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Landslide Susceptibility Mapping for Subalpine Grassland Using Frequency Ratio and Landslide Index Model (Case Study: Masoleh Watershed, Iran)

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Abstract. Subalpine ecosystems are highly fragile as compared to biological and environmental factors. Landslide is one of the ruinous upshots of this ecosystem. One of the impressionable areas in the cause of natural factor is Masoleh watershed in western Alborz Mt, (Iran). In order to landslide hazard zonation, landslide index and frequency ratio method based on twelve causative factors such as slope, slope aspect, land use, lithology, distance from faults, distance from road, distance from stream, rainfall, range condition, Stream Power Index (SPI), Component Topographic Index (CTI) and elevation Receiver Operator Characteristic (ROC) curve analysis method was also used to evaluate the model. The results showed that geological, physiographical and grassland conditions have an important role in landslide area. Overgrazing, grazing in forth of season, early grazing, late term egression, and excess livestock are considered as direct affecting factors on vegetation, so that they have simultaneous role to make the landslide risk. The verification results via ROC curve showed that the landslide index model (85%) performed slightly better than the frequency ratio model (82%). It was concluded that managers and protectors of this ecosystem can inhibit and conserve the landslide by decreasing the amount of livestock, and short-term exclosure on critical area, and biomechanical dams in landslide-occurred area.

Key words: Subalpine ecosystems, Frequency ratio, Landslide index, GIS, Masoleh, Iran.

Introduction

Subalpine ecosystems are very frangible because of their specific environmental circumstances (Johnson, 2004) that deliberately management can conduct ecological governance in these ecosystems. There are many species in subalpine ecosystem that are disturbed by abiotic and biotic factors (Kulakowski and Veblen, 2007). Abiotic includes climate and weather changing (Moore and Allard, 2011), geological formation, physiographical traits (Kulakowski and Veblen, 2002), and soil texture which can disturb subalpine meadows during the time. Biotic factors, however, can be divided in human activities, e.g. tourism (Cole and Spildie, 2006; Zhang *et al.*, 2012), animal grazing (Miller and Halpern, 1998) as highly impacting, and plant roots (Schmidt *et al.*, 2011) as less impacting from the others landslides, as one of the major natural hazards, account each year for enormous property damage in terms of both direct and indirect costs (Dai and Lee, 2002). For example, the average annual economic loss is 1.5 billion dollars in the United States, 2 billion in Japan and 2.6 billion in Italy (Blöchl and Braun, 2005). Li and Wang (1992) conservatively estimated that the number of deaths caused by landslides is totally more than 5000 in China during the 1951–1989 resulting in an average of more than 125 deaths annually, and annual economic losses of about US$500 million. Iranian Landslide Working Party, (2007) reported that about 187 people have been killed by landslides, and total economic losses from mass movements till the end of September 2007 have been estimated at 127,000 billion Iranian Rails (almost $12,700 million dollars) (Pourghasemi *et al.*, 2012). Many effective factors are caused to make the landslides, and so it is very difficult to predict its occurrence in order to prevent the landslide damages.

Landslide susceptibility map is very useful in estimating, managing and mitigating landslide hazard for a region (Anbalagan *et al.*, 1992; Kienholz, 1978; Piarc, 1997). Both landslide index and frequency ratio are bivariate statistical methods that are used in landslide susceptibility map. Bivariate method consists of a statistical comparison between landslide distribution, as the dependent variable, and a number of separate instability factors (input parameters). These methods are based on assuming that landslides will always occur in the same geological, geomorphological, hydrogeological and climatic conditions as in the past and the procedure considers a number of environmental factors thought to be connected with landslide occurrence. This approach makes it possible to calculate the 'weight' of an individual input parameter (Juang *et al.*, 1992). Since landslides are one of the major natural hazards that disturb subalpine ecosystem in the study area, this research attempts to study the subalpine ecosystems in Masoleh Mountain (Iran) to determine one of the disturbance factors via using the statistical methods including landslide index and frequency ratio.

Materials and Methods

Study area

Masoleh watershed is located in the south of Gillan province, north of Iran where most landslides have occurred, in the mountainous and grassland (Fig. 1). The study area is located in western part of Alborz Mt. nearly 40000 ha area (Fig. 2). The general physiognomy of the area is highlands with 530 to 2893 m altitudinal range and slopes vary between flat and over 60°. The bedrock mainly consists of limestone with dolomite, sandstone, marland conglomerate in this region. The land use of the study area mainly comprises forest with variant range of coverage from low to dense, poor range, medium range, good range, and orchard and settlement areas. The climate in the study area is Mediterranean with 601 mm annual precipitation that occurs in the form of snow during the winter. The climate is mostly affected by altitude with amount of precipitation decreasing with an increasing altitude. In addition landslides, it is possible to observe various types of erosional features (i.e., rill erosion, bank erosion, gully erosion and surface erosion) in the study area. The Masoleh River, which is the main river system in the study area, consists of alluvial fans and terraces, alluvial sheets and locally undivided lake deposits.

Fig. 1. Landslides in subalpine rangeland

Research approach

Landslides are assumed to occur in the future under the same conditions as for the past and current landslides (Guzzetti *et al.*, 1999). Therefore, a landslide inventory map has been considered to be the most important factor for prediction of future landslides. A total of 258 landslides were mapped in the study area at 1:25,000-scale. Then, landslide inventory was partitioned into 70% randomly for training the models and 30% for the model validation. Fourteen landslide conditioning factors such as: slope percentage, slope aspect, altitude, distance from rivers, distance from roads, distance from faults, lithology, land use, soil texture, range condition, distance

There are 258 landslide locations in the study area. Some of the landslides are presumably very old in age. Most of the landslides are shallow rotational with a few translational. However, during the analysis performed in the present study, only rotational failure is considered and translational slides were eliminated because its occurrence is rare. The minimum and maximum size of landslides is 102 and 12800 m^2, respectively. Some recent landslides are shown in (Fig. 2).

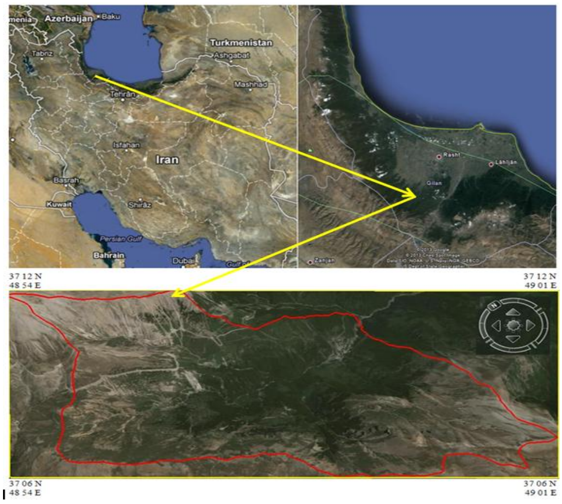

Fig. 2. Location map of the study area

from ranch, SPI[1], CTI[2] and rainfall were selected to build landslide models and predict landslides spatial distribution in study area.

The slope percentage, slope aspect, and altitude were extracted from DEM[3] based on 1:50,000-scale topographic maps with 20 m interval contours. Also the river, SPI, CTI and road networks map were extracted from 1:50,000 topography maps. The bedrock mainly consists of limestone with dolomite, sandstone, marland conglomerate in this region. Land use map derived from a Landsat Enhanced Thematic Mapper (2006) employing a supervised classification method and was calibrated by field

1. Stream Power Index
2. Component topographic index
3. Digital Elevation Model

survey. The land use of the study area mainly comprises forest with variant range of coverage from low to dense, poor range, medium range, good range, and orchard and settlement areas. Meteorological data including rainfall for 35 year period (1975-2010) and precipitation map created from rainfall data via internal and external rain stations of Masoleh territories and kriging order in ArcGIS 9.3 software.

Landslide susceptibility mapping
Frequency Ratio (FR) model

In general, to predict landslides, it is necessary to assume that landslide occurrence was determined by landslide-related factor, and that future landslide will occur under the same conditions as past landslide (Lee *et al*., 2004). In order to construct the landslide susceptibility map quantitatively, the frequency ratio model was first used by GIS. The frequency ratio, a ratio between the occurrence and absence of landslides in each cell, was calculated for each range of factor that had been identified as significant with respect to causing landslides. An area ratio for each range of factor to the total area was calculated. Finally, frequency ratios for each range of factor were calculated by dividing the landslide occurrence ratio by the area ratio. In order to calculate landslide susceptibility index we used following equation.

$$LSI=\sum Fr \quad (1)$$

Where LSI is landslide susceptibility index and Fr is weight of each conditioning factors. If Fr>1, correlation factors are very high in and Fr<1 means correlation factors are weak in occurrence landslide (Choi *et al*., 2012). Overall weights liner graph, slope failure as hazard boundary was divided into four risk categories of low, medium, high and very high and finally obtained landslide hazard map (Fig. 3).

Landslide index

Landslide Index methods are based on the logarithm (ln) concentration landslide in each class to the total landslide density maps. The following formula forms the basis of this approach (Van Westen, 1993; Rautela and Lakhera, 2000):

$$W_i = Ln\frac{Densclass}{Densmap} Ln\frac{\frac{Npix(S_i)}{Npix(N_i)}}{\frac{SNpix(S_i)}{SNpix(N_i)}} \quad (2)$$

Where:

Wi: The weight given to a certain parameter class, Densclass: Landslide density within the parameter class, Densmap: Landslide density within the entire map, Npix (Si): Number of pixels contain landslide in certain parameter class, Npix (Ni): Total number of pixels in certain parameter class. Each class has a specific weight according to Eq.2. Classifying and summation of weights has been done in ArcGIS. Overall weights liner graph, slope failure as hazard boundary is divided into four risk categories of low, medium, high and very high and finally obtained landslide hazard map (Fig. 4).

Validation models

The models were validated by comparing the calculated probability values for different cells and their actual present condition. This is achieved by using Receiver Operator Characteristic (ROC) curve analysis (Zweig and Campbell, 1993; Hanley and McNeil, 1982). The ROC curve is a plot of the probability of true positive identified landslides versus false positive identified landslides, as the cut-off probability varies. Equivalently, it is a representation of the trade-off between sensitivity and specificity. Sensitivity is the probability of slipped cell which is correctly classified, and is plotted on the Y-axis in an ROC curve. 1-sensitivity is the false negative rate. Specificity is the probability that a non-slipped cell is correctly classified. 1-Specificity is the false positive rate and is taken along the X-axis of the curve. The area under the curve represents the probability that the model-calculated landslide susceptibility value for a randomly chosen slipped cell that would exceed the result for a randomly chosen non- slipped cell. Thus, the area under the ROC curve can be used as a measure of the accuracy of the model (Mathew *et al.*, 2007).

Results and Discussion

In this study, landslide susceptibility maps have been constructed using the relationship between landslide locations and causative factors. Landslide index and frequency ratio be used to study the influence of different factors on landslide occurrence and subsequently landslide susceptibility maps (Figs. 3 and 4). In this study, 14 causative factors such as slope percentage, slope aspect, altitude, distance from rivers, distance from roads, distance from faults, lithology, land use, soil texture, range condition, distance from ranch, SPI[3], CTI[4] and rainfall were considered (Table 1). The selection of 14 factors is based on the availability of data for the study area and the relevance with respect to landslide occurrences. However, more factors can be considered based on availability of data for further study.

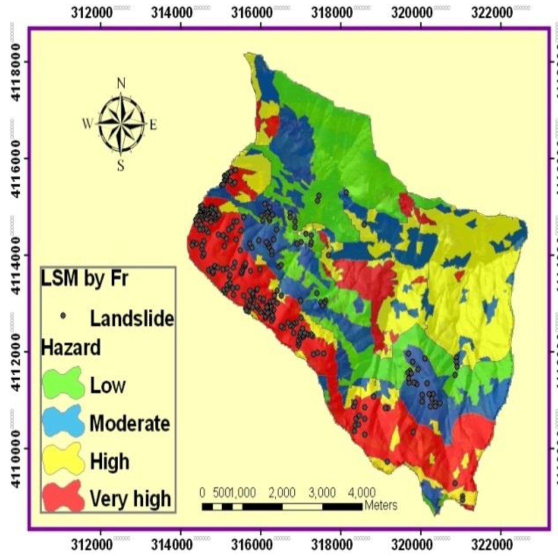

Fig. 3. Landslide susceptibility map by using frequency ratio

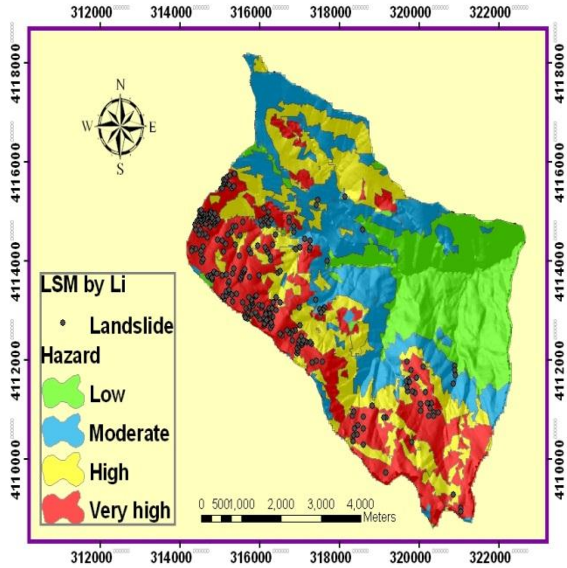

Fig. 4. Landslide susceptibility map by using landslide index

3. Stream Power Index
4. Component topographic index

Table 1. Distribution of training pixels in Masoleh watershed

Type	Range	Landslide not Occurred		Landslide Occurred		landslide	Frequency
		Count	Ratio	Count	Ratio	Index	Ratio
Aspect	N	74700	17.80	35	20.35	0.133	1.14
	NE	110132	26.25	86	50.00	0.644	1.90
	NW	39725	9.47	8	4.65	-0.710	0.49
	E	52021	12.40	22	12.79	0.031	1.03
	W	13243	3.16	3	1.74	-0.593	0.55
	S	56446	13.45	7	4.07	-1.190	0.30
	SE	33634	8.02	5	2.91	-1.010	0.36
	SW	27843	6.64	6	3.49	-0.643	0.52
	F	11815	2.82	0	0.00	-8.310	0.00
CTI	0-4	131624	31.37	39	22.67	-0.324	0.72
	4-8	114918	27.39	47	27.33	-0.002	0.99
	8-12	160179	38.18	79	45.93	0.184	1.20
	>12	12838	3.06	7	4.07	0.285	1.33
Elevation	<1000	9595	2.29	2	1.16	-0.676	0.50
	1000-1300	33095	7.89	0	0.00	-8.310	0.00
	1300-1600	59654	14.22	4	2.33	-1.810	0.16
	1600-1900	101017	24.08	21	12.21	-0.670	0.50
	1900-2100	69007	16.45	25	14.53	-0.123	0.88
	2100-2400	89950	21.44	81	47.09	0.786	2.19
	2400-2700	49966	11.91	38	22.09	0.617	1.85
	2700-3000	7275	1.73	1	0.58	-1.090	0.33
Distance of fault	<100	2936	8.09	15	8.72	0.075	1.07
	100-200	3348	9.22	13	7.56	-0.199	0.81
	200-300	3455	9.52	16	9.30	-0.022	0.97
	300-400	3536	9.74	27	15.70	0.477	1.61
	>400	23023	63.43	101	58.72	-0.077	0.92
Land Use	Forest thinning	1160	3.20	2	1.16	-1.010	0.36
	Forest	20202	55.66	17	9.88	-1.720	2.76
	Range	8469	23.33	111	64.53	1.010	0.17
	Rock	1246	3.43	3	1.74	-0.677	0.50
	Forest development	5221	14.38	39	22.67	0.455	1.57
Lithology	Jsc	2867	7.90	1	0.58	-0.44	0.95
	Js	12521	34.50	122	70.93	0.72	2.05
	Kln	11374	31.34	27	15.70	-0.691	0.5
	P	1922	5.30	5	2.91	-0.599	0.17
	Pzs	4925	13.57	0	0.00	-10.76	0.00
	Qal	34	0.09	0	0.00	-10.76	0.00
	T	2655	7.31	5	2.91	-0.922	0.39
Rain	488	3534	9.74	8	4.65	-0.738	0.47
	668	17706	48.78	106	61.63	0.233	1.26
	848	9463	26.07	3	1.74	-2.700	0.01
	908	5595	15.41	54	31.40	0.711	1.03
Range	Excellent	2714	7.48	3	1.74	-1.450	0.23
	Good	5158	14.21	3	1.74	-2.090	0.12
	Moderate	16309	44.93	91	52.91	0.163	1.17
	Poor	10383	28.60	63	36.63	0.247	1.28
	Very poor	1737	4.79	12	6.98	0.377	1.45
Road	0-100	4037	11.12	18	10.47	-0.060	0.94
	100-200	3644	10.04	18	10.47	0.041	1.04
	200-300	3353	9.24	21	12.21	0.278	1.32
	300-400	3192	8.79	13	7.56	-0.151	0.85
	>400	22072	60.81	102	59.30	-0.025	0.97
Slope	<15	12635	3.01	0	0.00	-8.310	0.00
	15-30	27232	6.49	16	9.30	0.359	1.43
	30-50	128453	30.62	74	43.02	0.340	1.40
	50-70	145455	34.67	54	31.40	-0.099	0.90
	>70	105784	25.21	28	16.28	-0.437	0.64
SPI	<-4.96	149556	35.65	58	33.72	-0.055	0.94
	-4.96- -1.46	161227	38.43	80	46.51	0.190	1.21
	-1.46-2.08	59717	14.23	25	14.53	0.020	1.02
	2.08-12.91	49059	11.69	9	5.23	-0.804	0.44
Stream	0-100	23574	64.95	112	65.12	0.002	1.00
	100-200	9315	25.66	41	23.84	-0.073	0.92
	200-300	2315	6.38	14	8.14	0.243	1.27
	300-400	822	2.26	3	1.74	-0.261	0.77
	>400	272	0.75	2	1.16	0.439	1.55
Soil texture	Clay	11306	31.14	26	16.35	-0.722	0.48
	Loam	22023	60.67	132	83.01	0.234	1.26
	Sandy	102	2	0	0	-0.999	0.00
	Sand-loam	2867	7.89	1	0.06	-0.044	0.95
Distance from Corral	<500	10082	27.77	125	78.16	0.961	2.61
	500-1500	11165	30.75	39	24.52	-0.304	0.73
	>1500	15051	41.46	8	5.03	-2.180	0.11

The Li model shows very high susceptible zone covers only 27% of the study area where about 82% of the observed landslides happened. High susceptible zone covers only 23% of the study area which covers 11% of the observed landslides. Fr model showed very high susceptible zone covers only 25% of the study area which contains 64% of the observed landslides, and high susceptible zone, covers only 26% of the study area which contains 14% of the observed landslides. These results show that the predicted susceptibility levels are found to be in right agreement with the past landslides. In this process, 258 landslides were identified and mapped. The number of 172 (70 %) landslides were randomly selected for generating a model and 86 (30 %) were used for validation proposes. In this study, the prediction-rate results of the two landslide susceptibility models were obtained by comparing them with the landslide grid cells in the validation dataset and finally ROC curve for the model developed as given in (Figs. 5 and 6).

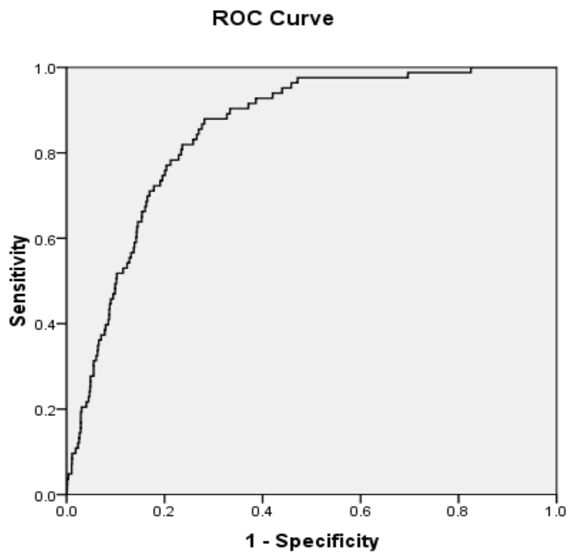

Fig. 5. Receiver operator characteristic curve of the developed landslide index model. Diagonal segments are produced by ties.

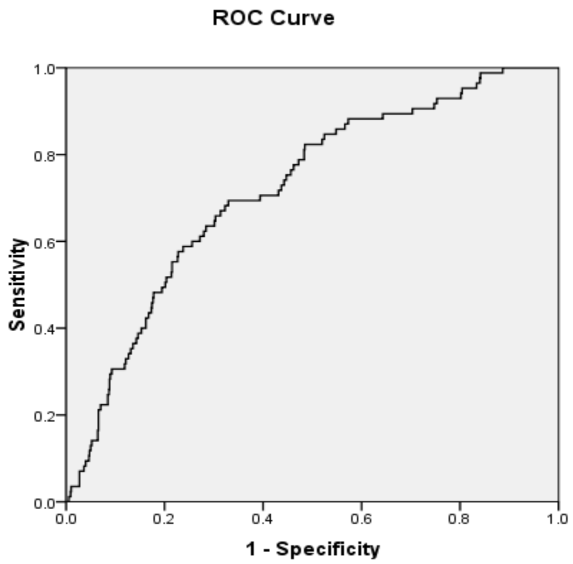

Fig. 6. Receiver operator characteristic curve of the developed frequency ratio model. Diagonal segments are produced by ties.

The area under the curve is 0.85 and 0.71 (Table 2), which gives an accuracy of 85% for the model developed using landslide index. The asymptotic significance is less than 0.05, which means that using the model to predict the landslide is better than frequency ratio. One of the most effective factors in landslide development was grassland condition based on weighting factor (Table 1). Hence, the grassland condition of Masoleh watershed is evaluated as poor condition which has the most influence on landslide outbreak. As this area is known as subalpine region, its sensitive vegetation covers are grazed by herds so that their grazing and trampling are affected the susceptible soil to degradation.

Table 2. Area under the receiver operator characteristic curve landslide index model and curve frequency ratio model

ROC Curve	Area	Std. Error[a]	Asymptotic Sig.[b]
Landslide Index Model	0.850	0.017	.000
Frequency Ratio Model	0.719	0.028	.000

a. Under the nonparametric assumption
b. Null hypothesis: true area = 0.05

Conclusion

Landslides are an important feature of Subalpine grassland degradation in the Masoleh watershed. Incidence of landslides is mainly influenced by the geological, physiographical and grassland condition in the affected areas. Landslides occur frequently on the poor condition region. Subalpine ecosystem has been formed by different factors include short period of growth, cold severity, and harsh wind in altitude that its vegetation has been adapted to this circumstance as well. Nonetheless, overgrazing, grazing in forth of season, early grazing, late-term departure of herd from upland in end of grazing period, and overstocking animal have directly influenced on Subalpine vegetation that these factors, unfortunately, have decreased grassland condition and have also caused some landslides in this ecosystem. On the basis of analysis and field observation, endemic vegetation community and perennial species have been replaced by annual forbs and grasses, which have surface roots, in critical area (e.g. around of folds and landslides areas). The sensitive soils of study area, therefore, have trended toward to short landslide because lack of deep and wide rooting by perennial species, rainfall, and climate environment. These positions are seen in some area of grassland as small and big spot-spot forms. The ecological management in this area, therefore, should concern on decreasing the amount of livestock, short-term exclosure on critical area, and biomechanical dams in landslide-occurred area.

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چکیده

اکوسیستم‌های شبه آلپی تحت تاثیر عوامل زیستی و محیطی از شکنندگی بالایی برخوردارند. زمین لغزش‌ها، یکی از تبعات منفی در این اکوسیستم است. از مناطق مستعد در بروز این عامل طبیعی، حوزه آبخیز ماسوله در شمال کشور می‌باشد. به منظور پهنه‌بندی خطر زمین لغزش از روش شاخص لغزش و نسبت فراوانی بر اساس ۱۲ عامل موثر که شامل: شیب، جهت شیب، کاربری اراضی، سنگ‌شناسی، فاصله از گسل، فاصله از جاده، فاصله از رودخانه، بارندگی، وضعیت مرتع، شاخص قدرت رودخانه، شاخص ترکیب توپوگرافی و ارتفاع استفاده شد. برای ارزیابی مدل از روش ROC استفاده گردید. نتایج مدل‌ها نشان داد عوامل سنگ‌شناسی، توپوگرافی و وضعیت مرتع نقش موثری در بروز زمین لغزش‌های منطقه داشته‌اند. چرای بیش از حد، خارج از فصل، زودتر از مؤعد، خروج دیرهنگام دام و نیز دام مازاد از عوامل زنده مستقیم تأثیرگذار بر وضعیت پوشش گیاهی، نقش توأمان ایجاد خطر زمین لغزش را داشته‌اند. نتایج ارزیابی مدل‌ها با استفاده منحنی ROC نشان داد مدل شاخص لغزش (۸۵٪) دارای کارایی بالاتری نسبت به مدل نسبت فراوانی (۸۲/۱۴٪) بوده است. مدیران و حافظان این منطقه می‌توانند با کنترل چرای دام و استفاده از ابزارهای مکانیکی در مناطق لغزشی، اقدام به جلوگیری و کنترل زمین لغزش مبادرت ورزند.

کلمات کلیدی: اکوسیستم‌های شبه آلپی، نسبت فراوانی، شاخص لغزش، GIS، ماسوله