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Landslide Risk Zoning using Frequency Ratio Model (Case Study: Fathabad Rectangular Map Area, Lorestan Province)

Siamak Baharvand*[1]

[1]*Department of Geology, Khorramabad Branch, Islamic Azad University, Khorramabad, Iran*

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ABSTRACT

Landslide is a natural disaster causing huge human and financial losses in different countries every year. Identifying and classifying slide-prone areas and zoning their hazards is an important step to assess environmental hazards. This research has been conducted with the aim of zoning the relative risk of slope instability in Fathabad Rectangular Map Area in Lorestan Province. To study the stability of slopes in this area, slide-prone points were first identified using satellite images and field visits, and then a landslide distribution map was drawn. By combining the map of factors affecting slide with a landslide distribution map, the impact of each of these factors including steepness and its direction, altitude, lithology, distance from the fault, land use, distance from the waterway, and road was measured in an ArcGIS software environment. Afterward, the Frequency Ratio Model was used for landslide risk zoning. The results of this method show that 18.55, 30.67, 26.51, 18.15, and 6.12% of the area is in the risk class of very low, low, medium, high, and very high, respectively. To evaluate and classify the output results of the model, the sum of the utility index has been used. The findings showed that the frequency ratio model has high accuracy in landslide risk zoning.

1. Introduction

Landslide is among the most alarming disasters that could cause irreparable damage to human life and property every year (Lan et al., 2004; Vineetha et al., 2019; Azarafza et al., 2021). This natural phenomenon may inflict damage or destruction to a variety of engineering and man-made structures, including residential areas, vital arteries such as roads, gas pipelines, water and power lines, forests and pastures, agricultural lands and mines. In addition, the social and environmental effects of this phenomenon, including adverse social impact and increased sediment load of rivers should not be ignored (Soori et al., 2012).

Iran has several natural conditions for a wide range of landslides because of its predominantly mountainous topography, tectonic activity and high seismicity, as well as diverse climatic and geological conditions (Nojavan et al., 2019). Therefore, as much as we enjoy the blessing of mountains and the diversity of climate, we are also exposed to their resultant dangers. The passage of large Zagros faults, the alternation of hard calcareous layers as well as loose shale marl layers in the edge of large anticlines have created favorable conditions for the instability of large parts of natural slopes throughout Lorestan Province. There have been several studies in Iran and other parts of the

*** Corresponding author.**
E-mail address: sbbaharvand53@gmail.com
Associate Professor, Academic Staff.

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world in the field of slide risk and mass movements, and various researchers have presented several classifications using frequency ratio method, all of which have emphasized the optimal performance of this model in landslide risk zoning. These researches include the following:

Lee and Pradhan (2007) Landslide Hazard Zoning in Selangor Region of Malaysia; Razavi Termeh and Shirani (2019) Landslide susceptibility study in Fahliyan Basin; Khan et al (2019) Landslide risk assessment in northern Pakistan; Rahman et al. (2020) Assessment of landslide sensitivity in East Hindu Kush in Shahpur Valley. Emadodin et al. (2020) is conduced landslide zoning in Oghan Basin. In general, the ultimate goal of studying landslides is to find ways to reduce the damage caused by them, which emphasizes the need to draw a hazard susceptibility map (Komac, 2006; Wang et al., 2016). Therefore, the goal of this study was landslide risk zoning in Fathabad Rectangular Map Area located in Lorestan Province using frequency ratio model.

2. Material and Methods

2.1. Geographical Location of Study Area

The study area is located in the east and southeast of Khorramabad city in Lorestan Province (Fig. 1). This region is situated in Folded Zagros, and the best way to reach it is through the ring road of Khorramabad. The surface area is 637 square kilometers and the altitude of the highest and lowest points is 2810 and 1258 meters, respectively, with average altitude of 2034 meters above sea level.

2.2. Information layers

The factors considered for landslide risk zoning are determined according to items such as purpose, scale of work and expected accuracy, area conditions, the extent to which each factor is effective, as well as sufficiency and availability of information. Accordingly, in addition to the map of slide points, eight other factors have been investigated as follows.

Slope: Slope is one of the main parameters of steepness stability analysis that directly affects the occurrence of landslides (El Bchari et al., 2019). To draw the slope map, the digital elevation model was used, which was prepared by 1:50,000 topographic map alignment lines of the study area in ArcGIS software environment.

Lithology: Lithology is one of the most important factors affecting slope instability that generally expresses the structure, texture, strength and relative durability of a rock mass. The characteristics and type of rocks have a major role in the stability and instability of slopes (Shahzeidi and Ghanbari, 2019). The lithological map of the study area has been prepared based on 1:100000 geological maps of Khorramabad and field studies.

Distance from road: Distance from the road has an important role in studying the occurrence of slope movements due to the removal of the slope basement and changing steepness of slopes (Safari and Hashemi, 2017). To draw the distance from the road map, the road network was extracted from topographic map and images of Google Earth and digitized in ArcGIS software environment.

Distance from fault: The spatial distribution and nature of the fault determine the distribution and intensity of seismic landslides (Ghanavati et al, 2019). To draw the distance from the fault map, the main faults of the region were identified and digitized in ArcGIS software environment using 1: 100000 geological maps of the region and satellite images.

Slope direction: This indicates various effects of sunlight, wind and precipitation in different directions. Slope direction map uses the digital elevation model prepared from 1:50,000 topographic map alignment lines of the study area in ArcGIS software environment.

Altitude: Altitude changes can have a significant effect on three factors: temperature, precipitation and humidity, which have a significant impact on landslide occurrence (Ildoromi and Rouzbahani, 2014). In the studied area, the altitude layers map has been drawn from DEM map classification of the area.

Distance from river: The effect of river activity and performance is distinguished as a set of external dynamic functions as well as mechanical activities such as material saturation, density increase, and decrease in mechanical strength of soil and rock masses, increase in groundwater level and in static and dynamic loads. Thus, a set of factors is stimulated by waterways and makes the slope prone to landslide (Mirsanjari et al., 2019). To draw the distance from waterway map, the waterway network was extracted from topographic map and digitized in ArcGIS software environment.

Land use: The type of land use and human activities play a decisive role in environmental change. In the studied area, the land use map has been extracted using ETM+ satellite images and the interpretation of NDVI index and completed with field operations.

2.3. Frequency Ratio Model

Frequency ratio is a quantitative method for assessing landslide sensitivity using GIS techniques and spatial data (Chen et al., 2016; Ding et al., 2017). This model reveals the quantitative relationship between the occurrences of landslides with various variables affecting it. In determining the frequency ratio, the rate of slide occurrence in each class is obtained from the influential factors in relation to the total slides and calculated relative to the area of each class to total surface area of the region. Finally, by dividing the landslide rate in each class by surface area rate of each class relative to the total study

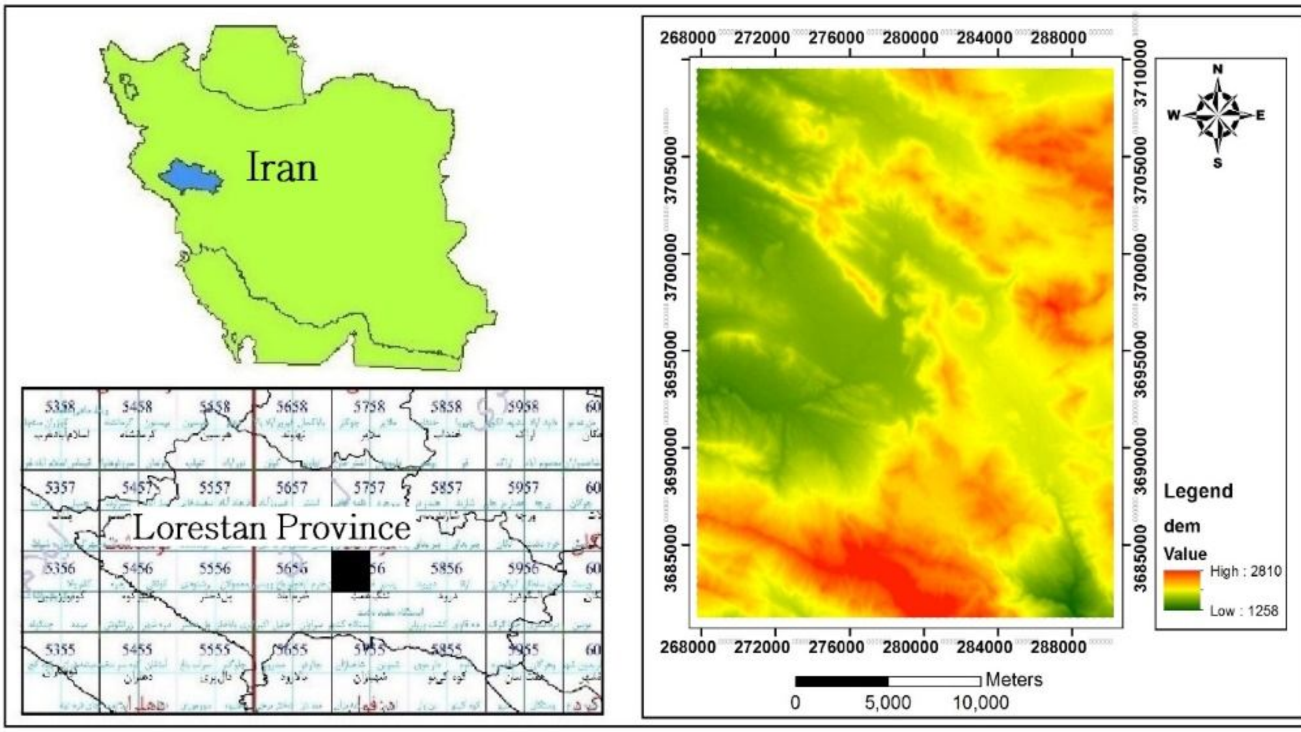

Figure 1. The geographical position of the study area

region, the frequency ratio of each factor is calculated. The steps of calculating the frequency ratio for each class of landslide factors is expressed in Eq. 1 (Mondal and Maiti, 2013). In this regard, if the frequency ratio is less than 1, the correlation of the factor affecting the landslide is very high, and if this value is <1, there is a lower correlation (Akgun et al., 2007).

$$F_L = \frac{[\frac{A}{B}]}{[\frac{C}{D}]} = \frac{E}{F} \qquad (1)$$

where, A represents the number of landslip pixels in each class, B the sum of slide pixels from the whole domain, C the number of pixels of each subclass of factors influencing the slide, D the total number of pixels in an area, E is the percentage of slide in each subclass of the effective factors and F the relative percentage of the area of each subclass in the total surface area. To obtain the landslide susceptibility index, Eq. 2 is used:

$$LSRI = \sum (FR)_i \qquad ; i = 1, 2, 3, \ldots, n \qquad (2)$$

where, LSI is the landslide potential index, FR the factor frequency ratio, and n the sum of input factors.

2.4. Evaluation of frequency ratio method

To evaluate the map drawn based on the frequency ratio model, first the map of slide points in the region has been prepared. Then, by crossing the map of these points with landslide hazard map, the amount of landslides in different risk classes is calculated and in the next step, using Eq. 3, the accuracy of model is calculated in terms of percentage.

$$P = \frac{KS}{S} \qquad (3)$$

In this Eq., P is experimental probability, KS slide surface area in medium to high risk categories, and S total surface area of slides in the region. The closer the experimental probability of the model to 100%, the better it is for zoning the landslide hazard in the area.

3. Results and Discussions

Landslide risk management plans should be developed to manage landslide hazard, which aims to reduce the damage and risks of landslides. One of the most important measures in this field is to draw a landslide hazard zoning map. For this purpose, first the slides and regions suspected of slide were identified using satellite images, and a field visit was made to complete the information and record new slides. In the study area, 95 slide points with an area of 6.47 square kilometers have been identified (Fig. 2).

Review of landslides observed in the study area shows that these slides are generally caused by various man-made, internal (tectonic) and external (climatic) processes (Fig. 3). The mass movement is a composite and multi-factor phenomenon, which is a function of many different processes. In this research, eight factors have been investigated for landslide risk zoning. To use these information layers, each of them is first weighted using the frequency ratio of each factor (Table 1). The results obtained from the weighting of each of the factors influencing the landslide are as follows.

Examination of the slopes of the area shows that the highest susceptibility to slide is in 35-45 class. This indicates that due to the reduction of gravity in lower slope as well as weakening of the soil formation process followed by the absence of materials prone to slide on the slopes, the probability of landslide is decreased. In this slope class, most of the landslides in the area are of downfall type. Review of lithology in the region shows that the marl and lime unit has the highest sensitivity to slide, which can be attributed to the type of material in this unit and its sensitivity to landslides.

Due to the impact of rivers in the form of withdrawing lateral and lower support of slopes because of erosion and subscription, the highest sensitivity to slides was expected in a distance of 0-100 meters from waterways, but the results showed that the highest susceptibility was in300-40 meter class. The findings regarding the distance from the fault classes showed that the highest sensitivity is at distances <3000 meters, which can be attributed to fractures and corrosions at distances close to faults. Examination of the relationship between altitude classes and slide distribution map shows that the highest susceptibility to slides is in the middle classes and that less landslides have occurred at higher altitudes due to the lack of suitable conditions for the soil formation phenomenon.

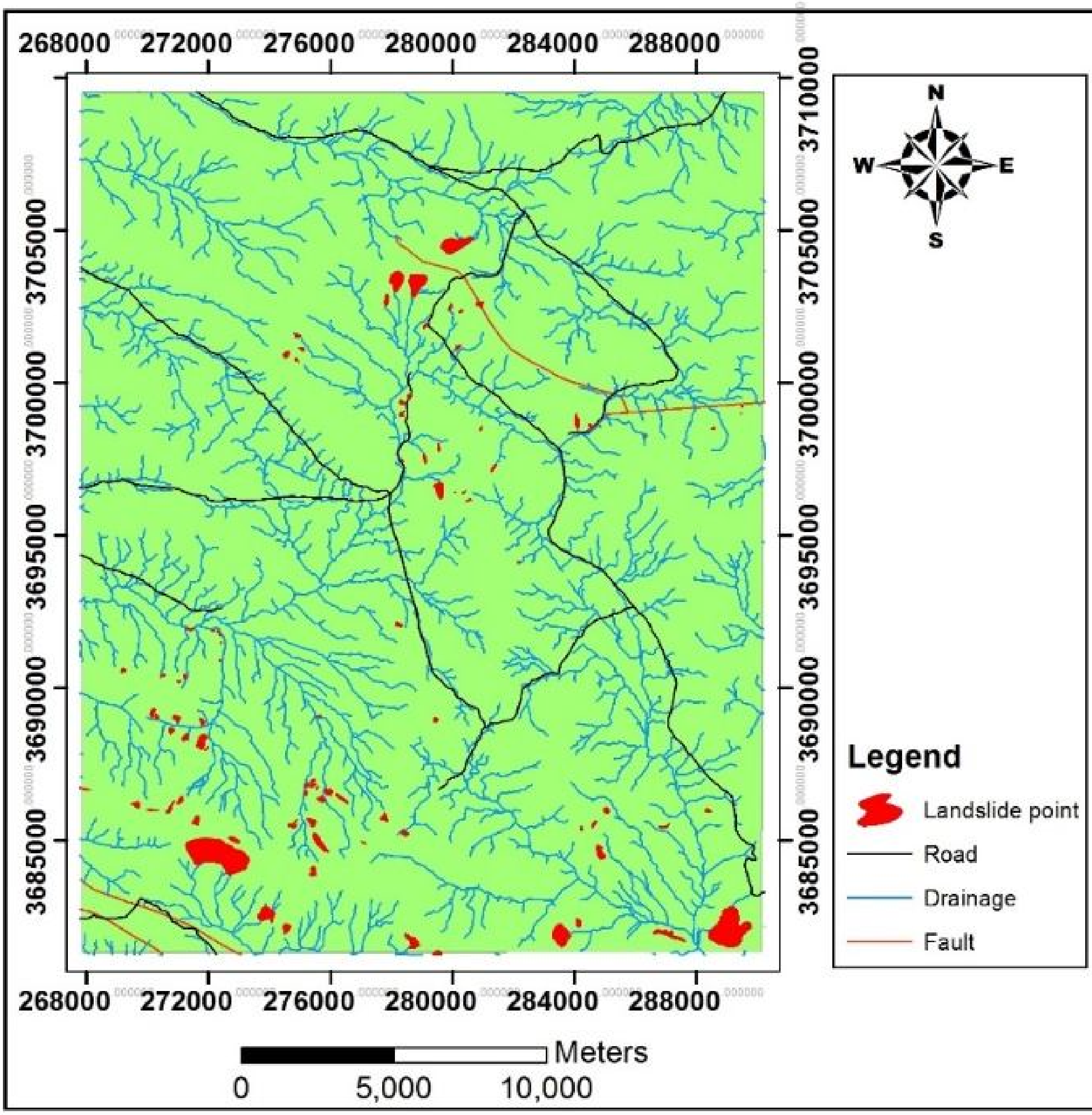

Figure 2. Landslide distribution map of the region

Figure 3. Occurrence of landslides due to river activity in the study area

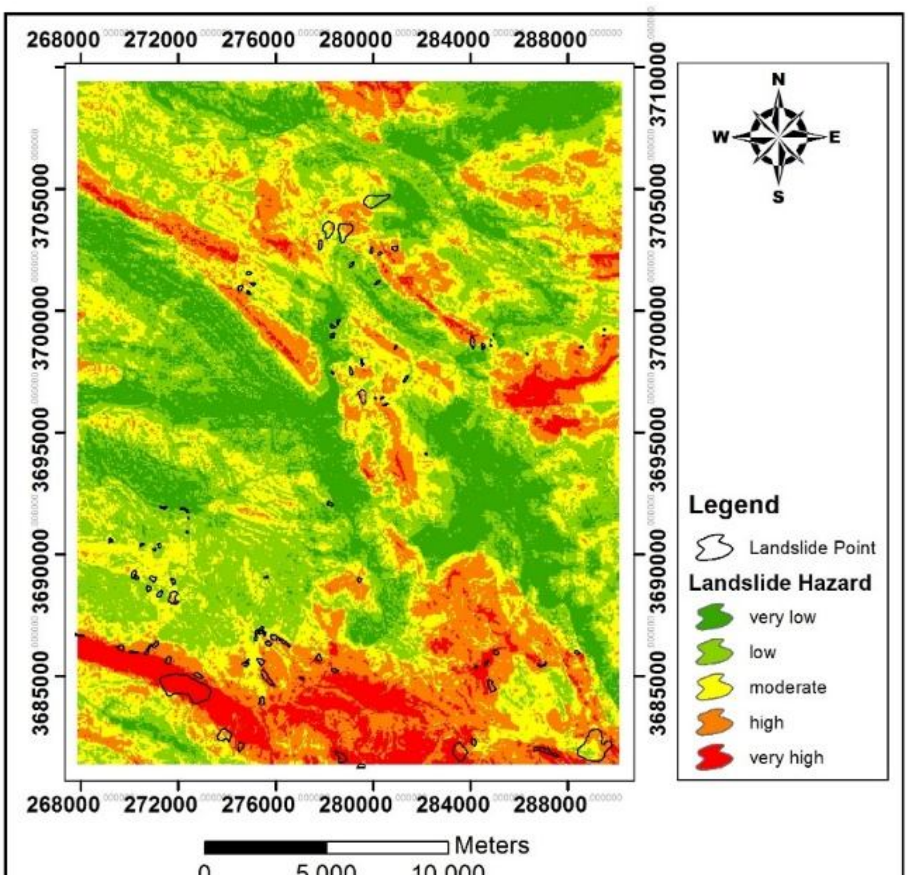

Figure 4. Landslide hazard zoning map in the study area

Table 1. Analysis of factors affecting landslides using frequency ratio model

Factor	Class	F	E	FR	Normalization
Slope (degree)	0 - 5	18.78	0.93	0.05	0.02
	5 - 15	44.68	30.83	0.69	0.22
	15 - 25	25.65	40.92	1.60	0.50
	25 - 35	8.90	21.25	2.39	0.75
	35 - 45	1.67	5.33	3.19	1.00
	45<	0.32	0.73	2.27	0.71
Lithology	Bakhtiari conglomerate	7.82	4.07	0.6	0.11
	Young alluvial sediments	31.68	10.44	0.33	0.06
	Old alluvial sediments	1.68	0.00	0.00	0.00
	Non-hardened conglomerate	4.04	2.62	0.65	0.12
	Gachsaran gypsum marl	1.41	0.00	0.00	0.00
	Asmari lime	16.07	42.7	2.66	0.48
	Kashkan conglomerate-sandstone	8.10	21.14	2.61	0.47
	Shale and sandstone of Amiran	10.35	5.43	0.52	0.09
	Marled lime	2.84	0.00	0.00	0.00
	Marl and conglomerate	1.12	0.00	0.00	0.00
	Marl and lime	1.32	7.35	5.58	1.00
	Sarvak lime	13.58	5.62	0.41	0.07
Distance from the drainage (meters)	0-100	19.73	14.44	0.73	0.49
	100-200	31.91	23.67	0.74	0.49
	200-300	22.11	24.50	1.11	0.74
	300-400	10.95	16.45	1.50	1.00
	400<	15.24	20.95	1.37	0.92
Distance from the fault (meters)	0-1000	7.09	12.29	1.74	0.55
	1000-2000	6.66	9.55	1.38	0.44
	2000-3000	7.36	23.29	3.17	1.00
	3000-4000	8.11	5.20	0.64	0.20
	4000<	70.79	50.0	0.71	0.22
Elevation (meters)	1258-1568	10.11	15.22	1.51	0.55
	1568-1879	39.94	18.08	0.45	0.17
	1879-2189	37.03	34.23	0.92	0.34
	2189-2499	11.10	30.33	2.73	1.00
	2499-2810	1.82	2.13	1.16	0.43
Land use	Dense forest	3.94	1.62	0.41	0.13
	Low density forest	8.57	3.13	0.37	0.12
	Agricultural lands	55.25	31.22	0.57	0.18
	Medium density forests	15.41	17.0	1.10	0.35
	Range	13.40	42.27	3.15	1.00
	Residential lands	0.13	0.00	0.00	0.00
	Groves and bushes	3.30	4.75	1.44	0.46
Distance from the road (meters)	0-500	19.48	3.23	0.17	0.11
	500-1000	16.85	10.29	0.61	0.40
	1000-1500	14.88	18.42	1.24	0.81
	1500-2000	12.29	12.32	1.00	0.66
	2000<	36.50	55.74	1.53	1.00
Aspect	Fault	0.06	0.00	0.00	0.00
	0-22.5	8.02	4.56	0.57	0.33
	22.5-67.5	14.99	14.84	0.99	0.58
	675-112.5	8.51	7.26	0.85	0.50
	112.5-157.5	8.30	5.99	0.72	0.42
	157.5-202.5	14.06	16.42	1.17	0.68
	202.5-247.5	16.93	28.86	1.71	1.00
	247.5-292.5	11.54	12.09	1.05	0.61
	292.5-337.5	11.29	6.30	0.56	0.33
	337.5-360	6.29	3.67	0.58	0.34

The results of land use showed that the highest susceptibility to slides is in the rangeland unit, which can be ascribed to the uncontrolled grazing of cattle in these lands. With respect to the distance from the road factor, the results indicate the low impact of this factor because due to the vastness of the area, the length of roads is short, most communication routes between villages are dated and there are no large scale road construction operations to increase the sensitivity of slopes in the region. The study of geographical directions with respect to the distribution of slides shows that the highest sensitivity to landslides is in southern and southeastern classes. This can be due to the fact that these classes absorb sunlight; there is plenty of evaporation as well as continuous evaporation and humidification cycle, especially at rainy seasons that causes landslide in the region. Afterward, to draw a landslide hazard map of the area in ArcGIS software environment, raster maps were combined using Raster calculator command and the final landslide hazard zoning map in the area was prepared (Fig. 4). According to the results, 18.55, 30.67, 26.51, 18.15 and 6.12% of the area is in very low, low, medium, high and very high risk classes, respectively. To evaluate the results using the frequency ratio, after preparing the slide points' map, the slide surface area in each hazard class was determined by crossing it with the landslide hazard map, and the accuracy of the model was estimated by Eq. 3 (Table 2). The findings show that the model has a very high accuracy in landslide risk zoning of the study area with 87.37% sum of utility index.

Table 2. Results of frequency ratio assessment

Accuracy of the model (%)	Number of sliding pixels in each class (50×50 m)	Surface area percentage of each class	Risk class
87.37	41	18.55	Very low
	284	30.67	Low
	636	26.51	Medium
	742	18.15	High
	872	6.12	Very High

4. Conclusion

The studied area is prone to landslide hazards due to its location in Folded Zagros Zone, as well as various geological features such as lithology, geology and special climatic conditions. Given the different importance degrees of the factors influencing landslides, it is necessary to identify and assess the factors correctly to draw a landslide sensitivity map and prevent the resulting danger. In this study, the frequency ratio model has been used for weighting the factors affecting the occurrence of slides in the region.

According to the results, more than 50% of the study area is located in medium to high risk zones, which indicates that the area is at high risk of landslide. These zones are mostly in line with areas in the south of the region, which can be attributed to sensitive lithology and proclivity of the slope of these areas for landslides.

The evaluation of study results using sum of utility index indicates that the frequency ratio model has a good performance in identifying areas at risk of landslide. Therefore, it is suggested to apply the results for land use decision-making, management and regional planning, andany land use change in the region should be done after conducting the necessary studies.

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