Probabilistic Landslide Risk Analysis and Mapping (Case Study: Chehel-Chai Watershed, Golestan Province, Iran)

Ebrahim Karimi Sangchini[A], Majid Ownegh[B], Amir Sadaldin[C], Armin Mashayekhan*[D]

[A]Postgraduate Student, watershed management. Gorgan university, Iran.
[B]Scientific Board of watershed management. Gorgan university. Iran.
[C]Scientific Board of watershed management. Gorgan university. Iran.
[D]PhD Student of Forestry Science, University of Sari. Iran. Email: mashaykhan@yahoo.com

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Abstract. The efficiency of three statistical models, AHP surface-weighted density bivariate (semi-quantitative models), stepwise multivariate regression and logistic multivariate regression models were compared in Chehel-Chai watershed in Golestan province, Iran. In current study the hazard map was prepared according to the top model of landslide hazard map. Chehel-Chai watershed is located as one of Gorganrud river sub basins in Golestan province. The distribution map of the area landslide was provided using the stereoscopically interpretation of aerial photos and field observations and nine effective factors including elevation, slope, aspect, lithology, distance from fault, stream and road, land use, and precipitation rate were chosen concerning the expert view and source review. The hazard potential of landslides was also prepared using three models. The differences were compared between models of hazard classes with Chi-square test, the agreement rate of risk maps with kappa index and the evaluation of the model accuracy with total quality index (QS). The risk map was provided based on the risk equation by the combination of the risk maps, the element frequency and the element vulnerability degree. The results showed that all models had 99% reliability level and there were a high separation among the risk classes. Kappa index was variable between 0.0 to 0.2 representing that the correspondence between them is negligible. The weighted (AHP) bivariate statistical model was selected as the best model for the basin with QS equal to 3.62. 12.13% of the surveyed basins were located in high loss class and very high loss class, respectively. It was concluded, 41% of Chehel-Chai watersheds were at moderate risk and from it 13% was in high classes risk that must be considered in risk management, landslide risk and land logistics of this mountainous area.

Key words: Landslide hazard zonation, Quantitative and Semi-quantitative models, Elements at risk, Vulnerability, Risk, Chehel-Chai watershed.

Introduction

Hazards have always created numerous problems for human being from very long time ago along with the threat of life and resources. So, identifying the appropriate solutions to alleviate, control and reduce the risk of natural events has been of great importance to the research centers, universities and international organizations, nowadays. Landslide phenomenon has an important position among the 43 natural dangers threatening human life and resources despite its severe differences to environmental conditions (Mostafaie, 2006). Tens of numerical models had been corrected with factors, weight rate, and computational logic and invent different scales in different circumstances based on the calibrated ground evidences to zonate the relative hazard of domain instability. We can refer to the researches done by Esmaeeli and Ahmadi, 2003; Ayalew and Yamaghishi, 2005; Shirani *et al*., 2006; Mostafaei, 2006; Shadfar *et al*., 2007; Kalarostaghi *et al*., 2007; Yalcin, 2008; Kalarostaghi and Ahmadi, 2009; Nandy and Shakur, 2009 and Yilmaz, 2009 in landslide hazard zonation using statistical models including AHP weighted bivariate, multivariate stepwise and logistic models. The general risk equation shows the risk level as a result of the within hazard, risk elements and landslides vulnerability. Landslide risk was simply calculated as the single product of three contributing factors: (1) the probability of landslide occurrence within a certain magnitude (2) risk valued elements and (3) Vulnerability; the expected degrees of risk resulting from a certain magnitude landslide loss (Cozier and Glade, 2005). Risk elements include roads, buildings, water supply and agricultural activities. Risk to the buildings and vehicles on the roads are a large part of the risk, but it is difficult to estimate the losses and there is also a lack of sufficient data. Additionally, the risk to human life (loss of life) can't be analyzed. Other vulnerable elements such as electricity and telephone networks are indirect costs and it is difficult to obtain the amount of risk (Zezere *et al*., 2008). Remondo *et al*. (2008) performed the qualitative and quantitative assessment of landslide risk and mapping was done based on the recent events in GIS environment in Bajo Deba region (Northern Spain). In this research, risk assessment was obtained by statistical relations between past landslides and parameters related to land instability. Landslide risk was mapped based on the involved risk, vulnerability, and valuation of the elements at risk. Direct loss map (euro/pixel/year) and indirect losses caused by the failure in economic activities were prepared by the evaluated landslides in the watershed. The final result was presented as a risk map and a composition table of all losses for a 50-year period. Zezere *et al*. (2008) carried out the landslide possible risk analysis in northern Lisbon (Portugal) with regard to the direct costs. They used the two-variable statistical model for landslide hazard zonation and the landslide direct cost was calculated using the three contributing factors namely, landslide, and vulnerability and risk elements. They selected roads and buildings as the elements at risk and stated that a large part of the risk can be considered as the risk to the building content and vehicles on the roads. But it is difficult to estimate these problems and there is also a lack of sufficient data. Moreover, the loss of human life cannot be analyzed. In a research under the title of evaluating the landslide qualitative susceptibility by Enrique *et al*. (2008), they prepared the landslide hazard map using multi-criteria evaluation in Guantanamu, Cuba with 9 factors namely, slope degree, line, slope shape, geological structure, active faults, distance from drainage (water way), distance from the spring, geomorphologic units and distribution of landslide and weighting based on the expert judgments.

The landslide density increase in higher classes of danger in the studied area indicated that the output map is reliable and eventually, they produced the risk qualitative map by combining the hazard map and available information on construction and infrastructure (houses, schools, cemeteries and roads).

The purpose of this research was to assess hazard with three statistical models namely, AHP weighted bivariate, stepwise multivariate and logistic multivariate models and also to evaluate the landslide risk using the hazard intensity, elements and vulnerability degree of the elements at risk in order managing the risk in Chehel-Chai mountainous area.

Materials and Methods

Introduction of the studying area

A) Chehel-Chai is one of the mountainous areas in Iran with the coordinates of 55°23' to 55°38' of eastern longitude and 36°59' to 37°13' of northern latitude with an extent of 25683 ha (Fig. 1). This area is within Minoodasht city in terms of political divisions as one of the large sub areas of Gorgan River (Fig. 1). The minimum and maximum altitude is 135 m and 2550 m above sea level, respectively. The average annual rainfall of the area is 766 mm. From the geological perspective, it is located between two big structural and sedimentary states of eastern Alborz and western Kappedagh. The constructive elements of this area are mostly in the fault type. More than %60 of its surface is covered with forests and the rest are of other cultivated lands.

B) Preparation of the landslide distribution map, selection and effective factor classification: Listing and landslide distribution maps were prepared using field visit in the area, local information, GPS devices and landslide distribution map which was prepared from aerial photo interpretation and field visit (Golestan watershed department) (Fig. 1). Landslides with an area of at least 10 × 10 SQ were chosen as the basis. Nine factors as: namely, height, slope, direction, distance from drainage, distance from the road (topographic map 1:50000 of Golestan watershed department), petrology, distance from the fault (1:100000 map of Golestan watershed department), land use (of watershed department map) and rainfall (of rain curves prepared by adjacent station's statistics of area of Golestan watershed department) were selected as the effective factors on landslide by browsing previous resources, examining Chehel-Chai watershed area and library studies. In the next stage, the area and the landslide percentage, the population density and the landslide density percentage in each class of these nine landslide factors were calculated (Table 2).

C) Landslide hazard assessment: Landslide hazard was evaluated using three statistical models namely, AHP weighted bivariate, stepwise multivariate and logistic multivariate models in Chehel-Chai watershed.

i) **Hazard zonation with two-variable statistical model of level density weighted with AHP:** Map of each effective factor with distribution map of effective factors was discontinued. The area and landslide percentages on each category of map of factors were calculated and then the rate of each category was calculated using the surface density equation (Kelarostaghi and Ahmadi, 2009).

$$Ra = 1000 \times (A/B) - 1000 \times (C/D) \quad \text{(Equation 1)}$$

Where:

A= The landslide area per unit

B= The area of each unit

C=The total landslide area in each watershed

D=The total area of watershed

Ra=Surface area rate

The weight of nine factors was calculated by AHP using expert-choice-1 software (Table 1). Finally, the risk intensity map was prepared with multiplying the weight of each factor to rate and the pixels were classified in 6 classes based on the turning points of the cumulative frequency curve (Fig. 3).

Landslide hazard map using AHP weighted two-variable statistical model =map of rainfall classes rate ×..264 + map of slope classes' rate ×..225 + map of litho logy classes rate ×..164 + map of direction classes rate ×..088 + map of land use classes' rate ×..08 + map of distance from the fault classes' rate ×.062 + map of distance from the road classes' rate ×..064 + map of distance from the stream classes rate ×..048 + map of height rate classes' ×..023.

ii) Landslide hazard zonation using stepwise multivariate regression model AHP was used to determine the numerical value of qualitative factors in different classes (direction, land use and lithology) and the classes were weighted according to slippage (landslide) rate in factors of different classes and the weight of each factor was evaluated after conducting the paired comparisons between classes. The nine layers were combined together in GIS environment and the map of homogenous units was produced. Then, the map of homogenous units was cut with landslide distribution map and nine factors and the logarithm of the sliding factor (it took place in order to standardize the logarithmic conversion) were chosen respectively as independent variables and dependent variable. The most effective factors were determined as height, slope, litho logy, distance from the fault, distance from the road, land use and annual rainfall using the SPSS software and stepwise method (Mostafaei, 2006). The equation determination coefficient equals with 67.96 percents being significant at 95% reliability level.

$$Y=1.31+0.0026P+0.0059S+.00058R+0.00054L+0.0016G+0.00037E-0.00012F \quad \text{(Equation 2):}$$

Where:
Y=hazard number
P=annual rainfall
S=slope rate
R=distance from the road
L=land use
G=litho logy
E=height
F=distance from the fault

The map of landslide hazard intensity was prepared in $ArcGIS_{9.3}$ environment using this equation and the pixels were classified in 6 classes based on the turning points of the cumulative frequency curve (Fig. 4).

iii) **Landslide hazard zonation by logistic multivariate regression model:** The map of homogenous units was cut with landslide distribution map and nine factors and the logarithm of the sliding factor (it took place in order to standardize the logarithmic conversion) were chosen as independent variables and dependent variable, respectively. The most effective factors were determined as height, slope, lithology, distance from the fault, distance from the road, land use and annual rainfall using the R software and logistic method.

$$Y= -5.16 + 0.029R + 0.012L + 0.017S \quad \text{(Equation 3)}$$

Where:
Y=hazard number
R=distance from the road
L=land use
S=distance from the stream

The map of landslide hazard intensity was prepared in $ArcGIS_{9.3}$ environment using this equation and the pixels were classified in 6 classes based on the turning points of the cumulative frequency curve (Fig. 5).

iv) **Evaluate indices of logistic multivariate regression model**

A: Pseudo-R^2 index:

Pseudo-R^2 index is one of the indicators used to evaluate the efficiency of logistic multivariate regression model. This index is based on the likelihood ratio rule and tests the goodness of fitness of logistic regression and can be calculated according to the following equation.

Pseudo-R^2= 1- (log (likelihood)/log (Lo) (Equation 4)

Likelihood: the likelihood functions in case of fully fitted model.

Lo: the likelihood function in case that all factors except the intercept are zero.

Unlike R^2 in ordinary regression, Pseudo-R^2 does not indicate the variance proportion clarified by the model but the experimental input and output of regression model, thus its value is typically much lower than R^2.

Pseudo-R^2 equals with a perfect fitness and Pseudo-R^2 equaled to zero indicates no significant relationship between independent and dependant variables. Location of studies when the Pseudo-R^2 amount is greater than 0.20, it can be considered as a relatively good fitting (Clark and Hosking, 1984). In this study, the Pseudo-R^2 amount equaled with 0.39 was calculated, as the result, the model fitting can be considered fairly well.

B: ROC index

The logistic multivariate regression model efficiency can be evaluated by ROC index (relative operative characteristic). ROC curve is a graph in which the pixels that have been predicted accurately by the model are plotted against its complement namely the proportion of pixels that are wrongly predicted. As already mentioned, the logistic multivariate regression model calculates the possibility of change for each pixel in a continuous range of zero and one. By determining certain thresholds (e.g. 0.5), the output can be converted to a discrete scale of zero or one (no change or changes thereto). That is to say, the pixels in which the change possibility is more than the threshold take 1 and those pixels in which the change possibility is less than the threshold take zero and the output is presented as a map. By comparing this map with the actual map, the relation of pixels that are accurately predicted and those that are wrongly predicted is determined that can be showed as a single spot on the ROC curve. By changing the certain threshold, other spots are specified and by connecting these spots, ROC curve is plotted. The ROC index equals with the area under the curve (Pontius and Schneider, 2001). In this study, the Pseudo-R^2 amount equaled with 0.897 was calculated. As the result, the model fitting can be considered fairly well.

v) **Evaluation of hazard models**

Quality sum (Qs) index was used for the evaluation of hazard model accuracy.

$$Q_S = \sum_{i=1}^{n}\left[(D_r-1)^2 \times S\right]$$ Equation (5):

Where:

Qs=Quality sum

D_r=Density ratio

S=Hazard class area/Watershed area

n=Hazard class number

$$D_r = \frac{S_i / A_i}{\sum_1^n S_i / \sum_1^n A_i}$$ Equation (6):

Where:

D_r=Density ratio

Si=Landslide area to hazard area

Ai=Hazard class area

n=Hazard class number

D) **Landslide risk assessment**

The overall landslide risk is estimated using the R=HEV risk equation in which R, H, E and V stand for risk, risk highness, elements at risk and elements vulnerability rate, respectively. In order to evaluate the risk in bridges which are smaller than 1×1 cm in 1:50000 scales (the bridges smaller than 25 hectares), the risk map of AHP weighted two-variable statistical model was combined with larger adjacent bridges. In conclusion, 121 units in different classes were deduced and this map is considered as the basis of landslide risk evaluation in the studied area.

i) Map of the elements at risk

The elements were identified and the map of elements at risk was prepared using land use and topographic maps and also by listing the elements at risk for each unit of the risk class map (Table 4 and Fig. 2).

ii) Element vulnerability map

The existence of risk and circumstances for any factors in terms of economy and ecology is important for calculating the element vulnerability score. Elements at higher risk levels are of more importance and have higher vulnerability. There are no major industrial facilities, highways, tourist complexes and town houses in the studied area. Communication ways, land use and residential places are more important than the elements aforementioned. The road is significant in this area for vehicle traffic and the villages' communication with the surrounding cities such as Minoodasht and Gorgan (Table 5 and Fig. 2).

iii) Landslide risk assessment

Risk number was calculated using the R=H.E.V equation in which the numerical values of risk elements, element vulnerability and risk intensity were multiplied and the final map was provided in 5 classes of very low, low, medium, high and very high based on the turning points of the pixel cumulative frequency curve (Table 7 and Fig. 6).

Results

Distribution map of the watershed landslide

Landslide distribution map showed that there were a number of 111 landslides scattered in the whole area. The total level of slippage in the area was 1192 ha that is tantamount to 4.64% of the watershed level (Fig. 1).

Hazard intensity

The landslide hazard map provided with different models

The selection of the suitable model using Dr and Qs indices

Dr and Qs indices for models and their hazard classes were prepared using the combination of the landslide hazard zonation map obtained from the models with the distribution map of the area landslides (Table 3).

Risk

The risk mapping was classified in 5 classes of very low, low, medium, high and very high based on the turning points of the pixel cumulative frequency curve (Table 7 and Fig. 6).

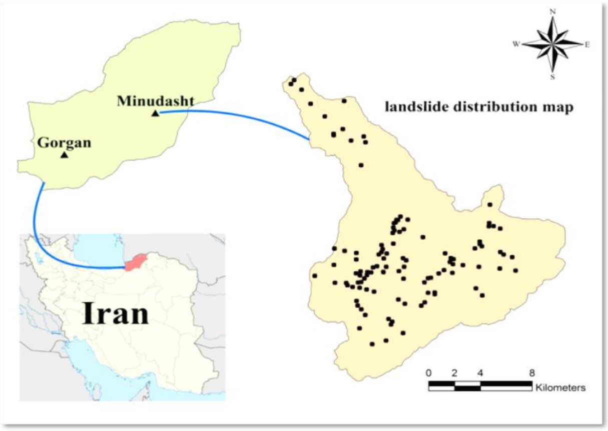

Fig. 1. Location of landslides in the study area, Golestan province and Iran

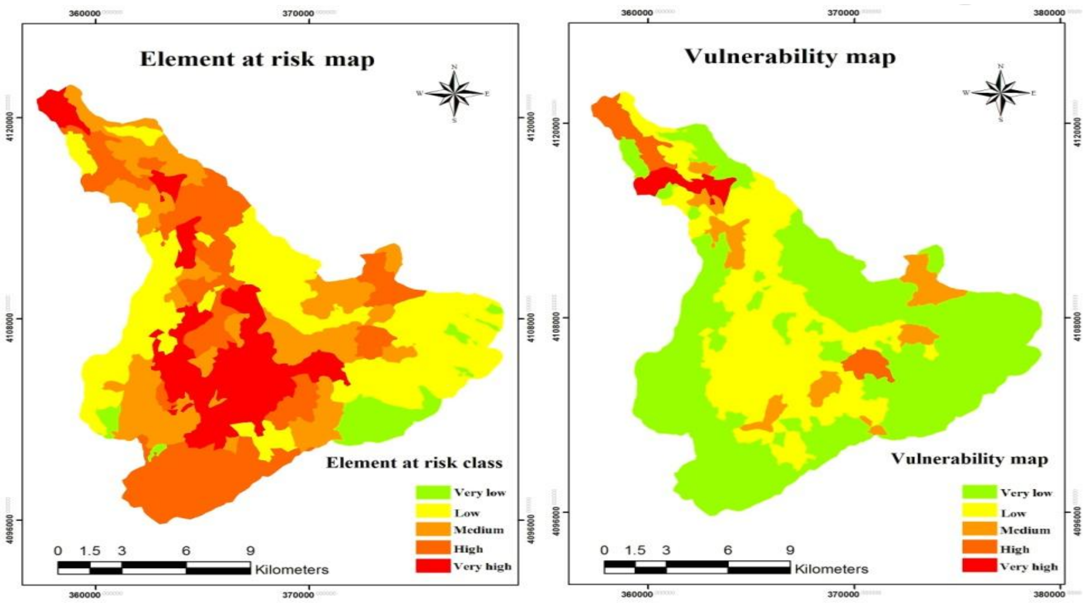

Fig. 2. Element at risk and vulnerability map in Chehel-Chai watershed

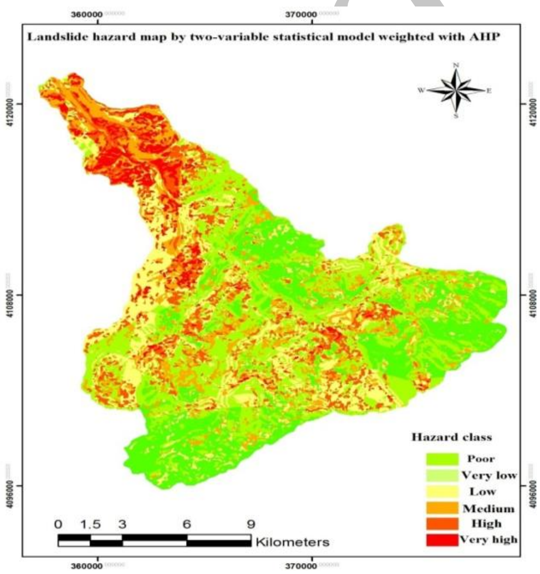

Fig. 3. Landslide hazard map by two-variable statistical model weighted with AHP in Chehel-Chai watershed

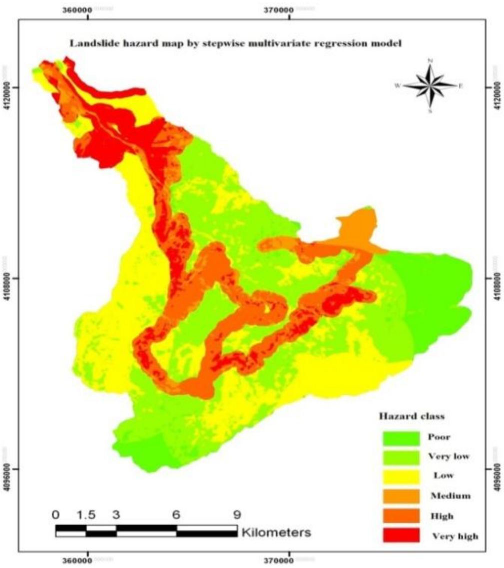

Fig. 4. Landslide hazard map by stepwise multivariate regression model in Chehel-Chai watershed

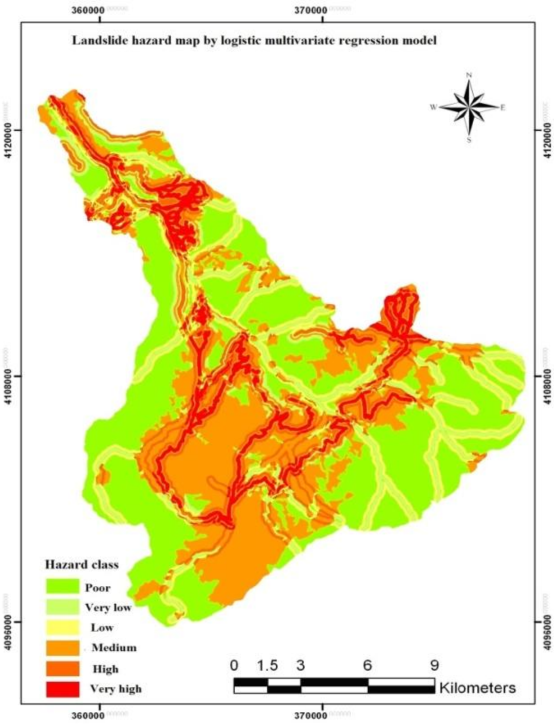

Fig. 5. Landslide hazard map by logistic multivariate regression model in Chehel-Chai watershed

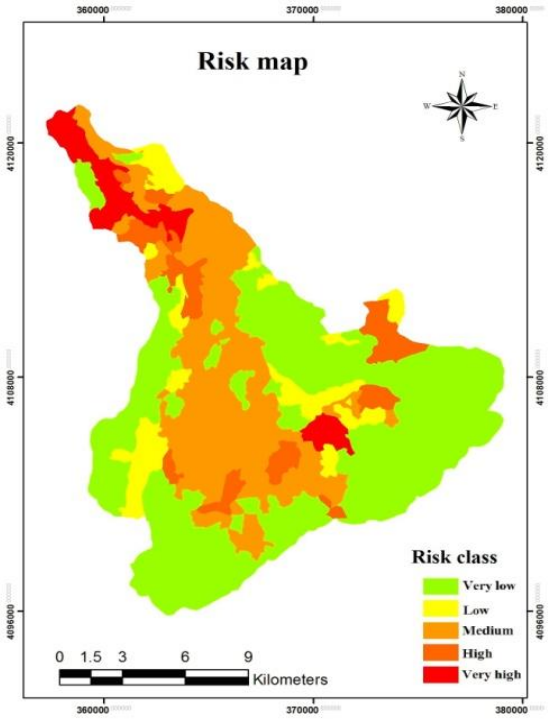

Fig. 6. Risk map in Chehel-Chai watershed

Table 1. AHP paired comparisons and determining final weight factors of landslide

	Rainfall	Slope	Geology Units	Aspect	Land Use	Distance From Road	Distance From Fault	Distance From Drainage	Elevation
Rainfall	1	2	2	3	4	3	3	4	7
Slope	0.5	1	3	3	3	4	3	4	7
Geology Units	0.5	0.33	1	3	2	3	4	4	6
Aspect	0.33	0.33	0.33	1	2	2	1	2	4
Land Use	0.25	0.33	0.5	0.5	1	2	2	2	3
Distance From Road	0.33	0.25	0.33	0.5	0.5	1	2	1	4
Distance From Fault	0.33	0.33	0.25	1	0.5	0.5	1	2	3
Distance From drainage	0.25	0.25	0.25	0.5	0.5	1	0.5	1	3
Elevation	0.14	0.14	0.17	0.25	0.33	0.25	0.33	0.33	1
Final Weight	0.24	0.22	0.16	0.08	0.08	0.06	0.06	0.04	0.02

Table 2. Calculation of the final hazard or susceptibility value of each identified land unit

Data layers	Total area (ha)	% of total area (A)	area of Landslide	% of area landslide (B)	Area density value	AHP weight
Elevation (m)						0.023
195-400	1124.67	4.34	7.773	0.65	-34.59	
400-600	1701.65	6.63	363.00	30.45	171.81	
600-800	2926.86	11.4	117.97	9.896	-1.205	
800-1000	3843.10	14.96	293.50	24.62	34.86	
1000-1200	4426.16	17.23	123.49	10.36	-13.60	
1200-1400	4402.28	17.14	102.43	8.59	-18.24	
1400-1600	2881.98	11.22	183.17	15.36	22.04	
1600-1800	2212.66	8.62	0.77	0.065	-41.16	
1800-2550	2162.45	4.22	0.00	0.00	-41.51	
Geology units						0.164
Jmz,El	3716.50	14.47	65.60	5.51	-28.76	
Dkh,Cm	15310.9	59.62	461.94	38.75	-16.24	
Pr,Jcb	3615.07	14.08	408.94	34.3	66.70	
Jk-sd,Jk-c,Dpd	2742.31	10.68	237.63	19.93	40.23	
Ql,Qt	296.45	1.154	6.994	0.59	-22.82	
distance from road (m)						0.64
0-75	2338.22	9.1	520.74	43.68	181.19	
75-150	1896.89	7.39	29.751	2.5	-25.82	
150-225	1624.95	6.33	27.23	2.28	-24.74	
225-300	1437.77	5.6	16.57	1.39	-29.98	
300-500	3051.14	11.88	188.45	15.8	20.25	
>500	15369.13	59.85	409.36	34.34	-14.87	
distance from stream (m)						0.048
0-50	1589.83	6.19	118.17	9.92	32.82	
50-100	1559.37	6.07	57.45	4.82	-4.66	
100-150	1512.63	5.89	388.83	32.62	215.5	
150-200	1464.32	5.7	44.96	3.77	-10.80	
200-300	2784.56	10.84	23.55	1.98	-33.05	
300-450	3728.18	14.52	51.67	4.33	-27.65	
>450	13079.2	50.93	507.47	42.57	-2.71	
distance from fault (m)						0.062
0-500	4856.19	18.91	551.05	46.22	67.05	
500-1300	7124.89	27.74	308.38	25.87	-3.13	
1300-2300	6591.42	25.67	151.60	12.72	-23.4	
2300-3500	4376.17	17.04	180.79	15.17	-5.10	
>3500	2734.41	10.65	0.28	0.02	-46.3	
Slope (%)						0.225
0-15	3368.80	13.12	76.94	6.45	-19.91	
15-30	4606.75	17.94	172.33	14.46	-7.74	
30-45	6695.94	26.07	752.30	63.11	78.58	
45-60	4806.17	18.72	76.72	6.44	-27.92	
>60	6204.66	24.16	113.81	9.55	-25.85	
Rainfall (mm)						0.246
560-640	477.95	1.86	0.00	0.00	-46.41	
640-720	2383.02	9.28	6.33	0.530	-43.76	
720-800	16893.3	65.78	728.26	61.08	-3.30	
800-880	5928.78	23.09	457.52	38.37	30.75	
Land use						0.08
Forest	10310.58	40.15	220.65	18.51	-32.47	
Agriculture	15291.71	59.54	971.43	81.49	52.20	
Range	116.61	0.45	0.00	0.00	-46.41	
Aspect						0.088
p	2480.11	9.66	42.24	3.54	-29.38	
N	3149.80	12.26	170.60	14.31	7.74	
NE	2771.93	10.79	106.44	8.93	-8.01	
E	2443.05	9.51	82.06	6.88	-12.82	
SE	2219.16	8.64	14.09	1.18	-40.06	
SE	1754.47	6.83	21.95	1.84	-33.90	
SW	2275.17	8.86	4.60	0.39	-44.39	
W	3581.95	13.95	244.43	20.5	21.82	
NW	5004.93	19.49	505.67	42.42	54.61	

Table 3. Dr and Qs index for hazard models to Chehel-Chai watershed

Hazard model	hazard class	area	Landslide area	Dr	QS
AHP weighted bivariate					3.62
	1	5101.91	34.83	0.15	
	2	7064.50	189.87	0.58	
	3	5040.38	155.46	0.66	
	4	4364.41	160.09	0.79	
	5	2874.01	128.40	0.96	
	6	1166.58	523.47	9.64	
Logistic multivariate					1.7
	1	10763.93	171.55	0.34	
	2	1594.45	128.07	1.73	
	3	1984.42	10.79	0.12	
	4	7299.06	213.08	0.63	
	5	2235.07	242.95	2.34	
	6	1736.37	425.70	5.27	
Stepwise multivariate					1.63
	1	2573.91	1.80	0.02	
	2	8666.54	271.43	0.67	
	3	6560.72	151.21	0.50	
	4	1518.67	20.97	0.30	
	5	4250.35	251.91	1.27	
	6	2064.18	494.82	5.15	

Table 4. Elements at risk classes in Chehel_Chai watershed, (Nazarinejad, 2010)

Elements At Risk Classes	Number of elements	Area (ha)	% Area
Very Low	1	1296.30	5.07
Low	2	7985.54	31.2
Medium	3	5698.58	22.3
High	4	6329.15	24.7
Very High	5	4246.72	16.6
Total		25683.1	100

Table 5. Vulnerability core of elements at risk, (Jamshidi, 2009)

Elements at risk	Potential of elements at risk	Vulnerability number
Roads	Increase Being paved, with foundations and increase with 3 coefficient with increasing hazard class	1-30
Buildings	Increase with 3 coefficient with increasing hazard class	1-18
Drainages	Increase with importance, and increase with 2 coefficient with increasing hazard class	1-18
Springs	Increase with consumption type, with increasing discharge and increase with 2 coefficient with increasing hazard class	1-30
Agriculture	Increase with decreasing slope and increase with 3 coefficient with increasing hazard class	1-36

Table 6. Vulnerability classes in Chehel_Chai watershed

Vulnerability classes	Vulnerability number	Area (ha)	% Area
Very low	0.0-25	14931.6	58.43
Low	26-50	7549.3	29.54
Medium	51-75	1703.8	6.67
High	76-100	890.03	3.48
Very high	101-132	481.33	1.88
Total		25683	100

Table 7. The distribution of area in different landslide risk classes

Risk class	Pixel value	Area (ha)	% Area
Very low	0-6	12822	50.18
Low	7-12	2194	8.59
Medium	13-30	7186	28.12
High	31-72	1980	7.75
Very high	73-150	1371	5.37
Total		25683	100

Discussion

In this research, the risk evaluation was calculated using R=H.E.V equation. This model was also used for landslide qualitative assessment by Ownegh (2009) in Ziarat Watershed, Gorgan and Remendo *et al*. (2008) in Bajodeba area (Northern Spain) and Zezere *et al*. (2008) in Northern Lisbon (Portuguese), Enrique *et al*. (2008) in Kuanatanamu, Cuba, weighted (AHP) two-variable statistical model was chosen as the suitable model for Chehel-Chay watershed with Qs=3.625 and logistic multivariate regression with Qs=1.703 and stepwise multivariate regression with Qs=1.627 were the next in the order of priority. The results of this research are in line with the researches of Esmaeeli and Ahmadi (2003) in Garmi-chai watershed, Shirini *et al*.(2006) in Semirom, Yalcin (2008) in Ardesen, Turkey, Yilmaz (2009) in Tatakat, Turkey, Kalarostaghi and Ahmadi (2009) in northern Iran and are inconsistent with the researches of Ayalew and Yamaghishi (2005) in Japan, Mostafaii (2006) in Alamut, Ghazvin and Nandi and Shakoor (2009) in the USA despite the multivariate statistical analysis methods which make it possible to analyze spontaneously the effect of independent variables on the dependant spatial variables and since phenomena such as landslides are caused by spontaneous different effect performances of some variables so it should be appropriate to use them; however, it can be seen that QS amounts of these models were made lower than QS amount of two-variable statistical model of weighting surface density with AHP. Perhaps, this factor needs to be sought in applying the expertise viewpoint in weighing by various factors with AHP. After the zonation thorough two-variable statistical model of weighting surface density with AHP, 15.77 percents of Chehel-Chai watersheds (mostly in northern parts and the basin outlet) were classified in high hazard and so many categories. According to the analysis of factors in logistic regression, the nine effective factors, 3 factors of land use, distance from the waterway and the distance from the road were chosen as the most effective factors with regard to these findings and the previous researches of Shadfar *et al*., 2007 in Chalkrood watershed and Kelarostaghi *et al*., 2007 in Tajan watershed.

Conclusion

It can be concluded that changing the land use and converting the forests to rainfed farming or road construction that so many of them have been made in North during recent years have led the role of human factors to appear more significant than other factors in the occurrence of landslides and have led large number of landslides to occur near arable lands and roads. It can be concluded from landslide hazard zonation in Chehel-Chai watershed that the landslides with greater areas are dependent on rainfalls, slope, lithology, direction and land use (two-variable statistical model of weighting surface density with AHP), at the same time the occurrence or absence of landslides (logistic regression) is dependent on factors like distance from the road, distance from waterways and land use and greater numbers of landslides have occurred near roads, waterways and farming places. Road, residential properties, springs, waterways and farming lands were selected as in danger elements. Ownegh (2009) in Ziarat watershed of Gorgan, had selected communicational roads, power networks, houses, tourism organization, water resources and population density and Zezere *et al*. (2008) in north of Lisbon, Portugal have selected roads and buildings and Enrique *et al*. (2008) in Kvantamv Cuba have selected houses, schools, cemeteries and roads as in-danger elements. It was concluded, 41.38% of Chehel-Chai watersheds were at the risk. However, only 5.38% of these watersheds were at landslide risk due to lack of important facilities, big factories, and highways, large recreational complex and important structures in this mountainous area. After multiplying the risk maps, at risk elements and element vulnerability, the risk qualitative map of landslide was produced. Eventually, 13.12% of Chehel-Chai watershed were placed in high and very high classes of risk that must be considered in risk management, landslide risk and land logistics of this mountainous area.

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