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Landslide susceptibility mapping using frequency ratio method along the Bhaderwah-Bani Road, Jammu and Kashmir, India

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ABSTRACT

This study outlines a method for landslide susceptibility mapping utilizing remote sensing and geographic information systems (GIS). Since the terrain from Bhaderwah to Bani in J&K is prone to landslide threats, the study has been conducted there. The purpose of the current study is to determine and identify the significant terrain elements causing landslides. Nine contributing factors on landslides were taken into account throughout the analysis. Thematic data layers are created in the GIS domain based on local events. Topographic maps, satellite images, on-site observations and publicly available published maps are used to gather the landscape data. To determine the standardized scores of criteria expressing their factor of importance for a given decision problem in terms of thematic parameters, categories, and their normalized weights the Frequency ratio (FR) method is used to digitize these maps along with tabular data and to create a GIS database. A particular landslide susceptibility zonation (LSZ) map was created on a GIS platform by statistically combining weightages from several thematic maps. Using FR, the LSZ map was divided into five separate susceptibility zones. According to the study's finding, 8% of the area is in a very high susceptibility zone, with the remaining 12%, 15%, 23%, and 42% falling into high, moderate, low, and very low susceptibility zones, respectively. The outcomes of the current study might aid policy and decision makers in moving forward with regional development initiatives including land use planning.

Keywords: Landslide, Hazard zonation, NH-244, frequency ratio, Remote Sensing, GIS

INTRODUCTION

Landslide is one of the most common natural hazards that has caused massive damage to infrastructure and property as well as loss of lives around the world. India is prone to variety of natural and human induced disasters such as landslides, floods, earthquakes, fires, windstorms hailstorms. Among various natural hazards, landslide is very common in hilly region of India. Landslide is the most harmful geological hazard in India causing significant number of fatalities, economic losses and is one of the major restraints in development (Petley et al., 2008). Landslide appraisal and hazard zonation are necessary for systematic landslide mitigation and management. Numerous methods for landslide appraisal and zonation have been developed during the last few decades. The correct assessment of landslide hazard of an area involves both intrinsic and extrinsic factors (Siddle et al., 1991; Dai et al., 2001). Since most studies for the assessment of hazard of an area involves only intrinsic factors, because it is difficult to obtain the data on extrinsic factors. Therefore, assessment of an area in the context of landslide hazard where extrinsic factors are disregarded is termed as landslide susceptibility mapping (Dai et al., 2001; Guzzetti et al., 2005). The landslide study has taken a great stride in modern times due to advancement and development of spatial information technology. The easy availability of high-resolution satellite imageries and application of geographic information system (GIS) has helped in managing and manipulating of the spatial data with suitable models for mapping landslide susceptibility for large areas (Carrara et al., 1991; Van Westen et al., 2006).

A number of schemes are in vogue in which GIS technique is used for landslide susceptibility zonation. The qualitative method normally incorporates landslide susceptibility based on professional acquaintance and is useful for regional assessment (Aleotti and Chowdhury, 1999). The quantitative analysis of landslide includes statistical methods and can be grouped into multivariate and bivariate methods. In the multivariate method, the relative contribution of each factor layer to the total landslide susceptibility map is considered, while in the bivariate method the contribution of each factor is compared with landslide inventory to find out the relative importance. The overall methodology used for landslide susceptibility mapping is generally based on the principle that future landslide will occur in areas of similar conditions where past landslides have occurred (Varnes, 1984; Guzzetti et al., 2003). In this study, bivariate statistical method was used to prepare the landslide susceptibility map. Frequency ratio is one of the bivariate statistical approaches of landslide susceptibility assessment based on the relationship between instability factors and the past and present distribution of landslides (Lee, 2005). The frequency ratio approach is a simple probabilistic form based on the observed relationships between the causative factors and distribution of landslides. The ratio value greater than unity represents a strong correlation for landslide and ratio value less than unity represent the lesser chance of landslide from an influencing factor (Lee and Pradhan, 2006). This method has been successfully used by various workers for landslide susceptibility mapping (Lee and Talib, 2005; Lee and Pradhan, 2006, 2007). In the present study frequency ratio model in GIS environment was used in which six intrinsic causative factors i.e., aspect, relief, curvature, slope, hill shade, and geology were taken into account.

In Jammu region most of the landslide's studies took place along national highways, because road network is considered to be the index of the development of the country and keeping in view the importance of National Highways (NH-44) mostly studies are concentrated along the highways (Andrabi, 2002; Bhat et al., 2002; Singh, 2006; Singh and Bhat, 2010; 2011; Singh et al., 2012, 2014). In the history of Jammu region, one of the deadliest landslide events was observed in Sadal Village in Panchari area of Udhampur district during the year 2014. This landslide devastated the entire Saddal habitation in the early morning of September 6, 2014 in which all the residents except those who were not in the village died. This landslide destroyed 45 houses, killing 41 people and more than 500 domestic animals perished. Besides this, number of landslides took place in and around Jammu region. These events often initiate especially during the onset of rainy season. A detailed knowledge about the expected frequency, character, pattern and magnitude of slope failures in an area can led to successful mitigation of landslide hazards. For conducting quicker and safer mitigation programs over a specific area identification of landslide-prone regions is essential.

STUDY AREA

The present study is confined between Bhaderwah (latitudes- N32°60' and longitudes- E75°40') and Bani (latitudes-N 32°40' and longitudes- E 75°60') sector of the National highway-244 (NH-244) which falls in the Lesser Himalayan tectonic zone of the northwestern Himalaya (Figs. 1 and 2). The prominent structural unit falling in the study area is the Panjal Thrust (Fuchs, 1975; Gansser, 1981; Thakur, 1981). The oldest rocks exposed along the highway in this area are represented by the Bhaderwah Group of Precambrian age composed of grey phyllitic slates, calcareous slates and talc bearing slates, overlain by the Dalhousie Formation (Salkhala Formation) comprising of augen gneisses and banded gneisses (McMohan, 1885). The Dalhousie Formation is overlain by the Sincha Formation which consists of bluish-grey sandy dolomite and pinkish limestone. The youngest rocks exposed in the study area are intrusive granites (Kaplas Granite). Seismically the area has been classified as seismic zone–IV and V. The area, in general, enjoys temperate to sub-tropical type of climate.

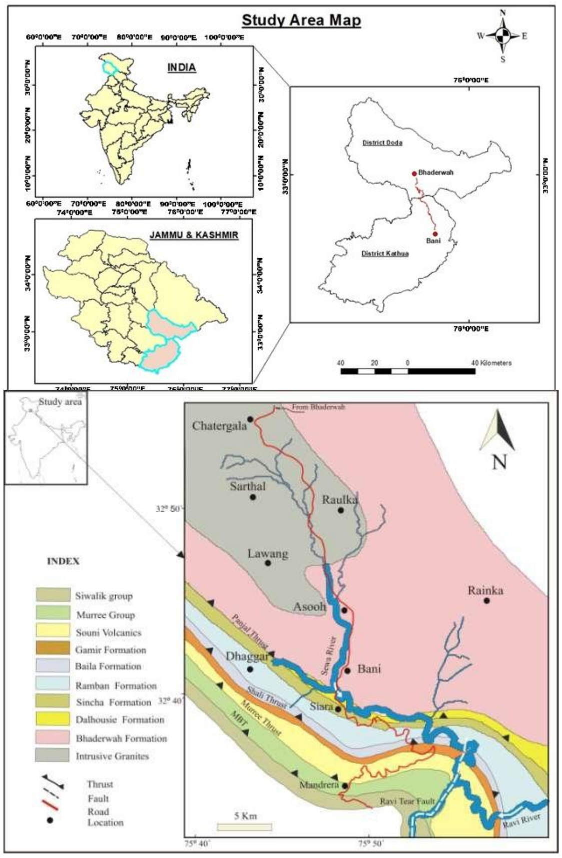

Fig. 2 Geological map of the study area (modified after Choudhary, 2006)

MATERIALS AND METHODS

The study is focused on different landslide causative factors, determination of their weights, preparation and analysis of the landslide susceptibility model while using Frequency ratio model and GIS-based statistical methods. Nine landslide conditioning characteristics, which are slope gradient, slope aspect, slope curvature, hill shade, relief, lithology, distance to road, distance to streams, and land use land cover (LULC) were taken into consideration for the study (Fig. 3). In the beginning, polygons are made to depict the sites of landslides in order to create a landslide inventory. Then, for each element taken into account in the research, thematic layers were produced, which were then resampled into raster format with uniform pixel size, categorized based on particular themes, and classed appropriately. The landslide inventory is used to determine the importance of each element. The unique sequence of various spatial and statistical datasets was used to develop a susceptibility map which characterize the whole study area into several susceptible classes such as: very high, high, moderate, low and very low (Soeters and van Westen, 1996; Brabb and Best, 1999).

LANDSLIDE SUSCEPTIBILITY ASSESSMENT USING FREQUENCY RATIO METHOD

From the correlation between places where landslides had not happened and the landslide-related variables, it was possible to infer the link between the landslide occurrence area and the landslide-related factors. One of the probability models, the frequency ratio, was utilized to quantify this distinction. The frequency ratio is the ratio of the likelihood that an event will occur to the likelihood that it won't happen given certain features (Bonham-Carter, 1994). The combination of multiple causal factors depending on their weight, which is estimated by various statistical methodologies, is the essential part of the assessment of landslide susceptibility. Due to its mathematical simplicity and relatively short evaluation time, frequency ratio (FR) was chosen for this study as the primary analysis for a preliminary probabilistic evaluation. When this ratio exceeds 1, there is a strong correlation between a landslide and the range or kind of the component. If the ratio is less than 1, there is a slight relationship between the range or type of the component and the likelihood of a landslide (Girma et al., 2015). The formula for calculating frequency ratios is as follows:

$$FR = \frac{Nlp / N}{Nlpi / N_l}$$

where,
Nlp = the number of pixels in each landslide conditioning factor class;
N = the total number of pixels in the research region;
Nl = total number of landslide pixels in the study region and
Nlpi= number of landslide pixels in each landslide conditioning factor class.

LANDSLIDE INVENTORY

The landslide inventory provides information regarding the types of landslides, their failure processes, their locations, their triggers, as well as their frequency of occurrence, density, and damage (Fig. 4) (Van Westen et al., 2008). A few places were verified on the ground. For the purpose

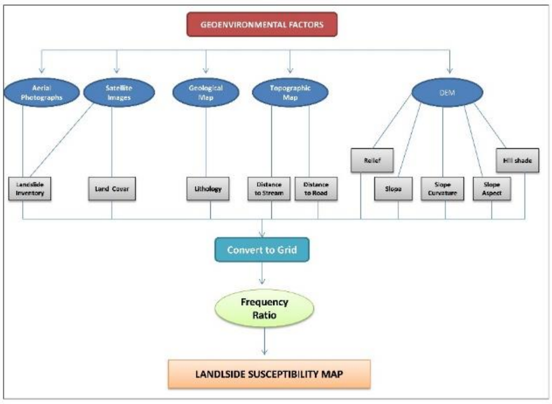

Fig. 3 Flowchart of the methodology used in the study

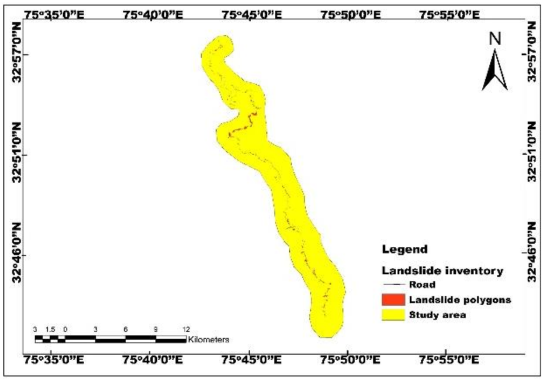

Fig. 4 Landslide inventory of the study area (Courtesy: Google earth pro).

of creating a landslide inventory map, 134 landslide locations were found and mapped overall in this study. Numerous studies have demonstrated that steeper slopes are more likely to have landslides (Poudel et al., 2016). Due to the varied wetness of the slope side, it is also one of the most important elements influencing the occurrences of landslides (Pham et al., 2018). Landslides may be influenced by aspect-related elements such as exposure to sunshine, drying winds, rainfall (degree of saturation), and discontinuities (Dai et al., 2001; Cevik and Topal, 2003). The acceleration or

Fig. 5 Field photographs showing the various types of slope failures in the study area.

slowdown of flow across a surface is influenced by curvature (Buckley, 2010). Some of the field photographs of the study area are shown in Figure 5.

RESULTS AND DISCUSSION

Utilizing the frequency ratio approach, the frequency ratio values for the various conditioning factors is given in Table 1. The examination of the current study's findings provides crucial new information about how different elements affect landslides vulnerability. In terms of slope sub-categories, the range of 45^0-55^0 shows the highest frequency ratio value (1.146), indicating the likelihood of landslides on these steep slopes. The slope sub-categories 20^0-30^0, 30^0-45^0, 55^0-65^0, also shows a frequency ratio greater than 1 (1.096, 1.105 and 1.086), which indicates a considerable probability of landslide happening in the areas with these slope sub categories. Furthermore, the frequency ratios for the slope sub-categories 0^0-10^0, 10^0-20^0 and >65^0 are all less than 1 (0.531, 0.792 and 0.974), indicating minimal likelihood of landslides (Fig. 6a). The impact of aspect is higher in the northeast, northwest, north and east directions with FR values 1.269, 1.261, 1.196 and 1.095 (Fig. 6b). Areas with concave curvature are more susceptible to landslides with FR value of 1.306 (Fig. 6c). According to the hill shade results, the hill shade ranges (205-254,117-161 and 0-69) have a stronger effect on the occurrence of landslides with FR of 1.102, 1.053 and 1.035 than the other hill shade ranges (Fig. 6d). According to the study's relief component, regions with high relief (2971-3415 m) have a bigger impact on the likelihood of landslides with a FR of 2.994. Areas with low relief, on the other hand, are less susceptible to landslides (Fig. 6e). Another affecting factor for landslides is the geological set-up of the area. The whole area is represented by three different rock formations. The effect of landslide is higher for the Salkhala Formation which has FR value of 1.15, followed by the Vaikrita Formation with FR value of 1.022 and lowest in the Kaplas Granite with FR value of 0.893 (Fig. 6f). Similarly, the study area's distance to stream map indicates that landslides are more common in the locations that are almost nearest to the river (100-200 m) with a FR of 5.333 (Fig. 6g). Landslides are more likely to occur in places covered by snow with a FR of 1.594, based on calculations from the land use and land cover map (Fig. 6h). According to the study area's distance to road map, the closest distance from a road (0–150 m) with a frequency ratio value of 17.026 has the biggest influence on the likelihood of landslides (Fig. 6i). Anthropogenic activities and haphazard toe cutting are two possible causes of this, which result in further instability.

Using the data of Table 1, the values for each factor were used to prepare the Landslide susceptibility index (LSI) map using raster calculator. LSI is classified into specific classes

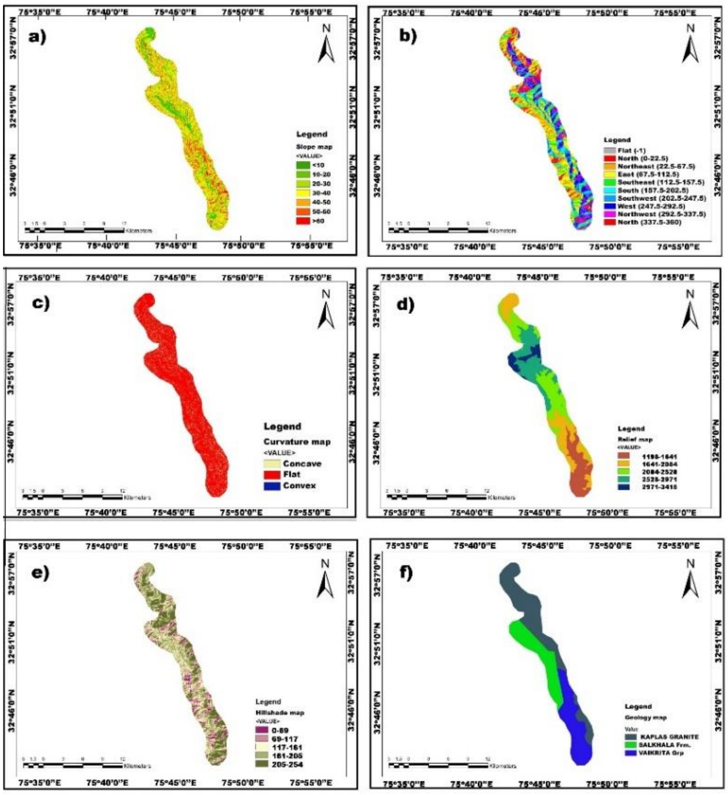

Fig. 6(a-f) Conditioning factors a) Slope map and b) Aspect map; c) Curvature map; d) Hill shade map; e) Relief map, and f) Lithology map

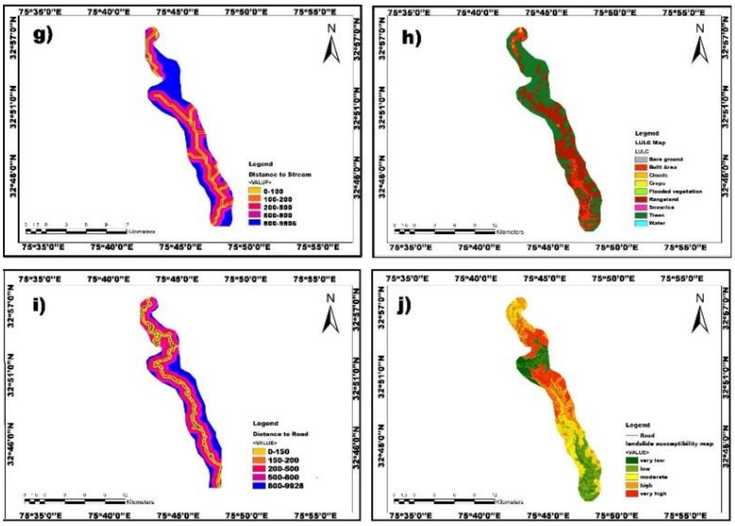

Fig. 6(g-j) Conditioning factors g) Distance to streams; h) LULC; i) Distance to road; and j) landslide susceptibility zonation map.

defining susceptibility level to prepare the Landslide Susceptibility Map (Fig. 6j).

LSM $_{\mathbf{Fr}}$ = Total Sum of (weight* factor map)

The LSM illustrates the landslide susceptible zones which are divides into five class i.e., very low, low, moderate, high, and very high. The area covered by each class of landslide susceptibility map using FR method is shown as Table 2. It demonstrates that among total land sliding area of 103.41 sq. km, the landslide probable area under classification very high and high are 8.1 sq. km and 11.52 sq. km respectively. The comparison can be interpreted by change in area in different classes of landslide susceptible zone. The graph showing the ranking criteria and weightage to each factor is shown in Figure 7, which indicates that the distance to road and distance to streams are the dominant factors affecting the stability of slope. The pie chart (Fig. 8a) describes the area of different classes in percentage in which the landslide susceptible zone

Fig. 7 Graph showing the ranking criteria and weightage to each factor

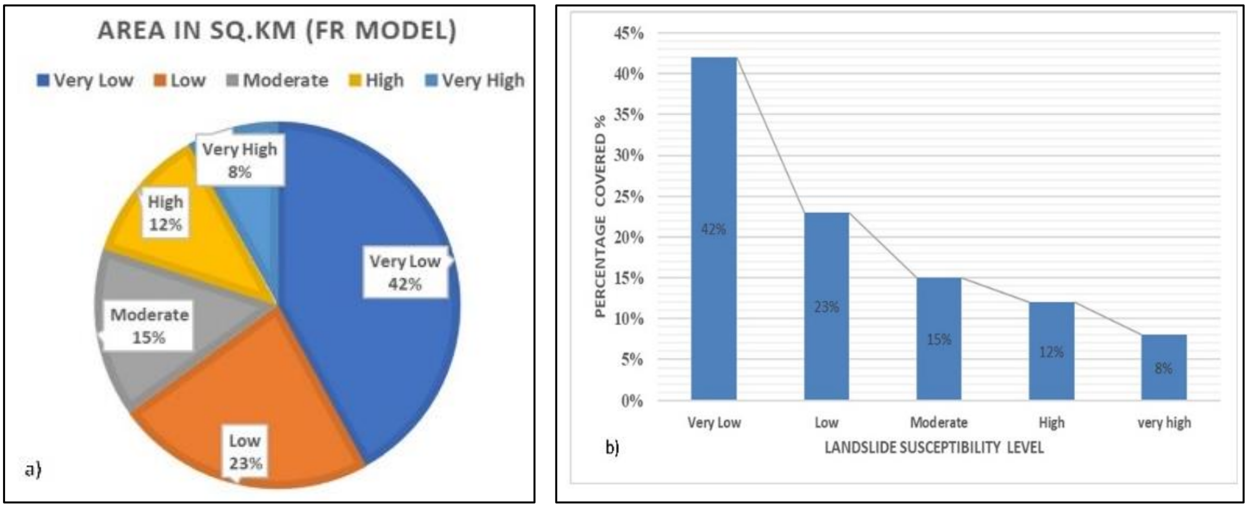

Fig. 8 a) Percentage distribution of landslide susceptibility zonation using FR and **b)** Relationship between percentage of areas of landslide and susceptibility level.

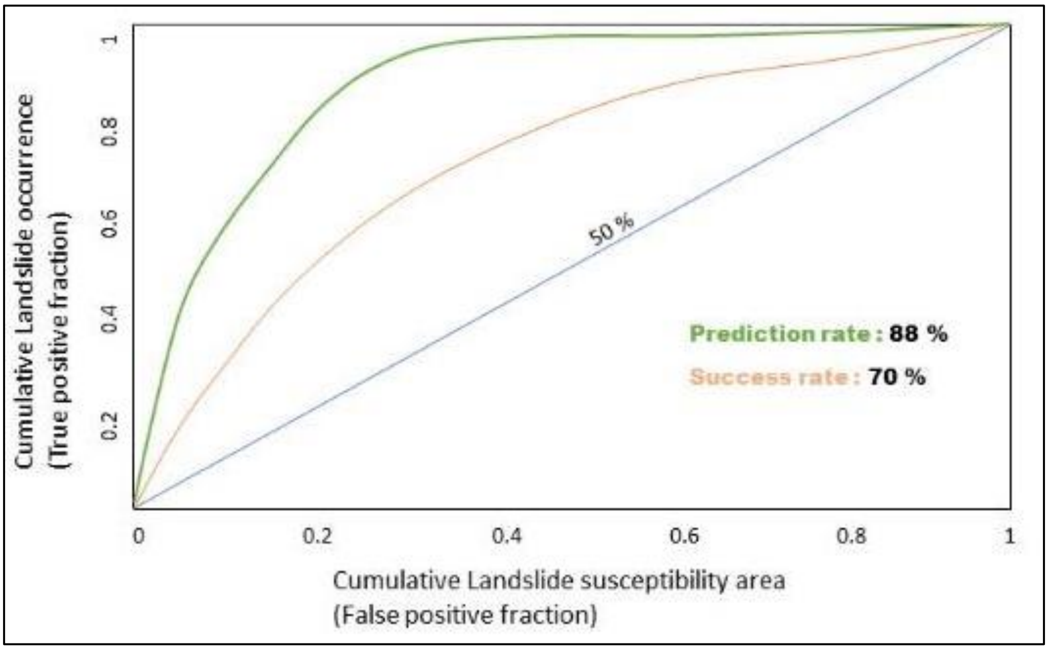

Fig. 9 Analysis of ROC curve for the landslide susceptibility map.

for very high and high classes are 8 and 12% respectively. Most of the area falls in very low susceptible zone. The relationship between landslide occurrence and each susceptibility classes as assessed by Frequency ratio method has been plotted and presented in Figure 8b. The receiver operative characteristic (ROC) curve for the validation of the results is shown in Figure 9.

Table 1. The Frequency Ratio (FR) values obtained for slope, Aspect, Curvature, Relief, Hill shade and Geology parameters

S. No.	Parameters	Classes	Class Pixels	% Class Pixels	Landslide Pixels	% Landslide Pixels	FR
		0 -10º	10665	10.644	65	5.657	0.531
		10º- 20º	13653	13.626	124	10.792	0.792
		20º- 30º	18931	18.893	238	20.714	1.096
		30º- 40º	22010	21.966	279	24.282	1.105
		40º- 50º	19099	19.061	251	21.845	1.146
		50º- 60º	11635	11.612	145	12.620	1.086
1.	**Slope**	>60º	4206	4.198	47	4.091	0.974
Total			100199		1149		6.732
		North	12605	12.580	173	15.057	1.196
		Northeast	18336	18.300	267	23.238	1.269
		East	14650	14.621	184	16.014	1.095
		Southeast	10965	10.943	93	8.094	0.739
		South	10230	10.210	72	6.266	0.613
		Southwest	12263	12.239	92	8.007	0.654
		West	12371	12.346	141	12.272	0.993
2.	**Aspect**	Northwest	8779	8.762	127	11.053	1.261
Total			100199		1149		7.825
		Concave	17874	17.451	262	22.802	1.306
		Flat	57552	56.192	645	56.136	0.999
3.	**Curvature**	Convex	26995	26.357	242	21.062	0.799
Total			102421		1149		3.104
		0-69	10352	10.419	124	10.792	1.035
		69-117	17562	17.675	197	17.145	0.970
		117-161	23139	23.289	282	24.543	1.053
		161-205	24688	24.848	245	21.323	0.858
4.	**Hill shade**	205-254	23617	23.770	301	26.197	1.102
Total			99358		1149		5.019
		1198-1641	18548	18.110	289	25.152	1.388
		1641-2084	24012	23.444	161	14.012	0.597
		2084-2528	22726	22.189	126	10.966	0.494
		2528-2971	23234	22.685	106	9.225	0.406
5.	**Relief (m)**	2971-3415	13901	13.572	467	40.644	2.994
Total			102421		1149		5.882
		Kaplas Granite	44821	43.760	449	39.077	0.893
		Salkhala fm.	27363	26.715	353	30.722	1.15
6.	**Geology**	Vaikrita Grp.	30241	29.525	347	30.200	1.022
Total			102425		1149		3.065
		0-100	10876	2.91	142	12.53	4.306
		100-200	15401	4.12	249	21.98	5.332
		200-500	23722	6.35	258	22.77	3.587
		500-800	25467	6.81	122	10.77	1.580
7.	**Distance to Streams (m)**	800-9806	29827	79.81	362	31.95	0.400
Total			373744		1133		15.208
		Bare Ground	35875	1.00	13	1.13	1.136
		Built Area	32708	9.08	155	13.49	1.486
		Crops	52486	0.00	4	0.35	0
		Snow/Ice	60201	16.70	306	26.63	1.594
		Trees	1465	0.00	79	6.88	0
8.	**LULC**	Water	21142	58.66	592	51.52	0.878
Total			202412		1149		5.095
		0-150	20420	5.831	1116	99.288	17.026
		150-200	14468	4.131	8	0.711	0.172
		200-500	17096	4.882	0.00	0.00	0
		500-800	23669	6.759	0.00	0.00	0
9.	**Distance to Road (m)**	800-9928	27452	78.395	0.00	0.00	0
Total			350175		1124		17.198

Table 2. Table showing the percentage of area covered by each class by using landslide susceptibility zonation map

Class	Pixel Count	Area (in sq. km)	% age of area covered
Very Low	14764	44.19	42
Low	17319	24.66	23
Mode rate	20519	14.94	15
High	26292	11.52	12
Very High	20464	8.1	8
Total	99358	103.41	100

CONCLUSIONS

The Landslide Susceptibility Index was calculated in the current study using a GIS environment and nine conditioning parameters (slope, slope aspect, slope curvature, relief, hill shade, lithology, distance to river, distance to stream, and LULC). The model employed in this research will reasonably estimate the landslide susceptibility along the Bhaderwah- Bani Road stretch. The main factors influencing the frequency of landslides have been identified as human activities, including an increase in built-up areas (roads and buildings) and agricultural practices having the greatest influence on steep slopes. Due to the burden of the expanding population, people have been compelled to concentrate their enterprises on high mountain slopes. In order to safeguard people and property against landslides, the susceptibility maps may be used as key instruments in the planning and management of upcoming development projects in this area. While the low susceptibility zones are often safe for the construction of infrastructure, the high and very high susceptibility zones require extra engineering, geological, and geotechnical considerations.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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