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An Investigation of Effective Factors on Landslide Occurrence and Landslide Hazard Zonation Using LNRF Model (A Case Study: Bababozorg Watershed)

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ABSTRACT

Landslide zoning is one of the tools that can be used to identify unstable slopes and use them in sustainable development programs. In this study, to assess the relative risk of slopes and estimate the experimental probability of landslides in the Bababozorg Basin, we used nine factors affecting the slope, including slope degree, slope direction, height, lithology, land use type, precipitation, and distances from faults, communication lines and water supply network. Then we made a map for each factor. We also identified and recorded the landslides in the basin and prepared a map of the landslides. By plotting the factors influencing the slope, with the landslide distribution map, and using the LNRF (Landslide Nominical Risk Factor) model in the ArcMap software environment, the effect of each factor on the slope status was estimated. Accordingly, 6.42%, 17.87, 27.13, 27.45 and 21.11% of the area were classified as very low, low, medium, high and very high, respectively.

1. Introduction

Landslides are the movement of sloping materials, including natural rocks, soil, artificial accumulations, or a mixture of them that are moved downward by gravity (Varnes, 1984). Slope movements, especially landslides, are one of the natural disasters that cause a lot of damage and in addition to human casualties (Ranjbar and Roghani, 2010). This natural phenomenon can cause damage to a variety of engineering structures, including residential areas, vital arteries such as roads, gas and water pipelines, power transmission lines, forests and pastures, agricultural lands and mines. Also, the social and environmental effects of this phenomenon, such as the adverse social effects and the increasing sedimentary load in rivers, should not be overlooked (Soori et al., 2012; Azarafza et al., 2018).

Iran has extreme natural conditions to create a wide range of landslides, due to its predominantly mountainous topography, high geological structure and seismic activity, diverse climatic and geological conditions. Therefore, as much as we enjoy the blessings of being mountainous and the diversity of the climate, we are also exposed to the dangers of those conditions (Nasiri, 2004).

Studies conducted in Iran show that by early 1999, the occurrence of about 2590 landslides in the country caused the deaths of 162 people, the destruction of 176 houses, the creation of financial losses of 1866 billion Rials, the removal of 6763 hectares of forests, the destruction of 170 km of roads and production 963807 cube meters deposited every year. This condition underscores the importance of the issue. Studies conducted in Iran show that by early 1999, the occurrence of about 2590 landslides in the country caused the deaths of 162 people, the destruction of 176 houses, the creation of financial losses of 1866 billion Rials, the removal of 6763 hectares of forests, the destruction of 170 km of roads and production 963807 cube meters has deposited every year (Mirsaneei and Kardan, 1999). This condition underscores the importance of the issue.

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In general, the ultimate goal of the landslide study is to find ways to reduce the damage caused by them, which emphasizes the need to prepare a zoning map (Komac, 2006). Numerous studies and researches have been conducted around the world on the risk of landslides and mass movements, and various researchers have presented several classifications using a variety of methods (Mengistu et al., 2019; Bera et al., 2019; Abija et al., 2020; Baharvand et al., 2020). The LNRF method was first used by Gupta and Joshi (1990) in the Ramgana Himalayan watershed to assess the risk of landslides. In Iran, this method has been used in several studies so far, including the following studies:

Using the LNRF model, Shadfar and Yamani (2008) addressed the issue of landslide risk zoning in the Jalisan watershed. Based on the results, this model has excellent performance for data analysis and landslide zoning in wet to semi-humid areas. Sorour et al. (2012) zoned the landslide risk. In this study, lithological factors, distance from faults, slope, altitude, and precipitation were determined as the most effective natural factors in landslides in the region. Using the LNRF model, Ildoromi and Rouzbahani (2014) zoned the risk of slope instability in the Malayer Kalan-basin. This study showed that lithological factors and distance from the fault have the most significant role in causing landslides in the region. The studies also showed that the LNRF model has excellent performance for data analysis and zoning of mass movements in the Kalan-dam basin.

Tulabi et al. (2014) covered the risk of landslides in the Nojian basin. In this study, the results of the LNRF model showed that about 40% of the area is located in high and very high-risk classes.

Iran's location on the Alpine-Himalayan earthquake-prone belt, the crossing of the Great Zagros Fault, alternation of hard and loose layers of marly-shaly limestone on the crest of large anticlines have created favorable conditions for the instability of large sections of natural slopes throughout Lorestan province (Tulabi and Abedini, 2016; Ajallooian et al., 2003). Therefore, this study has been conducted with the aim of zoning the risk of landslides in the Bababzorg basin located in Lorestan province and classifying the study basin into areas with different degrees of risk using LNRF method.

2. Material and Methods

Bababozorg basin is located in Noorabad city in the northwest of Lorestan province and is located in the high Zagros zone (Figure 1). The most important way to access this basin is through Noorabad-Imamzadeh Bababozorg road.

The LNRF model has been used as one of the common models in landslide hazard zoning. The research is done by analytical method and based on field and library studies. According to this, the following steps have been taken to perform the work:

- Preparing a map of the distribution of landslides in the region using aerial images, Google Earth images and field studies and determining the exact boundaries of these points using GPS
- Digitizing the topographic map of the region and building a digital model of height (Dem) in order to provide information layers of slope, slope direction, elevation floors, communication lines and waterway network.
- Preparing petrographic information layers and the distance from the fault using the geological map, the satellite images and field visits.
- Extracting the land use layer using TM satellite images and field visits
- Preparing a precipitation map in the basin using the statistics of barometric stations around the basin by establishing a correlation between precipitation and height.
- Determining the extent and percentage of landslides in different classes of each factor.
- Weighting different classes of factors affecting slipping based on LNRF model parameters.
- Preparing a map of the landslide danger zones with the overlap of the weight map of each factors.
- Evaluation of landslide risk zoning map.

The LNRF model, first introduced by Gupta and Joshi in 1990, is known as the Gupta and Joshi proposed method. After calculating the area of each class and the slip area in each class, the amount of LNRF is calculated from Eq. 1.

$$LSA = \frac{\sum W_i AS_i}{A} \quad (1)$$

LNRF= the landslide area in a unit of the operating map/The average area of landslides occurred relative to the total units of the operating map. We need to standardize the LNRF-values according to Table 1, which means that we consider for units with a value less than 0.67, the weight zero, for units with a value between 1.33 - 67/0, the weight one and for units with a value greater than 1.33, the weight two. To evaluating, based on the LNRF model, the slippery point's map of the basin has been prepared; then, by cutting the map of these points with the landslide risk map, the number of slips in different risk classes is calculated and in the next step, using the relationship of 2, the accuracy of the model is calculated in percentage.

$$P = \frac{KS}{S} \quad (2)$$

In this regard, P: Experimental probability, KS: Slipped area in the medium- to high-risk categories, and S: Total area of slippage. The closer the experimental probability of the model used is to 100%, the more suitable it is for zoning the risk of landslides in the region.

Table 1 Determines the amount of weight based on the extent of mass movements with the LNRF method (Gupta and Joshi, 1990)

Variation range of LNRF	Weight	Stability
< 0.67	0	Low
0.67 – 1.33	1	Moderate
1.33 <	2	High

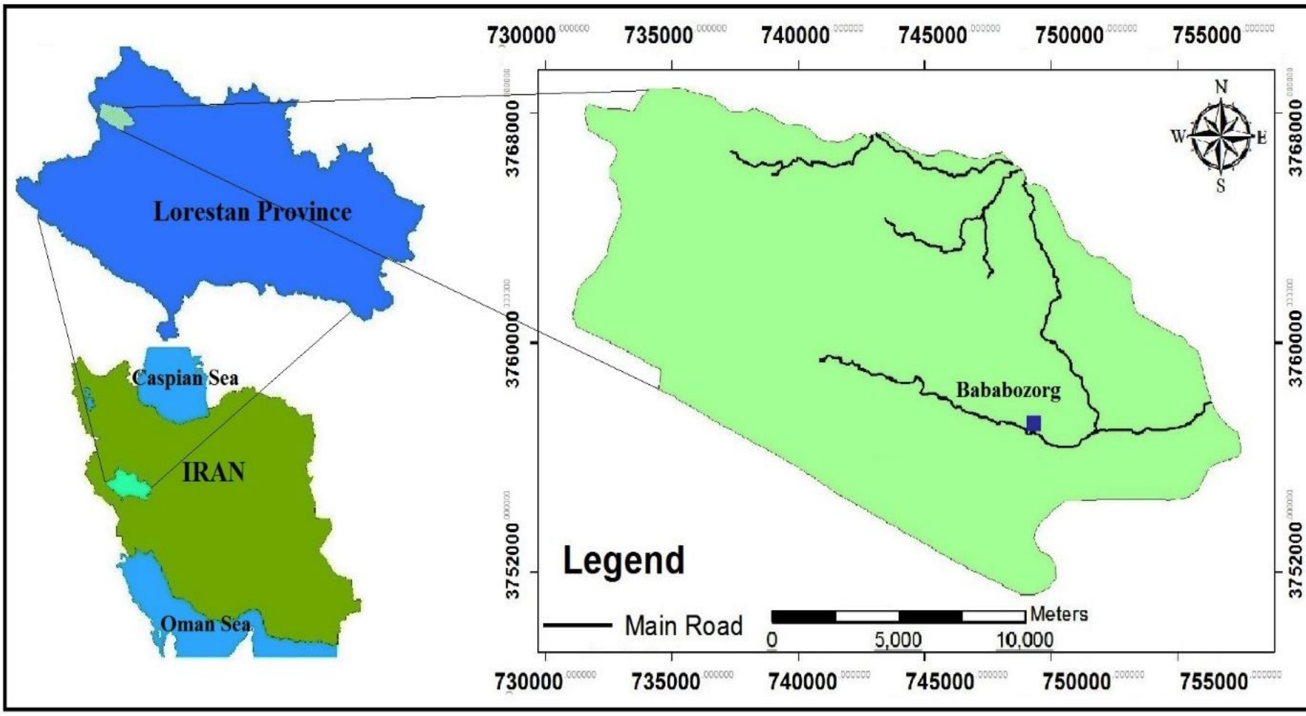

Figure 1. Geographical location of the Bababozorg Basin

Figure 2. View of the landslides

3. Results and Discussions

To assess and determine the risk of landslides in each region, the most important step is to study the factors controlling the landslides and identify the landslides that have occurred. In fact, mapping the area's old and new landslides is the basis of the work and the preparation of the zoning map. To map the distribution of landslides, satellite imagery, Google-earth, and aerial photographs of landslide-prone areas were identified, and then each of the sites was surveyed (Fig. 2). To use the points in the landslide hazard zoning area, after identifying the slip points, the slip distribution map was digitized in the ArcMap software environment (Fig. 3). Using the studies done and considering the existing maps, nine factors have been investigated to zoning the risk of landslides in the Bababozorg Basin. The factors include; slope degree, lithology, slope direction, land use, rainfall, elevation floors and distance from waterways, road and fault. After preparing the information layers, the LNRF value for each class was calculated.

Slope degree: It is essential to check the slope condition because the mechanism of many displacements related to surface materials and the transport processes are a function of the slope degree (Shadfar and Yamani, 2008). Investigation of the slide distribution relative to the slope map shows that the most prone to slip is on the 25 - 35-degree slopes. It indicates that on low slopes due to high stability and on slopes greater than 35 degrees due to reduced soil formation and also reduced sediments on the slopes, the occurrence of mass movements has decreased.

Lithology: In many landslides, the type of material involved is one of the main factors in the occurrence of landslides. Almost all zoning methods have considered this factor in some way. The Bababozorg region has a diverse lithology that has a significant impact on the region's landslides. The results of combining the landslide distribution map with the lithological map show that the alternation of clayey and shalely limestones lithology of Bangestan Formation has the highest sensitivity to landslides due to the swelling ability of those materials.

Slope direction: The slope direction usually plays a role in the occurrence of landslides due to its role in weathering and humidity in the range (Rezaei Moghaddam et al., 2006). The factor of geographical trends concerning the scattering of landslides shows that the highest sensitivity is in the southern route of 5/202 - 5/157. The southerly path is due to more sunshine than the northern slopes, and due to the high rainfall in the region compared to the annual average rainfall, and wet multiplicity and sediments drying cycles, there are many landslides in the area.

Land use: Land use affects the surface characteristics of the land and changes their behavior under the influence of geological processes governing the region, including weathering and erosion. As a result, the intrinsic earth features in terms of engineering properties are also affected by this phenomenon. Investigating the impact results of the land-use factor in landslide distribution map shows that the most considerable sensitivity to landslides is in the rangeland class by low-density vegetation. The Low-density vegetation is formed by wasteful grazing livestock in semi-arid soils, which indicates the role of humans in changing the natural ecosystem of the environment.

Rainfall: The infiltration of surface water during the rainy season raises the groundwater level and thus reduces the effective stress and shear strength of the slopes. Reducing the resistance parameters of the soil itself increases the potential for landslides. The rainfall is especially essential in areas prone to sliding grounds such as marly and clayey layers. The results of the rainfall factor study show that the most considerable sensitivity to slippage is in medium rainfall environments, which is also somewhat affected by other factors.

Height: Height has also introduced as one of the factors influencing the risk of landslides because it plays an important role in controlling the degree and type of erosion (Ayalew et al., 2005). The results show that the highest sensitivity to slip is in the middle height. At the higher elevations, it is less sensitive, due to the lack of suitable conditions for soil tillage.

Waterway Network: rivers are among the factors that cause landslides by erosion along rivers and upsetting the slope balance. How to consider this factor in the risk zone of landslides is done in different ways. Some believe the distance from the waterway (Mathew et al., 2007); some believe the water density (Haeri and Samiee, 1997), and some consider its presence or absence in units (Neaupane and piantanakulchai, 2006).

Communication lines: Road construction activity and the created trenches have changed the geometry of the slopes, and also the vibrations caused by vehicle traffic have built a significant relationship between the landslides and road congestion so that wherever the road density is high, the slip density is high. In addition to road congestion, unprincipled road construction is also a factor in causing landslides.

Fault: Faults have been considered as one of the important factors in many landslides, and researchers have reported the impact of this factor on landslides in various ways. Fatemi Aqda et al. (2003) used the fault distance factor, and Haeri and Samiei (1997) used the fault length factor in their models.

Examination of the distribution of landslides with respect to the distance from the waterway network, faults and communication lines shows that the greatest sensitivity to landslides is at a distance of more than 400 meters; this shows that these factors are more influenced by other factors and role. They don't have much to do with slipping. Therefore, in the final zoning, these factors have been ignored and not used.

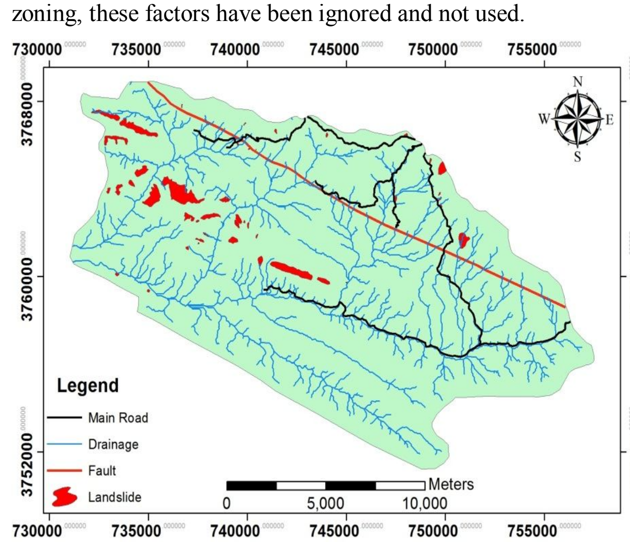

Figure 3. Landslide distribution map, in Bababozorg Basin

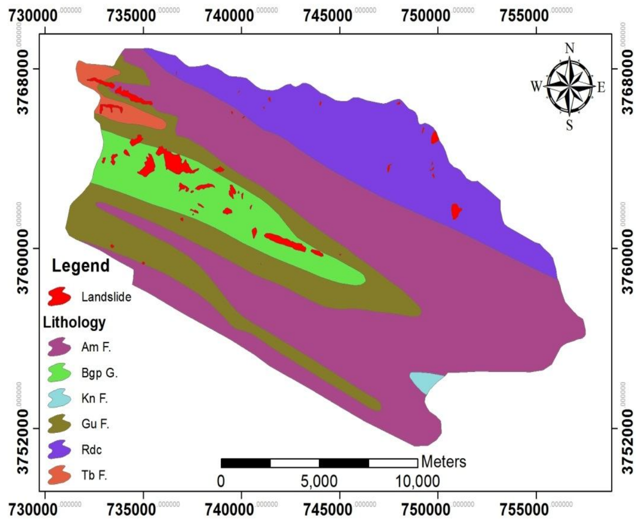

Figure 4. Lithological map of the study area

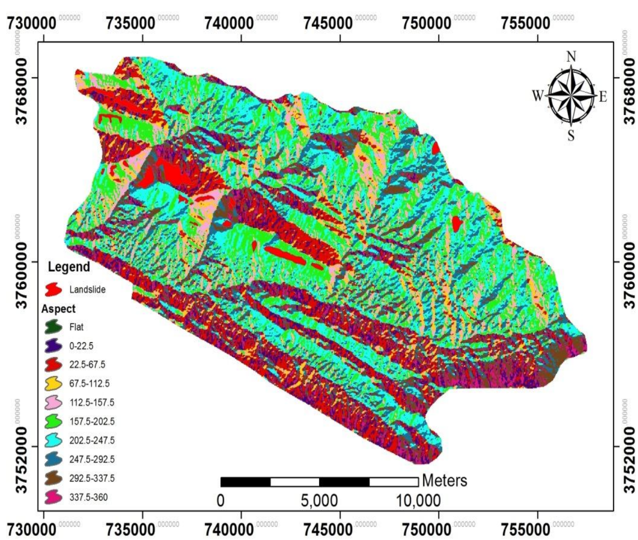

Figure 5. Steep direction map of the study area

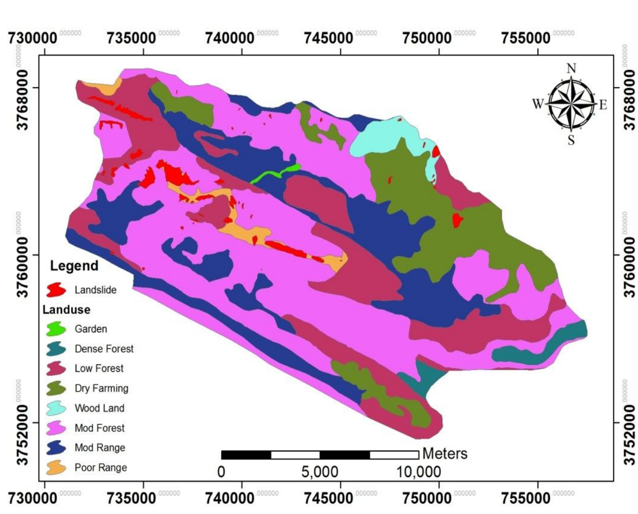

Figure 6. Land use map of the study area

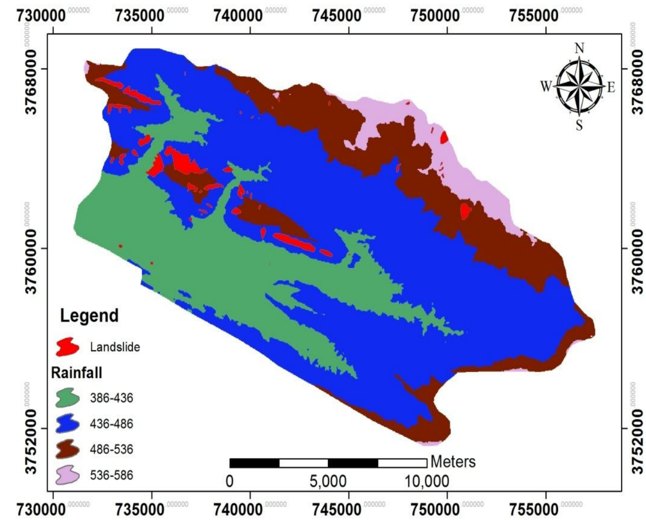

Figure 7. Precipitation map of the study area

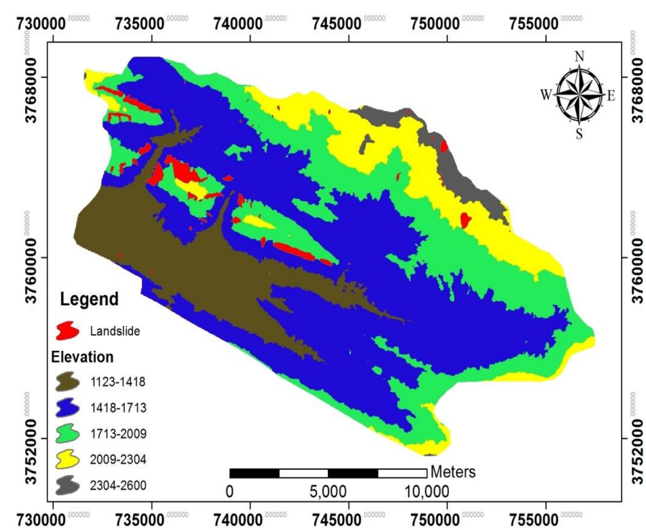

Figure 8. Elevation classes map of the study area

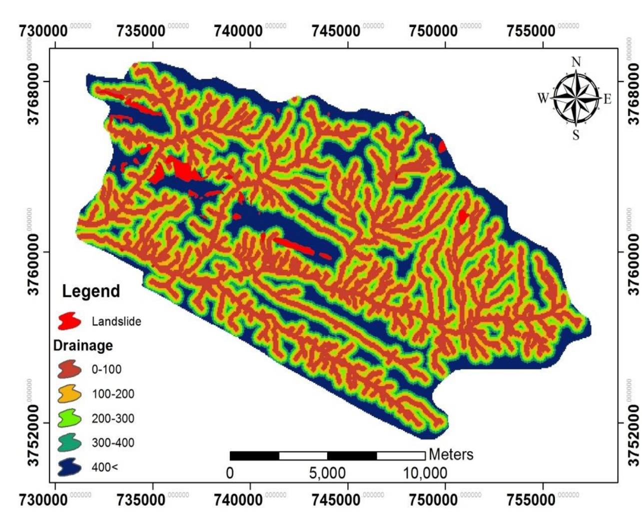

Figure 9. Distance map from waterways in the study area

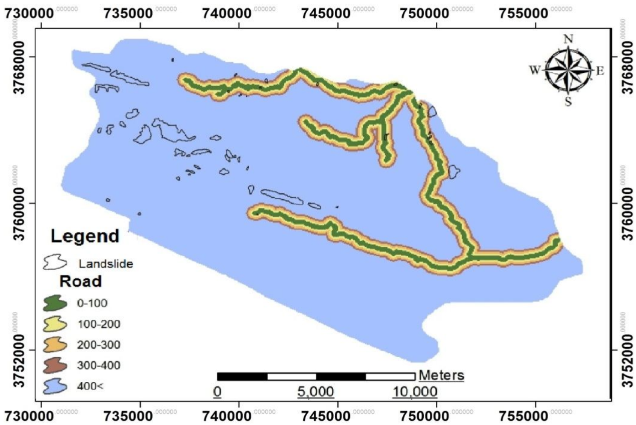

Figure 10. Distance map from communication lines of the study area

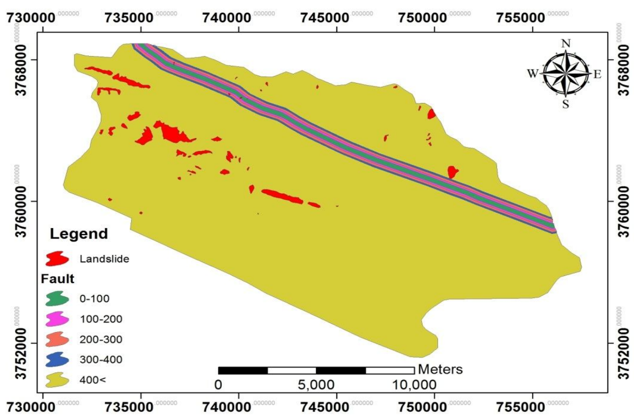

Figure 11. Map of distance from faults in the study area

We standardize the LNRF weights from Table 1, according to Table 2. We compile the maps obtained from the standardized weights using the Raster calculator command in the ArcMap software environment. Finally, according to the points of failure in the cumulative graph, we classify the map into five zones (Fig.12). In order to evaluate the results obtained from the LNRF model, by cutting the map of slip points and the risk map of landslides in the area, the slip area in each hazard class is determined and the relationship between the two models is estimated using Table 3.

Table 3 Results from the LNRF model evaluation

Hazard class	Area of each class (%)	Slip area in each class (Km^2)	The accuracy of the model used (%)
Lery low	6.42	0.017611	92.43
Low	17.87	0.359763	
Medium	27.13	0.244035	
High	27.45	0.500649	
Very high	21.11	3.866820	

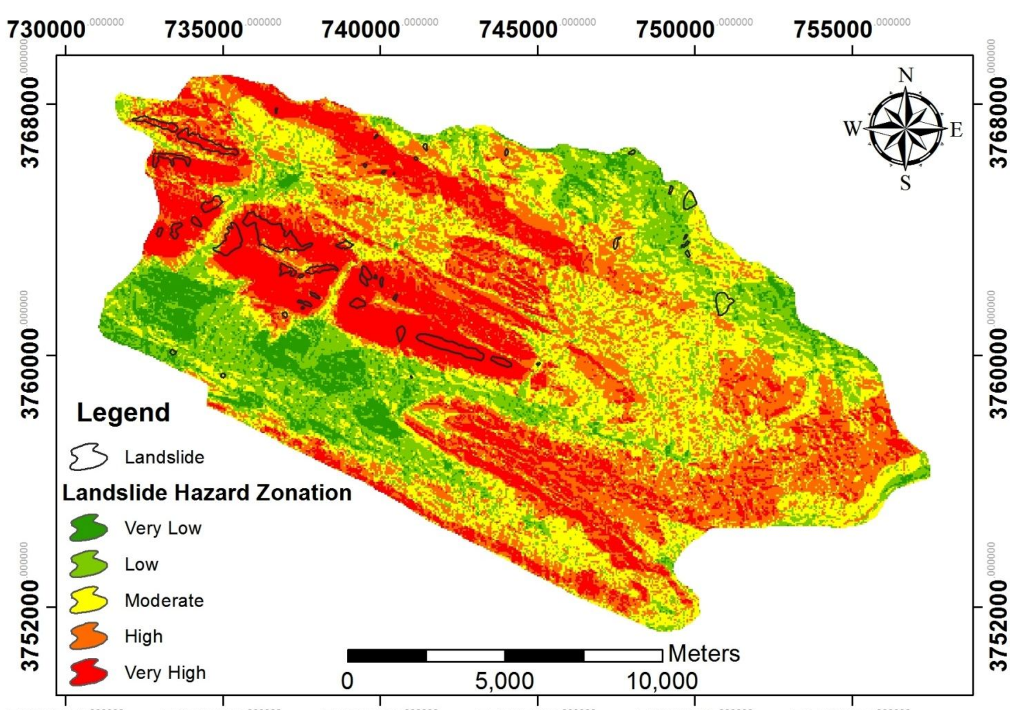

Figure 12. Landslide hazard zoning map in the Bababozorg Basin

Table 2 The values of the relationship between the factors affecting the slip and the slip occurring in the area

Factor	Class (°)	Area of each class (km^2)	Area of each class (%)	Slip area in each class (Km^2)	Slip area in each class (%)	LNRF	Standardized weight
Slope degree	0 – 5	10.882672	4.10	0.009891	0.198	0.01189	0
	5 – 15	95.888699	36.12	0.306634	6.14	0.36870	0
	15 – 25	97.076859	36.19	1.010724	20.26	1.21550	1
	25 – 35	49.726468	18.73	2.671584	53.55	3.21300	2
	35 – 45	11.823473	4.45	0.965763	19.35	1.16151	1
	45 <	1.0263275	0.38	0.024278	0.48	0.02929	0
Lithology	Kashkan	0.9872770	0.37	0.000000	0.00	0.00000	0
	Gurbi	48.221773	18.16	0.386183	7.74	0.46445	0
	Bangestan	27.944358	10.52	3.185788	63.85	3.83142	2
	Amiran	133.98262	50.47	0.517612	10.35	0.62143	0
	Tarbour	4.311799	1.62	0.320469	6.42	0.3854	0
	Radiolarit	49.97673	18.82	0.579725	11.62	0.69723	1
Slope direction Degree	0	0.029711	0.01	0.000000	0.00	0.00000	0
	1 – 23	19.42822	7.32	0.627650	12.58	1.25811	1
	23 – 68	32.39748	12.20	1.015223	20.35	2.03496	2
	68 – 113	15.42986	5.81	0.116899	2.34	0.23431	0
	113 – 158	23.92537	9.01	0.327317	6.56	0.65609	0
	158 – 203	51.67534	19.46	1.034144	20.72	2.07281	2
	203 – 248	54.61424	20.57	0.674417	13.51	1.35183	2
	248 – 293	29.75951	11.21	0.508950	10.20	1.02018	1
	293 – 338	24.21618	9.12	0.472093	9.46	0.94628	1
	338 – 360	13.94341	5.25	0.212210	4.25	0.42537	0
Communication Lines	0 – 100	87.61949	33.01	0.635978	12.74	0.63739	0
	100 – 200	57.99087	21.84	0.470462	9.43	0.47151	0
	200 – 300	44.99781	16.95	0.608992	12.20	0.61035	0
	300 – 400	28.69797	10.81	0.758317	15.20	0.76001	1
	400 <	46.11836	17.37	2.515128	50.41	2.52072	2
Fault	0 – 100	5.817740	2.19	0.010795	0.21	0.01081	0
	100 – 200	4.411906	1.66	0.006297	0.12	0.00631	0
	200 – 300	5.014021	1.89	0.008960	0.16	0.00818	0
	300 – 400	4.394806	1.65	0.000000	0.00	0.00000	0
	400 <	245.7862	92.60	4.963692	99.49	4.97472	2
Land use	Garden	5.210808	0.182	0.000000	0.00	0.00000	0
	Dense forest	5.210808	1.96	0.000000	0.00	0.00000	0
	Low forest	54.17088	20.41	1.180746	23.66	1.89343	0
	Farms	35.30572	13.30	0.300144	6.10	0.48135	0
	Groves	5.820085	2.19	0.224432	4.49	0.35989	0
	Medium forest	105.5265	39.75	1.321354	26.48	2.11888	2
	High pasture	52.66876	19.84	0.030645	0.61	0.04914	0
	Low Pasture	6.238575	2.35	1.931556	38.71	3.09733	2
Rainfall	386 – 436	65.13525	24.54	0.242746	4.86	0.19466	0
	436 – 486	136.7128	51.50	3.287858	65.90	2.63611	2
	486 – 536	50.84298	19.15	1.214628	24.34	0.97388	1
	536 – 586	12.73346	4.79	0.243645	4.88	0.19532	0
Height	1123 – 1418	42.00306	18.82	0.070127	1.40	0.07028	0
	1418 – 1713	118.5928	44.68	1.701918	34.11	1.70570	2
	1713 – 2009	66.89765	25.20	2.556024	23.51	2.51726	2
	2009 – 2304	30.85301	11.62	0.445034	8.92	0.44606	0
	2304 – 2600	7.078803	2.66	0.215774	4.32	0.21621	0

4. Conclusion

Landslide distribution map preparation is the first step in preparing a risk zoning map of landslides in each region. Based on this, 46 landslides with an area of 4.988 square kilometers have been recorded in Bababzorg area, which includes single and wide landslides. Field studies show that the mechanism of landslides in the area has been mainly of the type of Falls, Flows and transitional slip.

In this study, 9 factors have been studied for zoning the risk of landslides. These factors include slope, slope direction, geology, land use, precipitation, height and distances from the road, communication linesو waterway and fault. The factors influencing the slip have been investigated using the LNRF model. Accordingly, the distance factors from the waterway network, communication lines and faults did not play a significant role in the occurrence of landslides and were not used in preparing the landslide hazard map. The results of landslide risk zoning with LNRF model show that 6.42, 17.87, 27.13, 27.45 and 21.11% of the area are located in very low, low, medium, high and very high-risk classes, respectively. By this model, the experimental probability index, the p-value, was calculated to be 92.43 %, indicating the high accuracy of the method for the landslide risk zoning in the Bababozorg Basin. As such, the most focus of slip risk is in parts of the center and northwest of the region. The reason can be largely attributed to the sensitive lithology of the Bangestan group. Due to the fact that the basin has a high potential for landslides, it is recommended that scientific studies be carried out for any changes in the use of the area.

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