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Landslide susceptibility assessment along the National Highway-244 from Batote to Doda, J & K, India: A study based on the Frequency Ratio Method

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ABSTRACT

The National Highway-244 is highly susceptible to landslide occurrences, frequently resulting in road blockades and causing significant hardships for the local population. These landslides pose a threat to human lives, property and the environment, leading to substantial losses. In this study, an attempt has been made to carry out landslide susceptibility assessment through frequency ratio method along the National Highway-244 utilizing GIS and statistical computations. It considers eight parameters, which include topographical (slope, slope aspect, slope curvature, hill shade, and relief), anthropogenic (distance to road and distance to river) and geological parameters that mostly influence the occurrence of landslides in the area under investigation. The present study focuses only along National Highway-244 and data has been gathered from field visits and secondary sources. The results of the study inferred that the area under investigation falls into different susceptibility zones, namely very high, high, moderate, low, and very low, covering approximately 15%, 31%, 27%, 19%, and 8%, respectively of the total area. This study reveals that a considerable proportion, around 73%, of the study area falls within very high to moderate susceptibility zones. The conclusions drawn from this study hold significant implications for stakeholders and also provide valuable insights for future planning and infrastructure development, enabling them to make informed decisions. By considering the susceptibility zones identified in this study, stakeholders can implement appropriate measures to mitigate the impact of landslides, ensuring the safety and stability of the region.

Keywords: Landslide susceptibility, National Highway-244, Frequency ratio, GIS.

INTRODUCTION

The term landslide in our national language has been referred as “Bhuskhalan” where the word ‘Bhu’ stands for “earth” and the word “skhalan” stands for “movement” which undoubtedly articulates that it is the movement of earth under the influence of gravity. Landslide phenomenon is one of the most widely spread natural hazard in India particularly in hilly regions and along road networks. Every year, India experiences a considerable number of landslides events, particularly during rainy seasons or incessant rainfall, inflicts huge losses in terms of life and property (Singh and Bhat, 2010, 2011). The problem of landslides is of grave concern, especially during monsoon season as it seriously affects the livelihood of people by disrupting various networks, which are very critical for sustaining daily life. Landslide events are primarily triggered by heavy precipitation, earthquakes and anthropogenic activities (Bhat et al., 2002; Sangra et al., 2017; Hussain et al., 2018; Singh et al., 2018). The thorough understanding about the frequency, character, pattern and size of slope plays a decisive role in the effective management of landslide hazard. Landslide is one of the most frequent natural disasters which resulted in vast amounts of destructions (infrastructure, property, and lives) around the world. According to Gyawali et al., (2021) the highest number of fatalities due to landslides in recent years has been reported from China (695) followed by Indonesia (465), India (352), Nepal (168), Bangladesh (150) and Vietnam (130). An estimated 89.6% of all fatalities across the world were brought on by landslides triggered by heavy rain (Petley, 2008). With regard to understanding, evaluating and investigating landslide hazards, this concept emphasizes the necessity of anticipating both location-based spatial probability and time/frequency-based temporal probability (Tien et al., 2012; Hussain et al., 2019).

Landslide susceptibility (LS) assessment provides a relative estimation of the spatial occurrences of landslides in a mapping unit, which aids in quantifying the volume or area and the spatial likelihood of a landslide event depending on the geology of the area. It involves the integration of various geospatial data and factors that contribute to landslide occurrences. It aims to identify areas with a higher potential for landslides, allowing for better understanding and management of landslide hazards. In landslides susceptibility mapping (LSM), frequency ratio method is one of the most widely used technique among bivariate statistical procedures (Chimidi et al., 2017; Hamza and Raghuvanshi, 2017; Girma et al., 2015; Lee and Min,

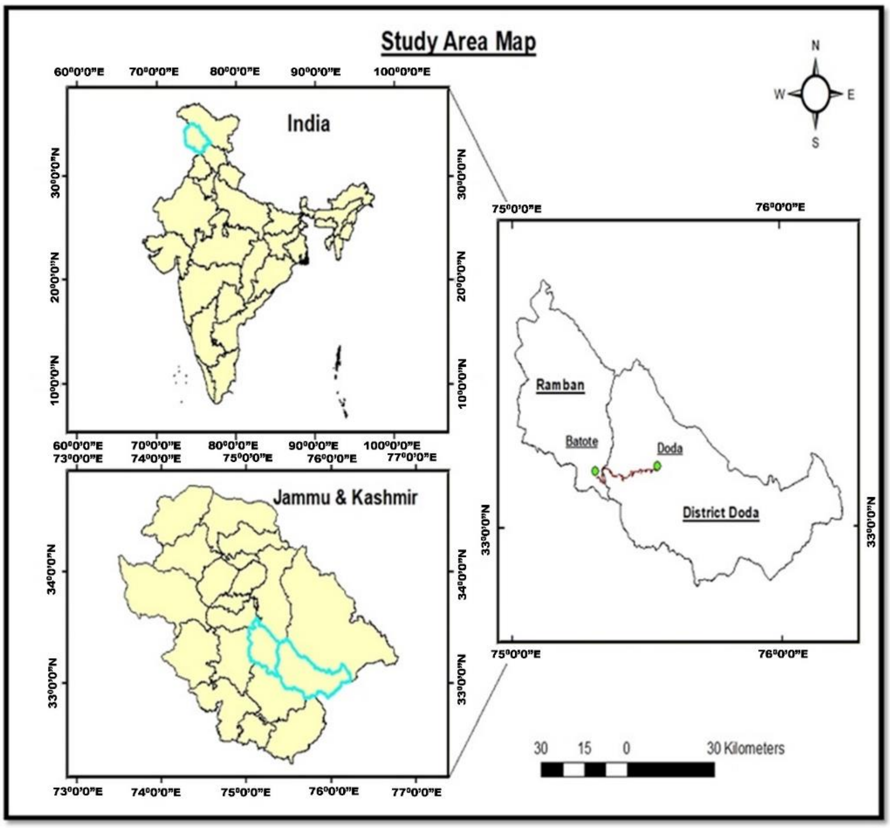

Figure 1. Location map of the study area (divaGIS).

2001). This approach makes use of the relationships between the spatial distribution of previous landslides in the area and that of relevant contributory factors (Lee, 2005; Pradhan and Lee, 2009; Akgun et al., 2012; Girma et al., 2015; Moung-Jin et al., 2014; Chimidi et al., 2017). Landslide susceptibility mapping, a significant approach (Chen et al., 2018) involves the result of combining all factor maps based on their weight for classifying the landslide susceptibility index into several susceptibility categories. The frequency ratio technique for landslide susceptibility mapping has been employed by various authors (Yilmaz, 2009; Fayez et al., 2018; Khan et al., 2019; El Abidine and Abdelmansour, 2019) in their studies to analyze vulnerability and to assess the association of different factors and landslide occurrences. Several studies (Gabet et al., 2004; Kanungo et al., 2006; Guzzetti et al., 2007; Alvioli et al., 2014) have focused on creating landslide susceptibility maps in mountainous regions, including the Himalayas to understand the causes of landslides. The frequency ratio value greater than one indicates a significant correlation of the factor class with landslide occurrences, while as the ratio less than one suggests a reduced correlation (Lee and Min, 2001; Girma et al., 2015; Chimidi et al., 2017). Shahabi et al., (2012) also conducted a landslide susceptibility study in Iran using variables such as slope, slope aspect, distance to road, distance to drainage network, distance to fault, land use, precipitation, elevation and geological factor. Overall, landslide susceptibility assessment has witnessed significant advancements, with various models and techniques being employed worldwide to understand and predict landslide occurrences based on causal factors and their associations. The present study attempted to classify the study area into different susceptibility categories using frequency ratio model.

STUDY AREA

The present study is confined between Batote and Doda sector of the National Highway-244 (NH-244) which falls in the Outer and Lesser

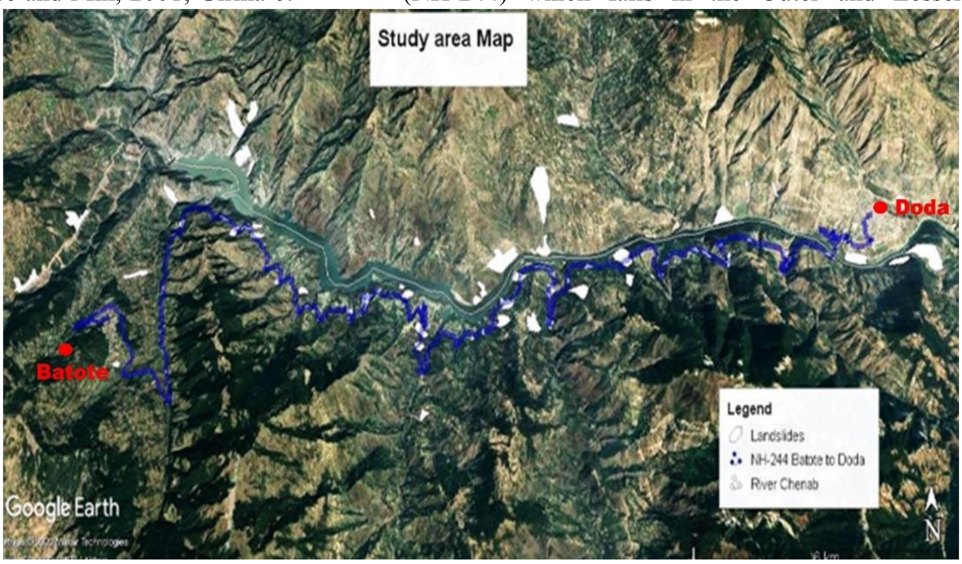

Figure 2. Google Earth image showing landslide locations of the study area (Google earth Pro).

Himalaya tectonic zones of the northwestern Himalaya. The proposed study area covers parts of Batote (latitudes 33°07'18.46"N and longitudes-75°19'17.66"E) and Doda (latitudes 33°08'45.53"N and longitudes 75°32'52.81"E) within Ramban and Doda districts of Jammu and Kashmir (Figs. 1 and 2). In this belt, about 90% of the region is made up of structural hills, which are mostly inhabited by Salkhalas, Jutogh group (Rocks of Panjal Thrust zone in J&K which includes Bhimdasa Formation, Sincha Formation etc.) and granites. The area is characterized by prominent structural units i.e., Murree thrust and Panjal thrust.

MATERIALS AND METHODS

In this study, three sets of key parameters (topographical, anthropogenic and geological) that influence the origin of landslides were considered for analysis. The topographical parameters include slope, slope aspect, slope curvature, hill shade, and relief. On the other hand, the anthropogenic factors considered are the distance to road and the distance to river and the third parameter is geology of the study area. These parameters were analyzed to determine their respective influences on the origin of landslides. The methodology employed for landslide susceptibility mapping includes GIS and statistical calculations involves several key steps. Initially, a landslide inventory is prepared by creating polygons to represent the precise locations of landslides. These layers were transformed into a raster format for each factor considered for investigation and layers are resampled into uniform pixel size. To facilitate analysis, the raster layers are categorized based on specific themes and reclassified accordingly. To analyze the relationship between landslides and the factors, the tabulated area tool in the Arc-GIS toolbox has used to obtain a table for each factor after reclassification. Then overlay and clip operations are employed to calculate pixel statistics of landslides within each class of a particular factor. The weight of each factor is determined based on the landslide inventory. These weights are then used to combine all thematic layers, resulting in the creation of the Landslide Susceptibility Index (LSI) map. Finally, the study region is divided into five relative landslide susceptibility zones: Very low, low, moderate, high, and very high.

LANDSLIDE SUSCEPTIBILITY ASSESSMENT USING FREQUENCY RATIO METHOD

The important aspect of landslide susceptibility involves the combination of several causative factors based on their weight, which are determined by various statistical approaches. In present study, the frequency ratio (FR) approach has been chosen as the primary analysis method for conducting a preliminary probabilistic assessment. This approach is favored due to its mathematical simplicity and relatively quick evaluation time. The quantitative relationship between landslide occurrences and other causal factors can be described as a frequency ratio (Pradhan et al., 2012). The frequency ratio value greater than 1 indicates a good correlation, while values lower than 1 indicates a low correlation (Lee and Min, 2001; Girma et al., 2015; Chimidi et al., 2017). The formula used for calculating the Frequency Ratio is as follows:

$$FR = \frac{Nl\,p / N}{Nlpi / N_l}$$

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.

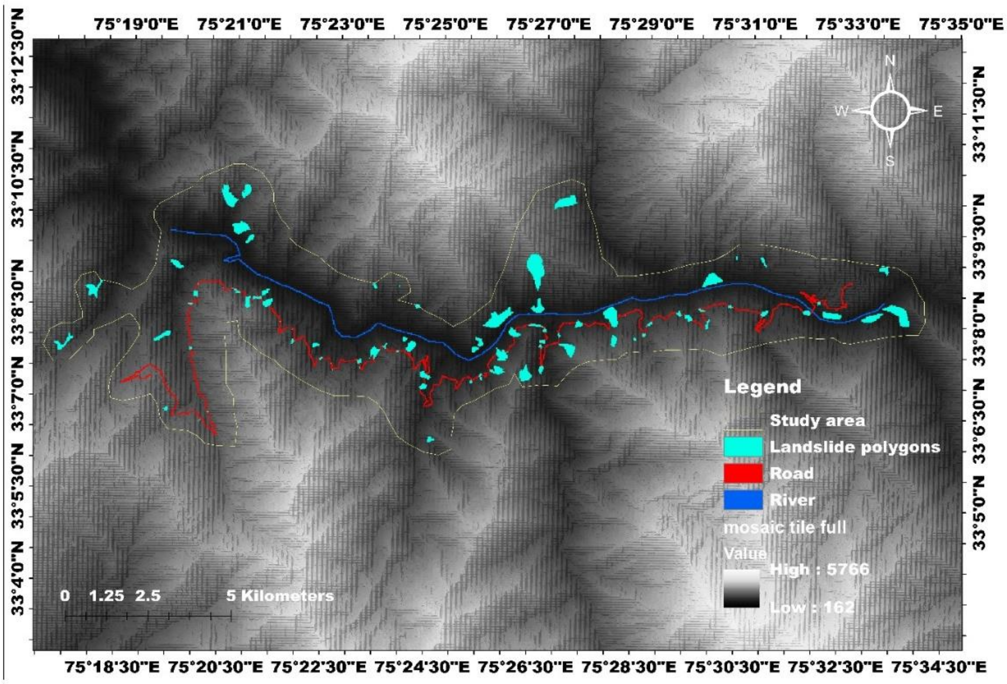

Fig. 3 Landslide inventory of the study area.

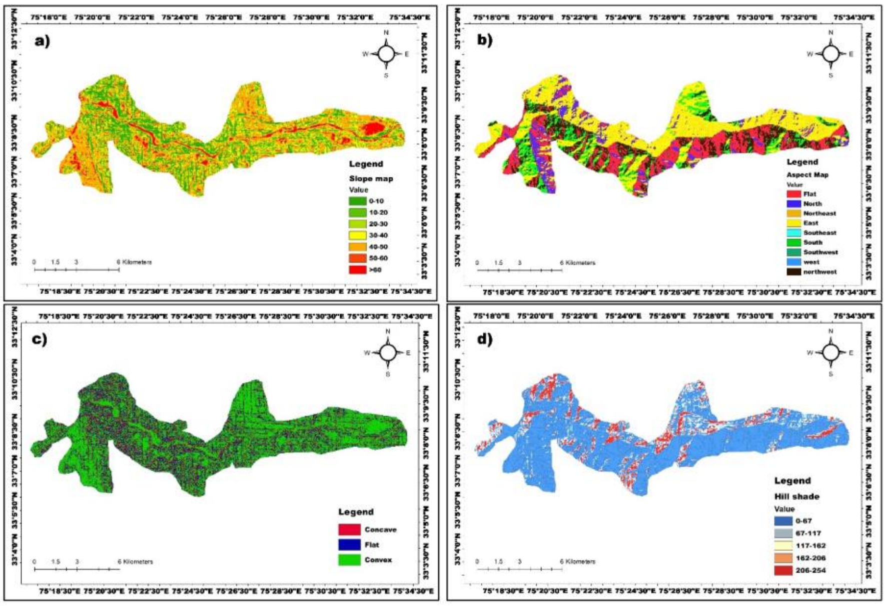

Figure 4 (a-d). Showing conditioning factors of the study area: a) Slope map, b) Aspect map, c) Curvature map, and d) Hill shade map.

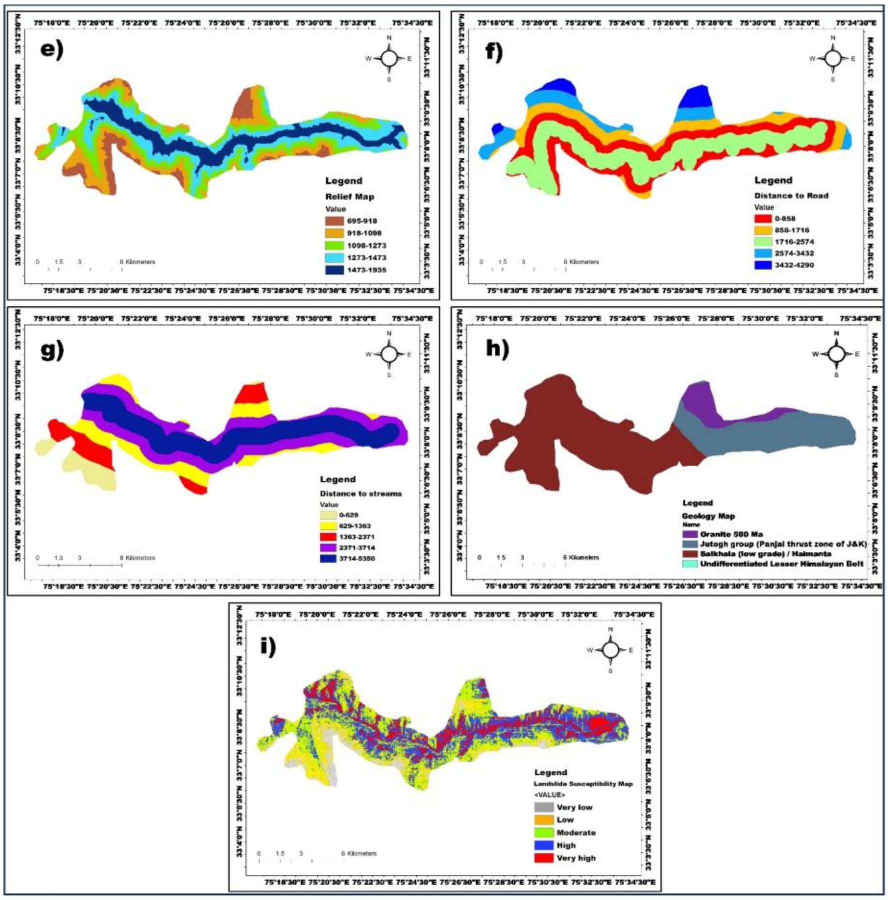

Figure 4 (e-i). Showing conditioning factors of the study area: e) Relief map, f) Distance to road map, g) Distance to river map, h) Geology map, and i) Landslide susceptibility zonation map.

LANDSLIDE INVENTORY

The landslide inventory generally refers to a comprehensive record of land sliding events within a specific area. It includes the locations, characteristics, and attributes of individual landslides, providing valuable information for landslide susceptibility and hazard assessment studies. This is considered as a base for determining a site's susceptibility to landslides. For the purpose of forecasting future landslides, the data's accuracy greatly depends on past and present landslides (Reichenbach et al., 2018). The landslide inventory (Fig. 3) offers insights into the many types of landslides, their failure mechanisms, their locations, their triggers, as well as their frequency of occurrence, density and damage (Van Westen et al., 2008). In this study, a comprehensive landslide inventory map was developed by identifying and mapping a total of 150 landsliding events. Field visits were conducted to verify the accuracy and validity of certain locations within the inventory.

RESULTS AND DISCUSSION

The frequency ratio (FR) is a statistical method used to assess the relationship between landslide occurrences and other causative factors. It involves calculating the ratio of the frequency of landslides within specific categories of a particular factor to the frequency of landslides within the entire study area. The frequency ratio approach is being utilized in this study in order to quantify the association between landslides and various causal factors (Fig. 4), aiding in the assessment of landslide susceptibility. The frequency ratio values obtained for the various conditioning factors are given in Tables 1 and 2. The stronger link between the parameters and the likelihood of a landslide is represented by a higher value of FR (>1).

The results reveal important insights into the susceptibility of landslides based on various factors. In slope sub-categories, the highest frequency ratio value (3.305) is observed in the range of 0-10^0, indicating the highest possibility of landslides (Fig. 4a). The high probability of landslides within 0-10^0 slope range can be attributed to poor geological conditions, increased anthropogenic activities which effect natural drainage system of the area and result soil erosion, particularly during incessant rainfall. These factors jointly emphasize the highest probability of landslides occurrences within 0-10^0 of slopes in the area. On the other hand, the slope sub-categories 50^0-60^0 and >60^0 exhibit the lowest frequency ratios (0.476 and 0.145) respectively indicating low possibilities of landslides. Additionally, slope sub-categories 10^0-20^0, 20^0-30^0, 30^0-40^0, and 40^0-50^0 also have frequency ratios greater than 1 (2.109, 2.108, 1.554, and 1.028), suggesting a significant risk of landslide occurrences in those areas as well. The slope map of the study area inferred that flat regions (2.10) have greatest impact on landslide occurrence (Fig. 4b). This suggests that areas with flat slopes are more susceptible to landslides compared to other slope aspects. The north aspect (1.55) suggests that it has a notable influence on landslide occurrence within the study area. North-facing slopes receive less direct sunlight, leading to reduced evaporation and potentially increased moisture retention. This increased moisture content can contribute to soil saturation and reduced stability, making north-facing slopes more susceptible to landslides. Similarly, the northeast and southeast aspect indicating moderate to low impact on landslide occurrence. The slope curvature map indicates highest frequency ratio value for flat curvature (1.11), which suggest that it has the greatest impact on landslides (Fig. 4c). The absence of slope in flat areas can contribute to the accumulation of water and instability of the soil, increasing the likelihood of landslides. The convex curvature (0.96) on the other hand has a lower frequency ratio compared to flat curvature but still shows a significant impact on landslides whereas, convex terrain features are characterized by slopes that curve outward or away from the observer. These areas may experience landslides due to the concentration of water and increased erosion along the convex slopes, leading to instability. The concave curvature has the lowest frequency ratio (0.756) among the three curvatures mentioned. However, it still demonstrates a moderate impact on landslides. The hill shade results inferred that the smaller hill shade range has a more pronounced influence on landslide occurrence compared to the greater hill shade range (Fig. 4d). The relief map of study area suggests that areas with low relief have greater influence on landslide occurrence due to water accumulation, reduced soil stability, and increased pore pressure. In contrast, areas with high relief have lower landslide susceptibility due to enhanced drainage, reducing the chances of landslides (Fig. 4e). The distance to road map of the study suggests that farthest distance from road (3432-4290 m) with a frequency ratio value (1.821) has highest impact on landslide occurrence (Fig. 4f). This may be attributed to factors such as limited accessibility for maintenance and monitoring, potentially leading to increased instability. The areas in closer proximity to the road indicate the lowest impact on landslide occurrence. This may be due to better accessibility, maintenance, and monitoring, leading to reduced landslide susceptibility compared to areas farther from the road. Similarly, the distance to river map of the study area suggests that areas in close proximity to the river within 0-629 m range are highly susceptible to

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

S. No.	Parameters	Classes	Class Pixels	Class Pixels %	Landslide Pixels	Landslide Pixels %	FR
1.	Slope	0-10^0	8526	8.220	105	2.487	3.305
		10^0-20^0	16479	15.887	318	7.532	2.109
		20^0-30^0	21187	20.426	409	9.687	2.108
		30^0-40^0	22828	20.008	598	14.164	1.554
		40^0-50^0	19072	18.387	755	17.883	1.028
		50^0-60^0	11288	10.882	965	22.856	0.476
		>60^0	4348	4.192	1072	25.391	0.165
Total			103728		4222	100	10.745
2.	Aspect	Flat	15843	15.274	307	7.271	2.100
		North	13062	12.593	342	8.100	1.555
		Northeast	11516	11.102	385	9.119	1.217
		East	9535	9.192	396	9.379	0.980
		Southeast	11565	11.149	441	10.445	1.067
		South	10440	10.065	447	10.587	0.951
		Southwest	9314	8.979	481	11.393	0.788
		West	9309	8.974	645	15.277	0.587
		Northwest	13144	12.672	778	18.427	0.688
Total			103728		4222	100	9.933
3.	Curvature	Concave	17450	16.424	917	21.720	0.756
		Flat	65018	61.196	2325	55.069	1.111
		Convex	23777	22.379	980	23.212	0.964
Total			106245		4222	100	2.831

landslides (Fig. 4g). This may be due to river erosion, water saturation and high pore pressure which decreases slope stability and increased landslide risk in these areas. In contrast, the areas farther away from the river are less prone to landslides. These areas may experience less direct influence from river-related processes, such as erosion or fluctuating water levels, resulting in reduced landslide susceptibility. The geological set-up of the area also plays a significant role in landslides. The Jutogh group (has a higher FR value of 0.0565, followed by the Salkhalas with a FR value of 0.0338, and the granites with a FR value of 0.0269 (Fig. 4h). Because just a small portion of the research region is located in the undifferentiated lesser Himalayan belt, so it does not have a significant impact. These observations indicate a clear relationship between various parameters and landslide vulnerability. However, it is essential to consider these observations within the context of the specific study area and the limitations of the frequency ratio method, as landslide susceptibility is influenced by various factors beyond these parameters such as geology, rainfall, anthropogenic activities and land cover to gain a comprehensive understanding of landslide susceptibility.

Landslide Susceptibility Index (LSI) is a quantitative parameter used in landslide susceptibility analysis. It is a numerical value assigned to different locations within a study area to represent their relative susceptibility to landslides. The LSI is typically derived through a combination of various factors and variables that contribute to landslide occurrence, such as topography, geology, slope, land cover, rainfall, and historical landslide data. Landslide susceptibility mapping based on the LSI allows for the identification and delineation of areas with different levels of landslide hazard. The creation of a landslide susceptibility map of the study area involves dividing the Landslide Susceptibility Index (LSI) into distinct classes that define different levels of susceptibility. This is achieved by applying the following equation to assign each LSI value to a specific class representing its susceptibility level.

$$LSM_{Fr} = \text{Total sum of (weight* factor map)}$$

The landslide susceptibility index values obtained help in the categorization of the area under investigation into five zones: very low, low, moderate, high, and very high (Fig. 4i). The area covered by each class of landslide susceptible map using the FR approach is presented in Table 3. The results of the study inferred that study area falls into five susceptibility zones, namely very high, high, moderate, low, and very low. The distribution of these classes in terms of the area's percentages has been illustrated through a pie chart (Fig. 5a). It revealed that the very high and high landslide susceptibility zones account for 15% and 31% of the total area, respectively. The high-susceptibility zone dominates with the highest percentage (31%). Significantly, the study reveals that a considerable proportion, around 73%, of the study area falls within susceptibility zones ranging from very high to moderate. The overview of the distribution of landslide susceptibility classes and the general relationship between landslide likelihood and each susceptibility class, emphasizing the significant presence of the high-susceptibility zone within the

Table 2. The Frequency Ratio (FR) values obtained for Hill shade, Relief, Distance to road, Distance to river.

S. No.	Parameters	Classes	Class Pixels	Class Pixels %	Landslide Pixels	Landslide Pixels %	FR
4.	Hill shade	0-67	8962	8.708	928	22.006	2.527
		67-117	17625	17.125	889	21.081	1.231
		117-162	22010	21.386	764	18.117	0.847
		162-206	26689	25.932	736	17.453	0.673
Total			102919		4217	100	6.073
5.	Relief	695-918	20894	19.666	1112	26.313	1.338
		918-1098	29509	27.774	1423	33.673	1.212
		1098-1273	25133	23.656	1081	25.580	1.081
		1273-1473	19844	18.678	528	12.494	0.669
		1473-1935	10865	10.226	82	1.940	0.190
Total			106245		4226	100	4.490
6.	Distance to road	0-858	41127	38.691	1713	40.554	1.048
		858-1716	29740	27.978	923	21.851	0.781
		1716-2574	17347	16.320	614	14.536	0.891
		2574-3432	12291	11.563	555	13.139	1.136
		3432-4290	5791	5.448	419	9.920	1.821
Total			106296		4224	100	5.677
7.	Distance to river	0-629	36202	34.058	1871	44.295	1.301
		629-1363	33181	31.216	1461	34.588	1.108
		1363-2371	17895	16.835	383	9.067	0.539
		2371-3714	11181	10.519	401	9.493	0.903
		3714-5350	7837	7.373	108	2.557	0.347
Total			106296		4224	100	4.197
8.	Geology	Undifferentiated Lesser Himalayan belt	23	0	0	0.000	0
		Granite	9143	0.086	246	0.058	0.0269
		Salkhala	63266	0.624	2239	0.530	0.0338
		Jutogh group	30804	0.290	1739	0.412	0.0565
Total			106296		4224	100	0.1171

study area (Fig. 5b) is also established. The landslide susceptibility results of the study area have been quantified and categorized into different zones, indicating varying levels of risk.

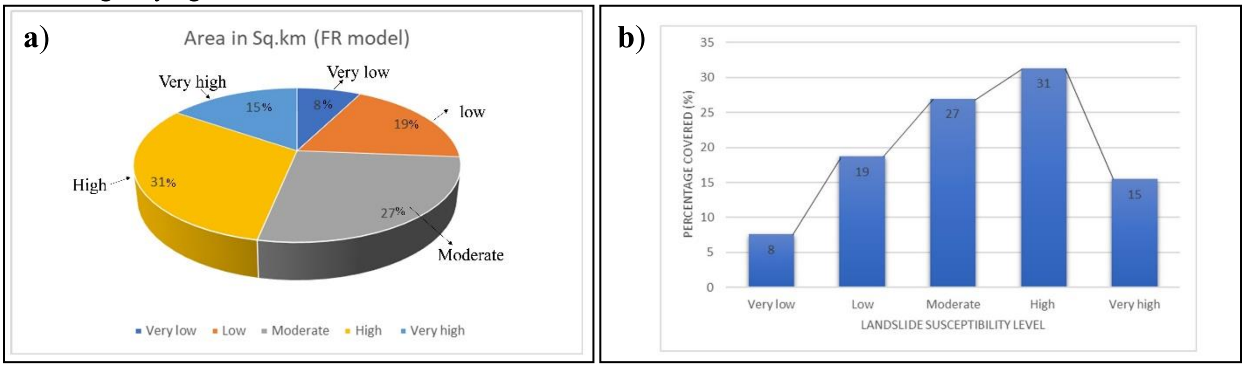

Figure 5 (a-b). a) Showing % age distribution of landslide susceptibility zonation using FR and b) Relationship between % age of areas of landslide and susceptibility level

Table 3. Landslide susceptibility zonation of the study area using frequency ratio approach.

S. No.	Category	Area in sq. km	Percentage (%)
1	Very Low	7.005	8
2	Low	17.313	19
3	Moderate	24.975	27
4	High	28.980	31
5	Very High	14.315	15
Total		92.587	100

CONCLUSIONS

The study utilized eight conditioning factors, including slope, slope aspect, slope curvature, hill shade, relief, distance from road, distance to river, and geology along with landslide inventory, to determine the Landslide Susceptibility Index (LSI) within a GIS environment. The model used in this study predicts the landslide susceptibility along the national highway-244 (NH-244) from Batote to Doda Road stretch with a reasonable level of accuracy. The findings of the present study suggest that anthropogenic activities in conjunction with factors like slope morphometry, geology, and rainfall play a key role influencing landslide occurrences. The growing population has led people to unplanned activities on slopes which increases the vulnerability to landslides. The susceptibility maps derived from this study can serve as essential tools for future construction projects, aiding in the planning and management of the area to mitigate the risk to life and property. High and very high susceptibility zones require additional attention regarding engineering, geological and geotechnical considerations, while low susceptibility zones generally present a safer environment for construction activities. It is crucial to urgently address the risk of landslides particularly in high and very high susceptibility locations, to prevent disruptions along Batote to Doda highway-244, which can result in significant inconvenience, financial losses, and human casualties.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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