirgan	12-20	500-1000	Range	280-330	1-2	1085-1170	East	200-400
3	Sarcheshmeh	20-30	1000-1500	Agriculture	330-380	2-3	1170-1500	South	400-600
4	Shurijeh	30-60	>1500	Other	-	>3	1500-1670	West	>600
5	Other	>60	-	-	-	-	1670-2165	-	-

Landslide susceptibility mapping (LSM) using AHP method

As stated previously, the comparison of each pairs of parameters is carried out by oral judgment (Table 1). The results of comparisons are in the form of matrix. The sum of each column is written below the column (Table 4).

In the next step, the value of each cell is divided by the sum of the corresponding column and written in another table. Then the average of each row is considered as the final weight of the related parameter (Table 5).

Table 4. Factor weight calculation in AHP method (first step)

	Road	Geology	slope	River	Land use	Fault	Precipitation	Aspect	Elevation
Road	1	2	3	3	4	5	6	7	8
Geology	0.5	1	2	3	4	5	6	7	8
Slope	0.33	0.5	1	2	3	4	5	6	7
River	0.33	0.33	0.5	1	2	3	4	5	6
Land use	0.25	0.25	0.33	0.5	1	2	3	5	6
Fault	0.2	0.2	0.25	0.33	0.5	1	2	3	4
Precipitation	0.17	0.17	0.2	0.25	0.33	0.5	1	2	3
Aspect	0.14	0.14	0.16	0.2	0.2	0.33	0.5	1	2
Elevation	0.125	0.125	0.14	0.16	0.16	0.25	0.33	0.5	1
Total	3.045	4.715	7.58	10.44	15.19	21.08	27.83	36.5	45

Table 5. Parameter weight calculation in AHP method (second step)

	Road	Geology	Slope	River	Land use	Fault	Precipitation	Aspect	Elevation	average
Road	0.33	0.424	0.395	0.278	0.263	0.237	0.215	0.191	0.17	0.28
Geology	0.164	0.212	0.263	0.278	0.263	0.237	0.215	0.191	0.177	0.22
Slope	0.108	0.106	0.131	0.191	0.197	0.189	0.179	0.164	0.155	0.16
River	0.108	0.069	0.065	0.095	0.131	0.142	0.143	0.136	0.133	0.11
Land use	0.082	0.053	0.043	0.048	0.066	0.094	0.107	0.136	0.133	0.085
Fault	0.066	0.042	0.033	0.032	0.033	0.047	0.071	0.082	0.088	0.055
Precipitation	0.055	0.036	0.026	0.024	0.022	0.024	0.035	0.054	0.066	0.038
Aspect	0.045	0.03	0.021	0.019	0.013	0.015	0.018	0.027	0.044	0.027
Elevation	0.041	0.026	0.018	0.015	0.011	0.012	0.011	0.014	0.022	0.019

The weight of different parameters as shown in Table 5 is as follows:

Road 0.28, geology 0.22, slope gradient 0.16, river0.11, land use 0.085, fault 0.055, precipitation 0.038, aspect 0.027, elevation 0.019 (all of the figures are dimensionless).

The rate of different classes of parameters is considered between 0 to 100 according to the number of occurred landslides in the classes, in which each layer is prepared based on these rates (Table 10).

Table 6. The rate of classes of parameters in landslide occurrence in Bojnord urban watershed using AHP method

	Road	Geology	Slope	River	Land use	Fault	Precipitation	Aspect	Elevation
	100	91	70	41	29	100	87	100	0
	63	100	93	31	100	67	100	37	0
	59	16	100	31	27	45	0	55	38
	88	18	67	100	52	58		42	58
		16	18						

Finally the landslide susceptibility map is obtained based on the following equation:

Final=road×0.22+land use ×0.085+geology×0.22+…   (Equation 3)

The resulted map is classified to four equal distance groups (Figure 2).

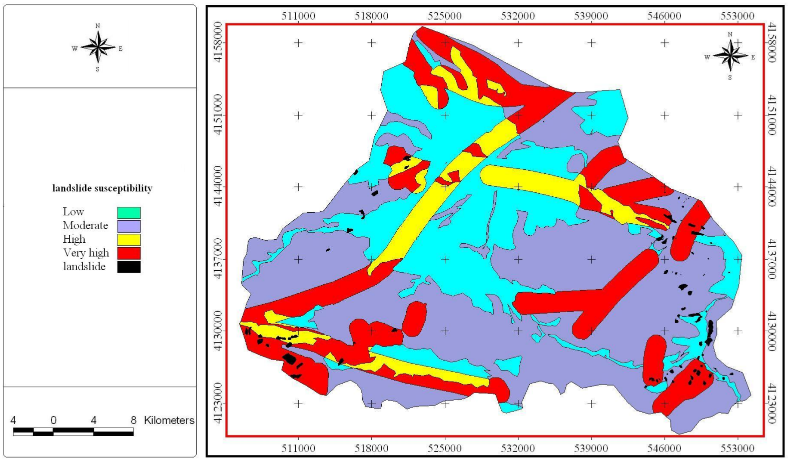

Figure 2. LSM in Bojnord urban watershed using AHP method

LSM using frequency ratio

After calculation of weight of different parameters (Table 7, the layers were added together and LSM was obtained by frequency ratio method (Figure 3).

Table 7. The weight of effective parameters in landslide susceptibility using frequency ratio method in Bojnord urban watershed

Factor / code	Geology	Slope (%)	Distance from road (m)	Land use	Precipitation (mm)	Distance from fault (km)	Elevation (m)	Aspect	Distance from river (m)
1	9.15	7	10	2.9	8.12	10	0	10	4.14
2	10	9.25	6.3	10	10	6.78	0	3.75	3.17
3	1.42	10	6	3.42		4.5	3.8	5.5	3.17
4	1.88	6.7	8.9	4.38		5.8	10	4.25	10
5	1.42	1.8							

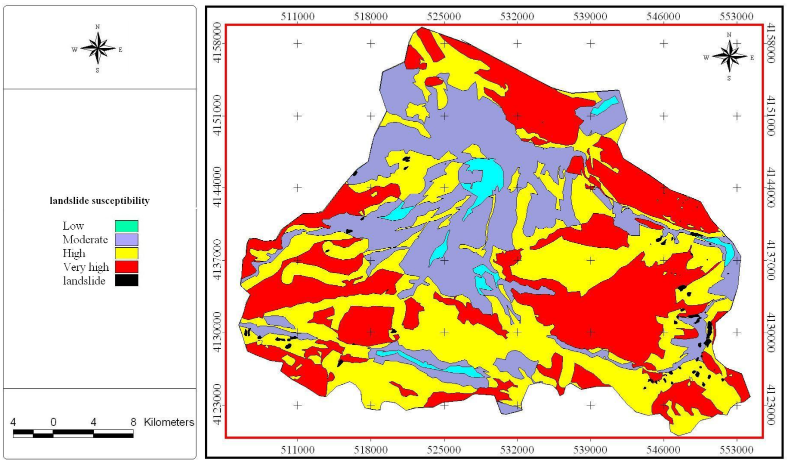

Figure 3. LSM in Bojnord urban watershed using frequency ratio method

Accuracy evaluation of LSMs

The Chamanbid watershed in the west neighborhood of Bojnord watershed was used for evaluation of the accuracy of LSM. This watershed located between latitude 37° 22' to 37° 27' N and longitude of 44° 30' to 44° 42' E. Most of the characteristics of this watershed such climate condition, lithology, land use. is similar to bojnord watershed.

At first, the landslide distribution map of chamanbid watershed was prepared by field studies and digitized. Then the effective factors in landslide occurrence in chamanbid watershed were prepared in the same way of bojnord watershed.

The obtained weights from the two methods were used for the LSM in the chamanbid watershed and susceptibility classes were defined similar to bojnord watershed. The LSM of chamanbid watershed was resulted.

Finally, the prepared LSM was overlaid by the landslide distribution layer and number of landslide in each class of susceptibility was counted (calculated) (Figures 4 and 5). A model is more effective which the higher number of landslides classify in the higher susceptibility classes. As can be seen in Table 14, 62% of landslides put in very high and high susceptible classes in AHP method. Therefore, among the methods employed models, the AHP model has higher capability in differentiation of susceptibility classes in the studied watershed.

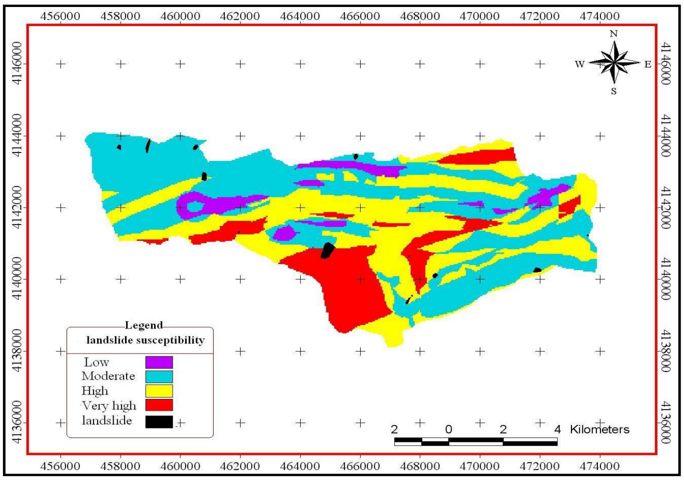

Figure 4. The evaluation map of AHP method in Chamanbid watershed

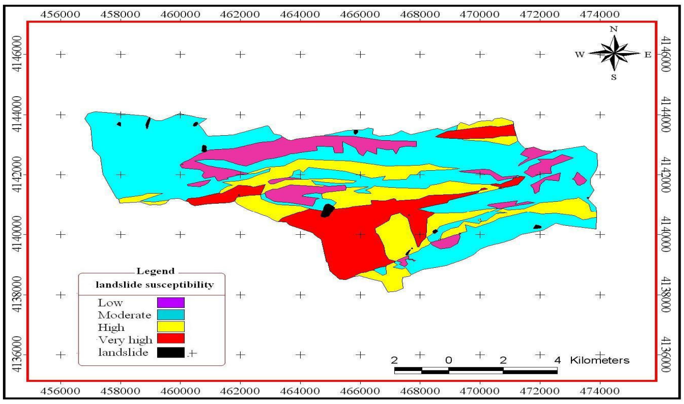

Figure 5. The evaluation map of frequency ratio method in Chamanbid watershed

Table 8. Effectiveness evaluation of LSM models in the Chamanbid watershed

Susceptibility class \ Mapping model	AHP	Frequency Ratio
Very high	24	23
High	38	23
Moderate	38	54
Low	0	0

Among the two methods discussed about LSM models in Bojnord urban watershed, the AHP model is more reliable. Ahmadi et al., (2004) used two different methods for landslide susceptibility in germichai watershed in Iran and concluded that AHP gives confident and acceptable results relative to other model.

Shadfar et al., (2004) concluded that the frequency ratio gives average results. The results of this study coincide with the above researches.

According to the landslide distribution map and high frequency in 0-100 m distance from roads, it can be concluded that among linear factors like roads, faults and rivers, road construction has highest effect on landslide occurrence. Moreover, among the 6 remaining parameters, the geology has the highest effect on the landslide occurrence, because large number of landslides formed in Tirgan formations, which are susceptible to landslide and erosion.

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