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Landslide Hazard Zonation Using AHP Model (A case study: Ayvashan damwatershed, Lorestan)

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Abstract

The landslide is one of the mass movement processes,which occurs in Iran and parts of the world every year. This phenomenonoften causes significant loss of life and financial damages. Therefore, this study has been carried out to identify the factors affectingthe landslide occurrence and to localize the landslide-prone areasin order to investigate the landslide hazard zonation of Ayvashan Dam Watershed using the Analytic Hierarchy Process (AHP) method. At the onset of the study, some of the most important factors that influencethe occurrence of this phenomenon such as lithology, slope, precipitation, landuse, elevation, aspect, distance from drainages, and fault,as the independent variables,were prepared and digitized in the GIS software environment. Then thelandslideareas were identified viathe aerial photos and field surveys, and the landslide distribution maps of the watershedwere prepared. In the next step, through the use of the AHP method, the factors examined in the previous step were comparedin pairs,and the weight of each factor that indicates the degree of its influenceon causing the landslides of the region has been calculated. According to the results of the landslide hazard zonation using the AHP, 14.85, 33.89, 23.75, 19.54, and 7.95 percent of the area of the region are located in very low, low, moderate, high, and very high risk classes respectively.

Keywords: **Ayvashan dam watershed, Landslide, AHP, Lorestan**

1. Introduction

We alwaysencounterthe phenomena thatare caused by various factors. If only one factor influencedthe occurrence of a phenomenon in the natural world, we could easily decide about and predict its occurrence.However, many quantitative and qualitative factors affect the occurrences of the phenomena that we generally confront in the natural world.Thus, in order to compute the probability of the occurrence of a phenomenon, there is always a need to determine the factors that cause it. If these factors are not identified properly, their role in calculating the probability of the occurrence of the phenomenon will not be taken into consideration,and the results will not be reliable (Moradi et al. 2010). Like other natural phenomena, the landslide is the aftermath of the presence and interaction of several factors.The landslide and the mass movements of soil and rock materials are a form of slopeprocesses and a particular kind of natural disasters that occur in Iran andsome parts of the world every year and bring aboutsignificantloss of life andfinancial and environmental damages. Due to the natural, geological, and climate features of the country of Iran, several mass movements and landslides occur in this countrythatresult in a lot of loss of life and financial damages (Karam & Mahmoodi, 2005).The prevention of such damagesentailsthe use of certain tacticssuch as the identification of factors that influencethe landslide. Determining the degree of the impact of each of these factors on the landslide occurrence is necessary for the landslide hazard zonation of a region.In this study, the Analytic Hierarchy Process (AHP) method was used to examine the factors affecting the landslide and its hazard zonation in Ayvashan Dam Watershed.The AHP is one of the multi-criteria decision making methodsthat can be utilized toanalyze and support different decisions even when there are multivariate and contradictory goals.

In recent years, studies based on the AHP have dramatically increased in Iran and other parts of the world. Some of these studies are mentioned subsequently. For instance, Shadfar et al. (2007) explored the landslide hazard zonation of Chalkrood Catchment. The obtained results indicated that the used method could prepare the hazard map of the region with high accuracy, and that more than 85% of landslides are located in the high risk areas.Also, Moradi et al. (2012) prepared the landslide hazard map of DenaCity.The obtained results showed that more than 82% of the landslides of the region are located in high and very high risk classes. Furthermore,Mezughi et al. (2012) prepared the landslide hazard mapofa northern part of Malaysia via the AHP method. The achieved results illustrated that the accuracyof the model was more than 80%. In the same vein, Soori et al. (2013) examined thelandslide hazard zonation of Kesmat Watershed through the use of the AHP model. The evaluation of the gained results using the experimental probability index demonstrated that 100% of the landslides of the region are located in moderate-to-high areas, and that the used model investigated the landslide hazard zonation with very high accuracy.Likewise, Soori et al. (2013) prioritized the factors that influence the landslide and its hazard zonation in Keshvari Watershed. The evaluation of the obtained results revealed that more than 92% of the landslides of the region are located in moderate-to-high hazard areas, and that the utilized model investigated the landslide hazard zonation of the watershed with high accuracy. Due to the geographical location of Ayvashan Dam Watershedthat is situatedin the east of Khorramabad and the Zagros mountain range, this watershed is highly prone to the landslide occurrence.Threatening the residential areas, the destruction of farmlands, the devastation of forest lands, and the increase of the sediment load of the reservoir of Ayvashan Dam Watershed aresome of the rationalesthat illustrate the significance of this study more than ever before.

2. The Geographical Location of the Region

Ayvashan Dam Watershed with an area of 12315

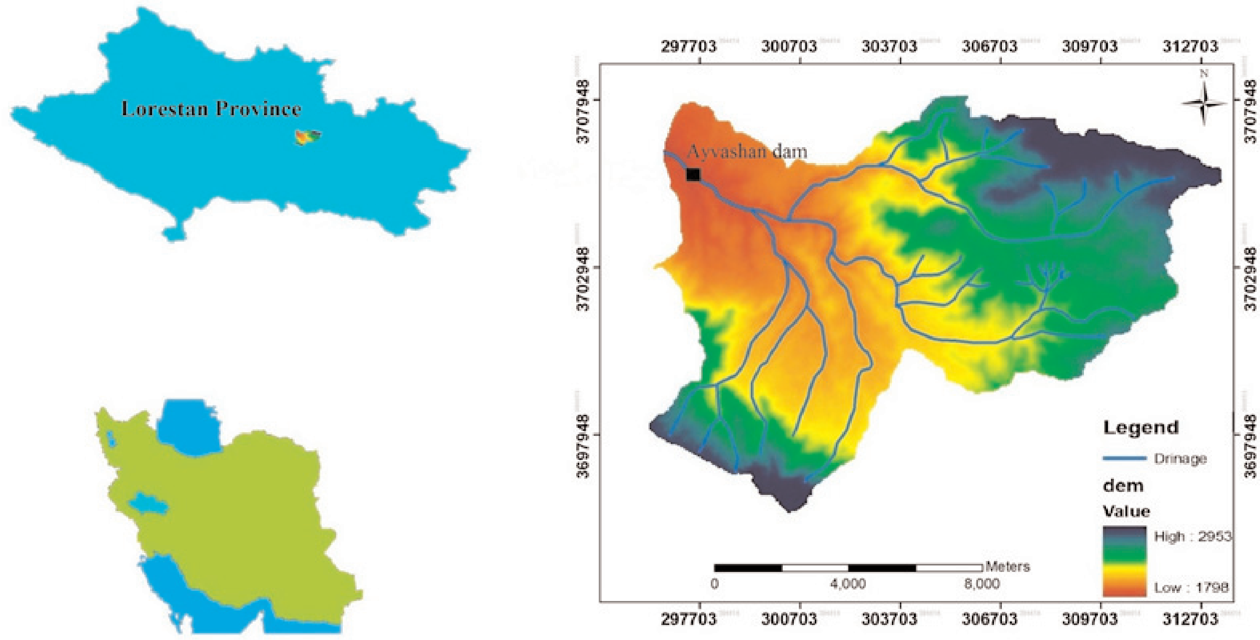

Figure 1. The Geographical Location of Ayvashan Dam Watershed

hectaresliesin the east of Khorramabad and 15 kmsouthwest of Dorud. It is located on the south side of the Dorud-Khorramabad Road. Thegeographical alignment of this watershed includeslatitude of 33° 22' N, 33° 29' N and longitude of48° 48' E, 48° 59' E. It is one of the sub-watersheds of Kashkan River (Fig. 1).

3. Methods and Materials

3.1. Used Factors

The various factors considered to investigatethe landslide hazard zonation are determined with respect to certain points such as goal, the expected scale and accuracy of the work, conditions of the region, the degree of the influence of each factor, and the availability of information. In this study, the factors that play a fundamental role in the landslide occurrence were used. Accordingly, the eight factors ofslope, aspect, geology, land use, elevation, faults, precipitation, and drainages have been utilized.

Geology: In order to prepare the geological map of the region, 1:20,000 aerial photos, +ETM satellite images, and 1:250000 Khorramabad geological map have been used.

Slope and aspect:In order to produce the aspect-slope map, the Digital Elevation Model (DEM) has been used. DEM was prepared via digitizing the contours of the topographic map of the region in the ArcGIS software environment.

Data obtained from line strings (fault and distance from drainages): In order to generate the map of the distance fromthe fault, the lineaments that were suspected of being faults were firstly separated on the basis of the aerial photos and satellite images.Then the map of the faults of the region was prepared through controllingthe linear elements with the watershed surface.

In order to provide the maps of the boundary of the distance fromthe drainage, the drainage nets were specified based on the topographic map and were then digitized in the ArcGIS software environment.

Elevation: The elevation map has been engendered from the classification of the DEM map of the region.

The land use map: The land use map of Ayvashan Dam Watershed was extracted from the interpretation of the NDVI index and has been completed through field tests.

Precipitation: In order to design the map of annual rainfalls,the rainfall gradient equation map of Ayvashan Dam Watershed is obtained from carrying out a linear regression analysis of the two parameters of elevation and the rainfall average of the stationsthat arein the vicinity of the region.

4. The Theory of Modelingwith the AHP

The AHP is a systematic decision making method that was used for the first time by Satty (1980). In the AHP system, a matrix was made from pairwise comparisons. The criteria weight will be the result of computations. What is more, the consistency ratio (CR) of decisions can be determined in pairwisematrices. The CR expresses the probability of random values in a pair-wise comparison matrix.If there are n criteria for comparisons, the AHP uses the following process to determine their weight (Chakraborty & Banik, 2006):

A) Thepairwisecomparison matrix A for n targets is prepared, which is as follows:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}$$

where a_{ij} indicates the degree of the importance of the ithgoalrelative tothe jthgoal,and a_{ii}=1 andaij= 1/ a_{ji}. The evaluation of the likely a_{ij} values in the pairwise comparison matrixand their corresponding interpretations are presented in Table 1.

B) Each value in the column j is divided bythe total value of the column j. The ultimate values in each column of the new matrix AW must be 1. In this way, the new normalized pairwise comparison matrix is prepared:

$$Aw = \begin{bmatrix} \frac{a_{11}}{\Sigma a_{i1}} & \cdots & \frac{a_{1n}}{\Sigma a_{in}} \\ \vdots & \ddots & \vdots \\ \frac{a_{n1}}{\Sigma a_{i1}} & \cdots & \frac{a_{m}}{\Sigma a_{in}} \end{bmatrix}$$

Table 1. The AHP Evaluation Scale (Satty & Vargas 2001)

interpretation	aijnumerical value of
Equal importance of i and j	1
Moderate importance of i over j	3
Strong importance of i over j	5
Very strong importance of i over j	7
Extreme importance of i over j	9
intermediate values	2, 4, 6, 8

C) In the AHP, the weight values (c_i) are determined by finding the principal eigenvector of the matrix A. The civaluecan becomputedasaverage valuesinthe rowi of thematrixAW andpresented as thecolumnvector C:

$$AW = \begin{pmatrix} c_1 \\ \vdots \\ \vdots \\ c_n \end{pmatrix} = \begin{bmatrix} \frac{\frac{a_{11}}{\Sigma a_{il}} + \cdots + \frac{a_{1n}}{\Sigma a_{in}}}{n} \\ \vdots \quad \ddots \quad \vdots \\ \frac{\frac{a_{n1}}{\Sigma a_{i1}} + \cdots + \frac{a_{m}}{\Sigma a_{in}}}{n} \end{bmatrix}$$

D) The consistency of weight values $c_i$is controlled. To this end, it is needed to follow the subsequent steps:

- In the first place, the consistency vector (x_i) is calculated by means of the A×C operation:

$$A\times C = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \times \begin{pmatrix} c_1 \\ . \\ c_n \end{pmatrix} = \begin{pmatrix} x_1 \\ 1 \\ x_n \end{pmatrix}$$

- Using the values obtained in the previous stage, the special value of the pairwise comparison matrix is computedas follows:

relation 1 $\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{X_i}{c_i}$

- The value of the consistency index (CI) is computed:

relation 2 $CI = \frac{\lambda_{\max - n}}{n-1}$

- Finally, in order to ensure the consistency of the pairwise comparison matrix, the consistency of judgments of appropriate values of n is evaluated using the CR:

relation 3 $CI = \frac{CI}{RI}$

where RI is the random consistency index. RI values for different values of n are presented in Table 2. If CR≤0.1, the consistency degree will be acceptable. CR>0.1will be extremely inconsistent, and the AHP will not provide significant results (Chakraborty & Banik 2006).

5. The Evaluation of the AHP Model

In order to evaluate the map that was prepared based on the AHP, the map of the landslide areas of the watershed was generated. Afterward, the map of these areaswas combined withthe landslide hazard map, and the amount of landslides in different risk classes was reckoned.In the next step, the degree of the accuracy rate of the model was also calculated usingthe relation 4.

relation 4P=KS/S

In this relation, P stands for the experimental probability, KS corresponds tothe area of the landslide in moderate-to-high risk classes, and S represents the area of the total landslides of the region. The closer the experimental probability percent of the model is to 100%, the more suitable it is for the landslide hazard zonation of the region.

6. Results and Discussion

In this study, the information layers were firstly prepared and analyzed. Subsequently, all of the layers and substrates were compared with each other and then weighted on the basis of the expert judgment and the pairwise comparison (Tables 3&4). The results obtained from comparing the criteria indicate that the factors of geology, slope, precipitation, distance from the drainage, land use, distance from the fault, aspect, and elevation play the most important role in the occurrence of the landslides of the watershed respectively. The testsconducted onthe soil samples in the locations of the landslides of the region showed that the average soil ph was 7.5, and the soil texture containing 36% clay, 46% silt, and 18% sand was a silty clay loam. Therefore, the shear strength of the soil is decreased due to the absorption of water in the clay soil that causes the landslide on the suitable slopes. This point reveals the further impact of the factors of lithology, slope, and precipitation more ever than before.

7. The results obtained from comparing and weighting substrates are as follows

The geological survey of the region indicates that due to the susceptibility of the old landslide deposits, this unit has the highest susceptibility tothe landslides of the region and thus received the greatest weight in the pairwise comparisons.

The study of the slope of the region on the basis of the expert judgment shows that the highest landslide susceptibilityis in the 15-25 degrees classes.This

Table 2. Random Consistency Index (RI) (Satty 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56

Table 3. The Comparison Matrix of the Factors Used in the Landslide Hazard Zonation of Ayvashan Dam Watershed

factors influencing landslide	lithology	slope	precipitation	drainage	land use	fault	aspect	elevation	weight	inconsistency coefficient
lithology	1	1	2	3	4	5	7	7	0.266	0.02
slope		1	2	3	4	5	6	7	0.262	
precipitation			1	2	3	4	5	6	0.172	
drainage				1	2	3	4	5	0.115	
land use					1	2	3	3	0.073	
fault						1	2	3	0.051	
aspect							1	2	0.034	
elevation								1	0.026	

indicates that due to the decrease of the forceof gravity acting on the low slope and the weakening of the process of soilmaking on the high slopeplus the subsequent lack of materials prone to the landslide on the slopes, the landslide hazard probability is decreased.

The results obtained from the study of the faults of the region reveal that the susceptibility to the landslide is reduced with the increase of the distance from the fault. This points to the creation of the fracture and the production of debris in the areas that are closer to the fault.

The factor of the distance from the drainage also shows an inverse relationship with the occurrence of mass movements. This reflects the influence of rivers onthe removal of the lateral and underlyingsupportof slopes through the process of erosion and undercutting. This ultimately results in changing the geometry of the slope of the region, unbalancing the restoring forces, and the stress increment.

The study of the relationship between the elevation and the landslide distribution map indicates that the highest landslide susceptibility exists at the elevations of 2200-2400 meters, and few landslides have occurred at the higher altitudes due to the lack of suitable conditions for the phenomenon of soil making.

The results obtained from the land use study demonstrated that the highest landslide susceptibility exists in the forest unit that hasalowdensity canopy coverandthe dry lands. To a great extent, this can be attributedto the large area of the lands of this region.

The examination of the factor of geographical directions in relation to the distribution of the landslides in Ayvashan Dam Watershed based on the expert judgment shows that the highest landslide susceptibility is in thesouthwest(247/5° -202/5) because of the high amount of the local humidity in this class.

The results achieved from analyzing the precipitation factor reveals that the landslide susceptibility isenhancedbythe increase in the rainfall. This can be attributed to the absorption of more water by the clay soils and the reduction of the shear strength of the soil.

8. Evaluation of Results

In this study, in order to prepare the map of all of the landslides occurred in Ayvashan Dam Watershed, the aerial photos and satellite images of the region were used.Then the authenticity of the areasidentified and suspected of being prone to landslides was determined through field surveys, and a total of 664 landslide pixels with dimensions of 50*50 meters were identified.

In order to evaluate the results obtained from using the AHP method, the map of the landslide areas was prepared.Afterward, this map was combined withthe landslide hazard zonation map of the region (Fig. 2), and the area of the landslide in each hazard class was determined.What is more, the accuracy of the used model was estimated using the relation 4 (Table 5). The achieved results indicate that the utilized model

Table 4. The Comparison Matrix of Classes of the Factors Used in the Landslide Hazard Zonation of Ayvashan Dam Watershed

classes of factors affecting the landslide								weight	percentage of the area in each class
lithology	old landslide deposits	massive limestone	Breccia	Alluvial terrace					
old landslide deposits	1	4	6	7				0.628	1.05
massive limestone		1	2	3				0.192	23.31
Breccia			1	2				0.111	65.49
Alluvial terrace				1				0.069	10.14
slope	0-5	5-15	15-25	25-35	35-45	45<			

0-5	1	1/3	1/7	1/6	1/5	1		0.038	20.9
5-15		1	1/5	1/4	1/3	3		0.081	43.04
15-25			1	3	4	8		0.444	27.56
25-35				1	2	6		0.238	7.56
35-45					1	5		0.162	0.865
45<						1		0.037	0.066
precipitation	700	700-720	720-750	750<					
700>	1	1/3	1/5	1/6				0.058	38.37
700-720		1	1/4	1/5				0.110	14.28
720-750			1	1/3				0.285	22.20
750<				1				0.547	25.14
drainage	0-300	300-600	600-900	900-1200	1200<				
0-300	1	2	5	6	7			0.465	44.21
300-600		1	4	5	6			0.314	28.46
600-900			1	2	3			0.101	12.87
900-1200				1	2			0.071	6.65
1200<					1			0.050	7.8
land use	forest with average density canopycover	forest with low density canopy cover	irrigated farming	dry farming	pasture with average density canopy cover				
forest with average density canopycover	1	1/6	2	1/4	1			0.085	0.32
forest with low density canopy cover		1	5	4	6			0.526	43.75
irrigated farming			1	1/4	2			0.077	0.03
dry farming				1	5			0.251	55.77
pasture with average density canopy cover					1			0.061	0.12
aspect	north	north east	east	south east	south	west	north west		
north	1	2	2	5	1/2	1/2	4	0.114	22.96
north east		1	1	4	1/3	1/3	3	0.073	7.66
east			1	4	1/4	1/3	2	0.064	11.97
south east				1	1/7	1/6	1/2	0.024	5.19
south					1	2	5	0.211	16.50
south west						3	7	0.318	9.81
west						1	5	0.162	17.46
north west								0.035	8.42
elevation	1798-2000	2000-2200	2200-2400	2400-2600	2600-2800	2800<			
1798-2000	1	1/3	1/6	1/5	1/2	2		0.057	20.22
2000-2200		1	1/3	1/2	2	4		0.151	29.86
2200-2400			1	2	5	8		0.407	26.44
2400-600				1	3	6		0.255	15.55
2600-2800					1	3		0.092	6.97
2800<						1		0.037	0.95
fault	0-300	300-600	600-900	900-1200	1200<				
0-300	1	2	3	5	6			0.415	25.82
300-600		1	3	5	6			0.314	27.77
600-900			1	3	4			0.154	21.17
900-1200				1	2			0.070	12.50
1200<					1			0.047	12.72

delineated the landslide hazard zonation with high accuracy.

9. Conclusion

The study of the slope instability phenomenonis carried out with the identification and assessment of factors influencing the landslide and the preparation of the landslide hazard zonation map.This study has been considered to be of importanceon several grounds and has thus attracted the attention of many planners at various scales. On the one hand, it is conducive to the detection of the areas that are prone to the landslide in the range of human activities. One the other hand, it helps to identify the safe areas for developing new habitats or other future human uses, including roads, power transmission lines, energy,

Table 5. Results Obtained from the Evaluation of the AHP Process

risk class	the percentage of the area of each class	the number of landslide pixels in each class	the accuracy of the used model (percent)
very low	14.85	3	95.03
low	33.89	30	
moderate	23.75	65	
high	19.54	116	
very high	7.95	45	

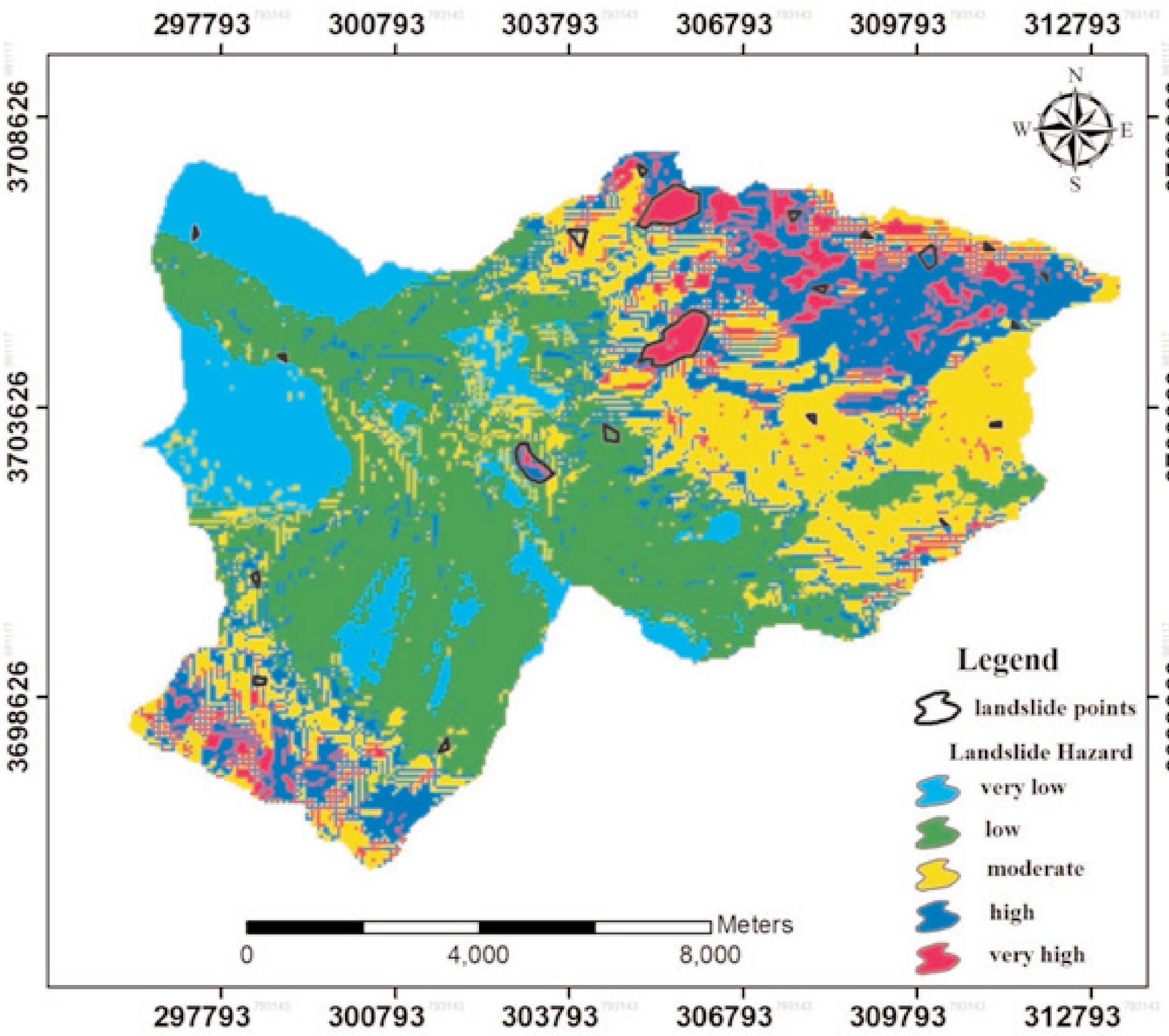

Figure 2. The Landslide Hazard Zonation Map of Ayvashan Dam Watershed

and the like. Lorestan Province is prone to the landslides due to its various geological characteristicssuch as lithology, tectonics, seismicity, and particular climate conditions. Because of the geographical location of the study area, several landslides have occurred in this region. The future risks of this phenomenon can be prevented by the identification of the factors affecting the landslides of this region accompanied by the preparation of the hazard map of this phenomenon.Becausethe factors that cause the landslide are different in terms of their degree of importance,the identification andproper prioritization of these factors is necessary to preventthe landslide occurrence. In this study, the oral judgments (the expert opinion) and the AHP, as one of the multi-criteria decisionmaking methods,have been drawn on to prioritize the factors affecting the landslide. The obtained results indicate that the geological factors, slope, precipitation, distance from the drainage, land use, distance from the fault, aspect, and elevation play the most important roles in causing the landslides of Ayvashan Dam Watershed respectively.

In this study, the AHP was used for the landslide hazard zonation of Ayvashan Dam Watershed. Based on the results obtained from the landslide hazard zonation through the use of this model,14.85, 33.89, 23.75, 19.54, and 7.95 percent of this region are located in very low, low, moderate, high, and very high risk classes. The evaluation of the results using the experimental probability index points to the performance utility of the AHP model with an accuracy of over 95%.

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