Feature-Based Model for Landslide Prediction Using Remote Sensing and Digital Elevation Data

Litesh Bopche and Priti P. Rege

Abstract This study aims to generate landslide susceptible maps and landslide hazard zonation maps using the digital elevation model for the prediction of future landslides. The landslide zone is based on the qualitative and quantitative factors combined using the weighted sum of the different features and hydrological parameters. The main aim of the research is to discover the damaged areas with the help of detailed field observation of prior and post landslide events. Landslide hazard zonation is a map classified into six different zones ranging from very low hazard zone to scars hazard zone and to represents the prediction of future landslide occurrence under the area of the study. The result of this study shows that a very high and scars susceptible region depicts a higher chance of landslides.

Keywords Landslides · Landslide hazard zonation · Digital elevation model

1 Introduction

Landslides have always been one of the most destructive natural calamities that affect properties, agriculture land, livestock, and human lives on a large scale. They obstruct the development of infrastructure such as roads, dams, communication lines, bridges, and so on, in that particular region. The various complex geological settings are directly or indirectly responsible for triggering the landslides. There are various factors, affecting the occurrence of the landslide like tectonic activities in the region, presence of thrust and faults, heavy rainfall or snowfall or cloudburst, hill slope, and increased human intervention in the environmental process. Landslides are generally failures in the slopes caused by the various geomorphological activities. According to the statistical survey, hundreds of human lives and properties worth thousand

L. Bopche (✉) · P. P. Rege
College of Engineering, Pune, India
e-mail: litesh.bist02@gmail.com

P. P. Rege
e-mail: ppr.extc@coep.ac.in

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crores are estimated to be lost almost every year due to the occurrences of the landslides. The landslide event such as Lwara slides and Basukedar landslides (1992), Madhyameshwar and Kaliganga sub-watersheds (1998), Phata cloudburst (2001), Balganga valley landslide (2001), Bhagirathi valley landslide (2003), Ukhimath landslide at Uttarakhand (2012), and many others, have largely affected the valley in terms of human lives and damage to resources [1–3].

In this study, we focus on the prediction map of the landslide detection for risk management. The prediction map is generated through the weighted raster calculation method of the classified slope map, classified aspect map, classified elevation map, hydrological parameters, and relative relief map based on the area under the study. There are various reasons such as high altitude, rugged terrain, shortage of agricultural land, a lesser amount of industrial development, and extreme environmental conditions that limit the economic growth of the mountainous areas like the Uttarakhand state of India. This condition becomes more severe during the monsoon period as the rain causes more instability in the slope surfaces. The interaction between slopes and various other conventional geological factors is different in different regions and hence a susceptibility map depicts this relationship providing a metric to access the safety of the region concerning the landslide occurrences.

A Digital Elevation Model (DEM) is a 3-D representation (X, Y, Z) of the continuous geography of the terrain's surface and generate a terrain elevation model [4, 5]. A DEM is a regularly spaced grid that contains the elevation of a point on the surface that is coincident with the location of the grid cell. The terrain attributes mean not only the elevation values but also includes the slope values, aspect values, PH value of soil, surface values like groundwater-surface. DEM representing a surface is presently used in a large number of geographic environmental applications, such as hydrology, agriculture, geology, cartography, rural and urban planning, disaster risk mitigation, geomorphology, among others [6, 7]. It is one of the essential input rasters for observing the landscape as well as dynamic natural phenomena such as soil erosion, flooding, earthquake monitoring, and landslide detection.

1.1 The Area Under the Study

The area under the study is about 7626 km^2 between 30° 25′ 12″ N, 79° 19′ 48″ E to 30° 42′ 8.66″ N, 79° 33′ 56″ E in the Chamoli district of Uttrakhand (Fig. 1). The district is enclosed by Tibet area on the north, Pauri Garhwal to the south, Rudraprayag to the southwest, and Uttarkashi to the northwest. In the Chamoli district variety of destinations present for tourists interest like Badrinath, Valley of Flowers, and Auli. The altitude of the Chamoli district lies between 603 to 7100 m above mean sea level. In Chamoli 70–80% of the yearly rainfall occurs in the period of July to September. Most of the region is a highly elevated terrain. Alaknanda is the major river in the valley having some other tributaries.

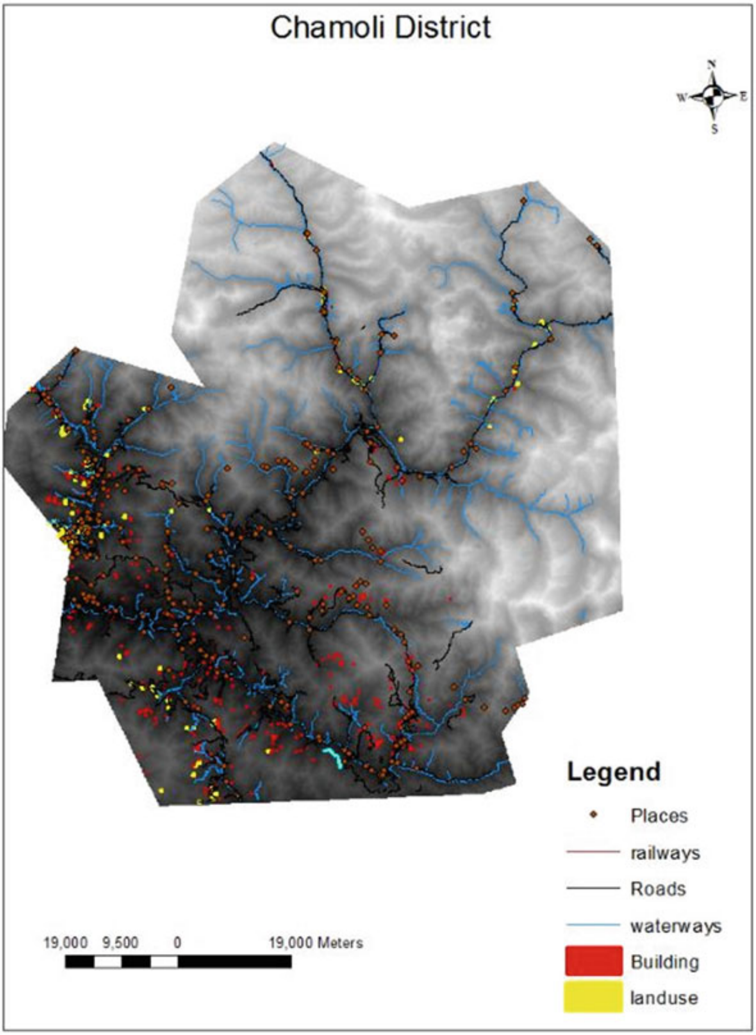

Fig. 1 CARTOSAT-1 DEM image of area under consideration

The data used for the present study is the Cartosat-1 digital elevation model based on the stereoscopic technique. The data is downloaded from the Indian Geo-platform of ISRO, BHUVAN's official website [8]. CartoSat-1 is the first Indian satellite launched in May 2005. Fore-Aft stereo capturing capability and recording stereo images in five days of revisit time. Cartosat-1 has two panchromatic cameras. The panchromatic cameras mounted with a tilt of +26° (Fore) and −5° (Aft) from Nadir point operate in the 0.5–0.85 microns spectral band [9]. The satellite data is processed using Arc-Map and ERDAS Imagine software.

This research was an effort towards the detection of feasible causes of landslide and to identify the potential and highly landslide-prone areas with the help of high-resolution Cartosat-1 DEM imagery of the Chamoli area. There are various factors responsible for the occurrences of the landslide. However, the hydrological parameter is one of the most prominent factors. In this research, we have shown the effect of hydrological parameters on the landslide.

2 Methodology

Landslide susceptible zonation is performed with the help of the weighted sum of the classified slope map, classified aspect map, classified elevation map, and hydrological parameter. It is the combination of the Geographic Information System (GIS) and image processing techniques on the stereoscopic based satellite image [10, 11]. The work consists the selection of features (such as slope map, aspect map, relative relief map, and elevation map, etc.) and hydrological parameter (such as flow stream network, flow accumulation, stream order, and stream feature) from digital elevation model for the monitoring and detection of the landslide in Chamoli district region. There is a necessity for landslide susceptibility mapping for the identification of landslide-prone areas. The monitoring and detection of the landslide are very important for relief management in the landslide-prone area [12, 13]. The methodology involves the generation of digital data and the selection of various features from DEM as shown in Fig. 2.

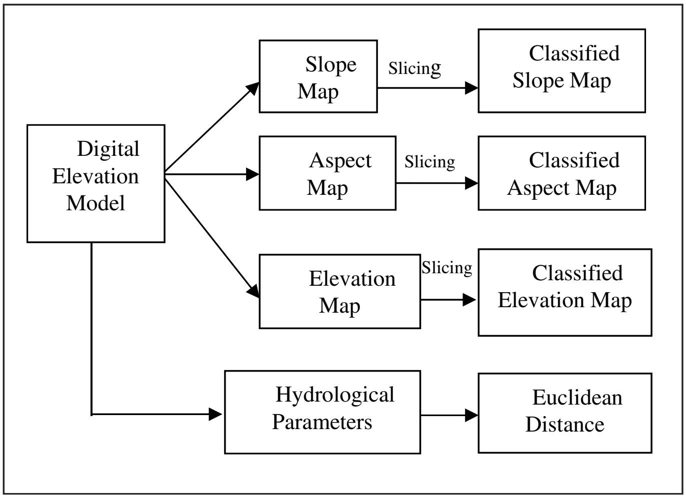

Fig. 2 Block diagram of feature extracted from DEM

2.1 Slope Map

The steep ridges, peaks, valleys, and scarps are the results of the denudation process. The measurement of the slope is a very important factor in the identification of the area, which is more prone to the occurrence of the landslide. The slope map identifies the gradient of altitude from each cell of a raster-scanned surface to its neighbor's cell and categorizes the steepest downwards hill descent from the cell. Cartosat-1 digital elevation model is used to generate a slope map for the area under the study as shown in Fig. 3a. Further, the slope image obtained through the above method is classified into nine classes. Each class consists of uni-variate data. The highly unstable part of landslides lies in the middle slope areas, such as 35°–50°. The slope values are given by Eq. (1):

$$\text{Slope}(\theta) = \arctan\left(\frac{\delta(x)}{\delta(y)}\right) \tag{1}$$

where $\delta(x)$ and $\delta(y)$ are the rates of change in x and y direction respectively. The algorithm for the slope map is based on the 3×3 neighborhood of the elevation values can be stated as below:

- The use of the middle cell values and its neighbors determines the horizontal and vertical deltas as shown in Table 1.
- change in x-direction $\delta(x)$:

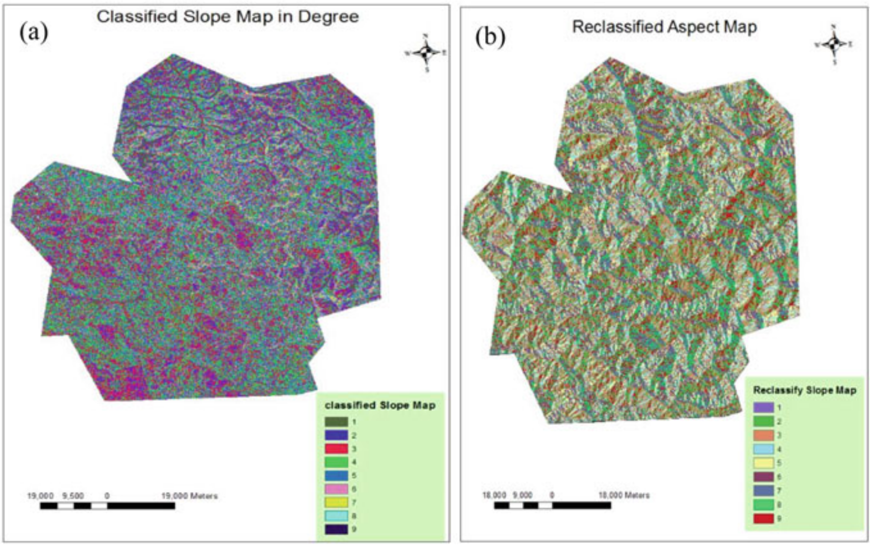

Fig. 3 Feature class map of the study area. **a** DEM classified slope map, **b** DEM classified aspect map

Table 1 3 × 3 block from DEM

a	b	c
d	e	f
g	h	I

$$\delta(x) = \frac{((c + 2f + i) - (a + 2d + g))}{(8 * \text{cellsize})} \quad (2)$$

- Change in y direction $\delta(y)$:

$$\delta(y) = \frac{((g + 2h + i) - (a + 2b + c))}{(8 * \text{cellsize})} \quad (3)$$

- The slope is calculated by using Eq. (1) and shown in Table 2.

2.2 Aspect Map

Aspect map shows the direction and orientation of the rate of change of the altitude from each cell of the raster surface. Aspect is measured clockwise from the north and expressed in positive degrees from 0 to 359.9. Slope facing in the study area is given in Table 2. There is some unification to the occurrence of landslides with the slope facing and classified aspect map shown in Fig. 3b. The appearance of the Landslides is preferentially on south to east-facing slopes. The aspect value is given by Eq. (4):

$$\text{Aspect}(A) = 57.92578 * \arctan\left(\frac{\delta(x)}{\delta(y)}\right) \quad (4)$$

The value of Eq. (4) is then converted into 0°–360° (compass direction values).

2.3 Elevation Map

The Uttrakhand region is characterized by Himalayan geography with a series of criss-cross ridges, weaker rocks, springs, and deep narrow valleys. The altitude varies from 603 to 7100 m above the mean sea level. The specific area is selected due to the presence of moderately elevated hills, disserted valleys, and several clifted hills in the area. Initially, a DEM is re-projected to a linear datum from its non-linear datum and then classifying the DEM such that each of its classes will contain uni-variate data shown in Fig. 4. A DEM for the study area was built using Arc-GIS software. The occurrence of the landslide is more prominent in the high altitude area.

Table 2 Numerical rating scheme

Layer	Factor	Value	Class
1	Slope (°)	1	0º–11º
		2	11º–18º
		3	18º–25º
		4	25º–30º
		8	30º–36º
		9	36º–42º
		7	42º–48º
		6	48º–55º
		5	55º–83º
2	Slope aspect map	1	Flat (–1)
		2	North (337.50–22.50)
		3	Northeast (22.50–67.50)
		8	East (67.50–112.50)
		9	Southeast (112.50–157.50)
		7	South (157.50–202.50)
		4	Southwest (202.50–247.50)
		5	West (247.50–292.50)
		6	Northwest (292.50–337.50)
3	Elevation (m)	1	1091–1142
		2	1142–1193
		3	1193–1244
		4	1244–1295
		5	1295–1346
		6	1346–1397
		7	1397–1448
		8	1448–1499
		9	1499–1550
4	Euclidean distance (m)	3	0–4
		6	4–8
		9	<8

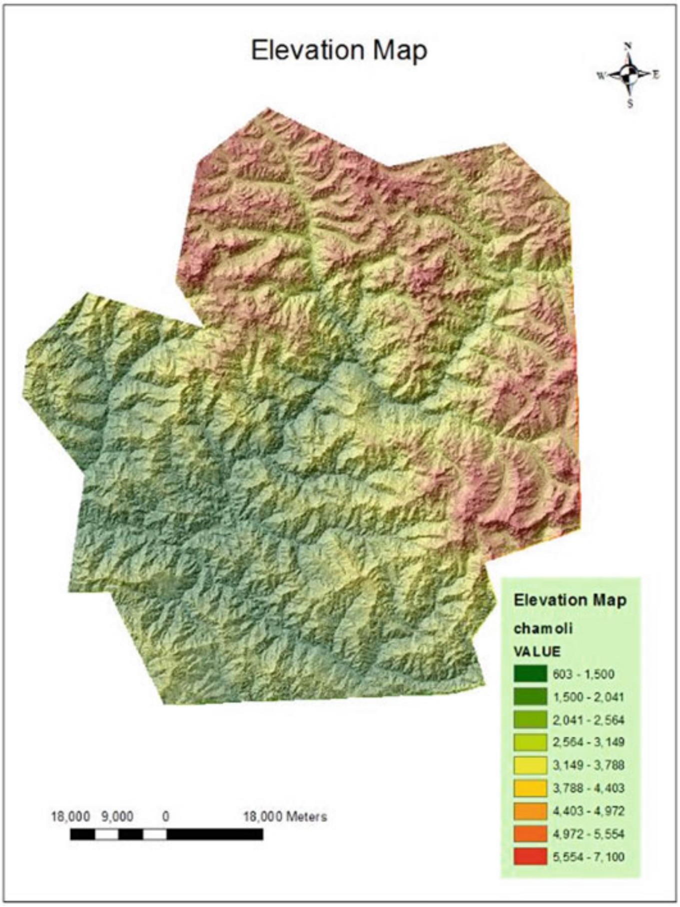

Fig. 4 The elevation map of the area under the study

2.4 Hydrological Parameter

The downloaded DEM has some errors during the collection or interpolation techniques that have been used for the generation of an elevation model. Hydrological parameters are used to correct the data set. First, fill sink is used to remove small imperfection in the raster data, and then a flow direction is created from each cell to its nearest steeper downslope. A weight factor applied to generate raster of accumulation flow into each cell as shown in Fig. 5a. After that, a unique value is assigned to each section of a raster between the intersections, and a numeric order is assigned to each branch of the linear network. A stream to feature conversion converts a raster stream network into features representing a linear network. The stream to feature is used for the generation of the Euclidean distance for each cell to the closest sources

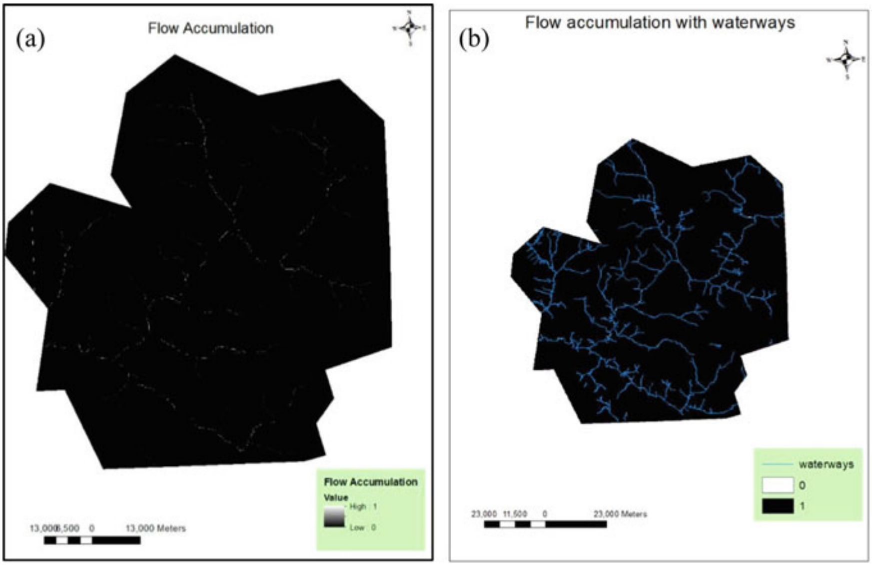

Fig. 5 **a** Flow accumulation map of the study area, **b** flow accumulation map with waterways

and the results show that the waterways and flow accumulation overlap each other as shown in Fig. 5b.

2.5 Rating Scheme Used

The features in the landslide-prone area need to be organized based on their relative importance on the initiation of the landslide. By developing a scheme to assign numerical values to different features the above objective is achieved. In this method, the features are classified into different classes. These classes are formed such that there is unit variance within the class. A numerical weight value from 0 to 9 is assigned to each class in the order of their importance to landslide occurrence, where higher weights indicate greater influence on the landslide. The numerical assignments are given in Table 2.

2.6 Knowledge-Based

Knowledge-Based (KB) is derived from the past landslide occurrences overlapped with the feature set. The KB is used for deciding the suitable weights assigned to each class of the classified features in the numerical assignment step. Table 2 is prepared based on the KB. The feature class that overlaps with the past landslide scars are assigned a relatively higher ordinal number from 0 to 9. The weight and ratings used in the scheme represent the relative significance of different causality factors and the actual field knowledge on them. We have selected the weights using trial and error and matched them with the ground truth obtained from scars. The value of the landslide susceptibility greater than eight indicates higher chances of the landslides. The computation of Landslide Susceptibility Map (LSM) is given by:

$$\begin{aligned} \text{LSM} &= \text{weighted sum of attributes of the data layer} \\ &= [0.5 * \ \Phi + 0.3 * A + 0.3 * H + 0.3 *]. \end{aligned}$$

where

- Φ classified slope angle.
- A classified aspect map.
- H classified elevation map and.
- D Euclidean distance map.

3 Results and Discussions

The combination of all the calculating parameters and different numerical rating scheme, the final landslide susceptible zonation map was prepared and categorized into a low susceptible zone (0) and highly susceptible zone (1) shown in Fig. 6a, b. Figure 6a shows the landslide susceptible zone of all the major known landslides and

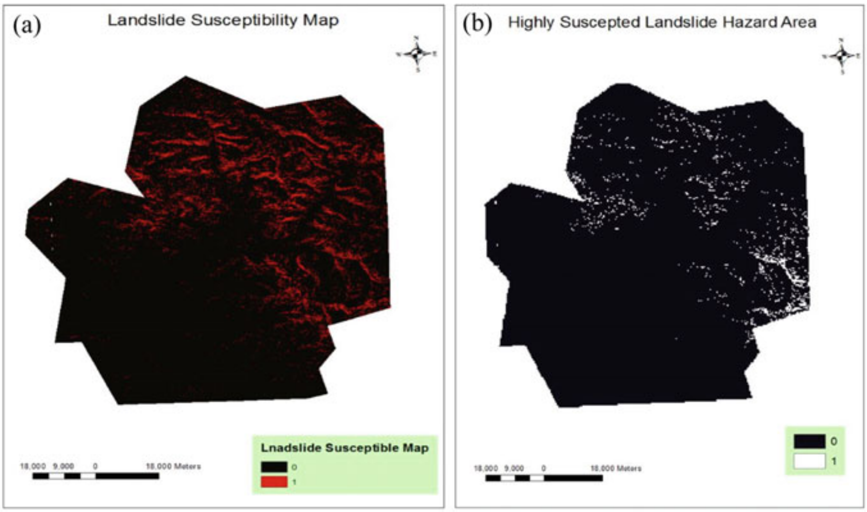

Fig. 6 Landslide susceptible zonation map. **a** The landslide susceptible zone of all the known landslides. **b** Scars and high susceptible landslide hazard area

Fig. 6b shows scars and very high susceptible landslide hazard area, which is very dangerous. Very high and scars susceptible region depicts a higher chance of failure of slopes and it is found to be 8–12% of the study.

Landslide Hazard Zonation (LHZ) map has been prepared using the pre and post landslide scars event shown in Fig. 7. This map shows the level of damage area under the study. The landslide hazard zonation map was finally divided into six hazard levels: very low, low, moderate, high, very high, and scars. The landslide events are also dependent on the climatic condition of the area under study. The allocation of major development and settlements should be avoided in such areas. The present research is an effort to prepare a comprehensive landslide susceptible zonation map of Chamoli district, Uttarakhand. The following conclusion can be drawn on the bases of landslide susceptible zonation map.

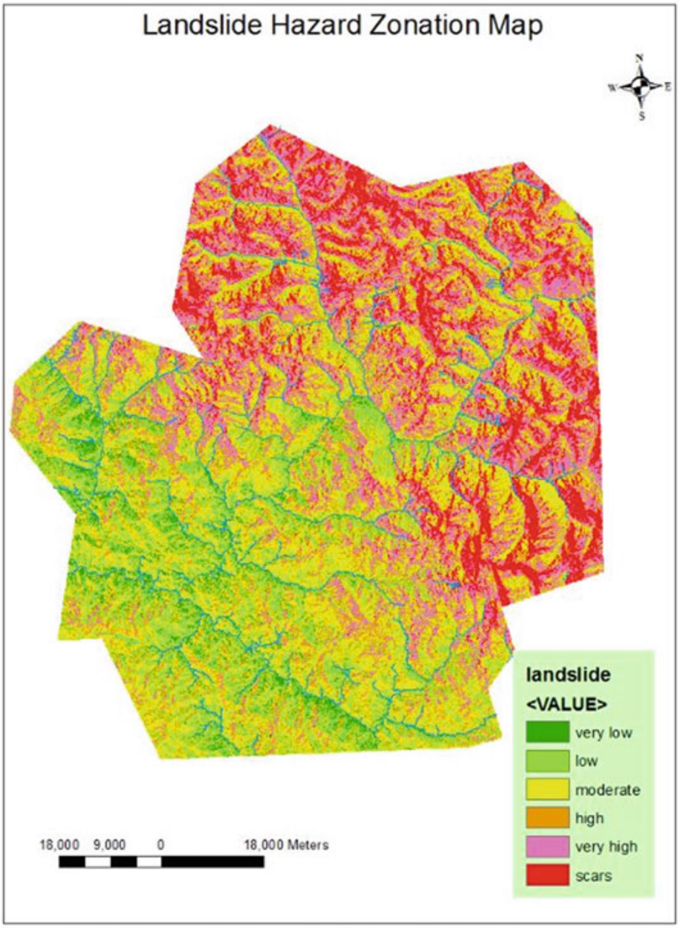

Fig. 7 Landslide Hazard Zonation map derived using a weighted sum of features

Table 3 Range of parameters affecting various landslide

Landslide susceptible zone	Slope (°)	Aspect map	Elevation (m)	Euclidian distance (m)
Scars and high susceptible zone	30–50	South and South-East facing	<1300	<8
Moderate susceptible zone	20–30	West and North-West facing	1200–1300	4–8
Low susceptible zone	>30	Flat and North facing	>1200	>4

1. Scars and very high-susceptibility regions have a very high possibility of slope failure and hydrological parameter effect. This zone occupies as much as 8–12% of the study area. This area contains mainly 30º–50º slope value, south and south-east facing, elevation value greater than 1300 m for this study area, and Euclidian distance which contains hydrological parameters is greater than 8 m.
2. High and Moderate susceptible zone occupies approximate 25–30% of the total area. This area contains mainly 20º–30º slope value, west and north-west facing, elevation values lie between 1200–1300 m for this study area, and Euclidian distance which contains hydrological parameters is 4–8 m.
3. The remaining part of the area occupies a low and very low hazard zonation map. This area contains slope values less than 20º, flat area and north-facing, elevation value less than 1200 for this study area, and Euclidian distance which contains hydrological parameters is less than 4 m. Table 3 gives the ranging of parameters affecting the landslide for the study area.

The contour map has been generated for the study area and is shown in Fig. 8. Landslide susceptible zone can be verified using the contour map of the digital elevation model. It shows that most of the landslide events occur at the high altitude area of the contour map.

Landslide is one of the national disasters in India. It generally occurs in the hilly areas due to the slope failures and results in massive destruction of buildings and human lives. The work depicts an attempt to identify the landslide susceptible map of the area under study in advance using remote sensing. The identification of landslide-prone areas will help in planning and building new structures.

4 Conclusion

The present study has demonstrated that the slope, elevation, aspect ratio, and hydrology have a strong influence on the occurrences of the landslide. The very high and scars hazard zones predicted using the algorithm indicates the geographical unstable area. Slope aspect failures in such areas can be triggered particularly after heavy rainfall. The results show that the slope of 30°–50°, the orientation of southeast

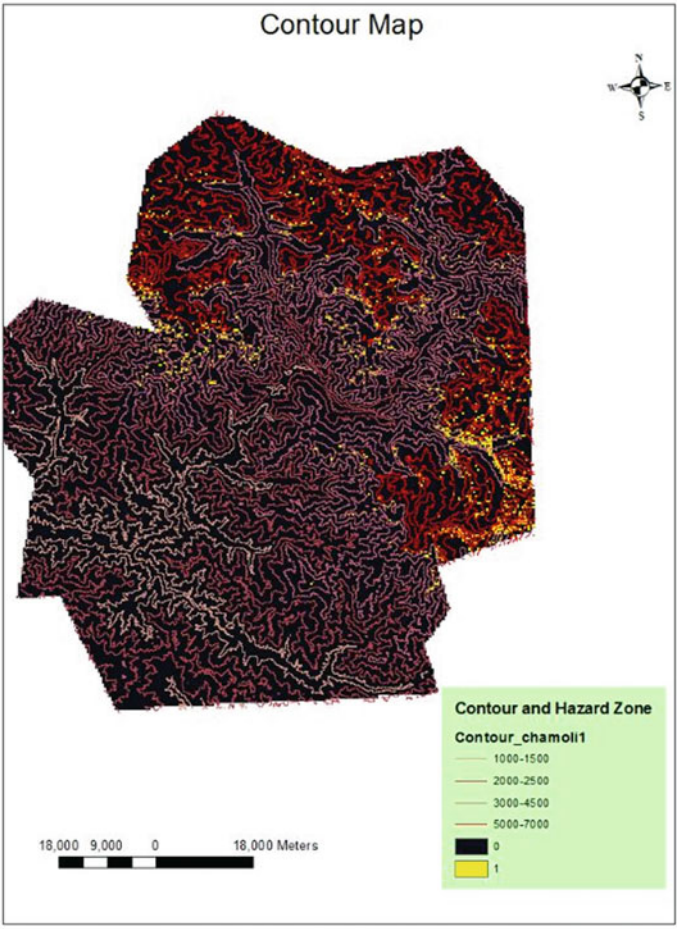

Fig. 8 Contour map showing landslide susceptible area

to east-facing slopes, high altitude region and flow direction play an important role in the occurrences of the landslide. The use of the contour map also validates the prediction of the landslides.

The landslide susceptible and hazard zonation map can be of great help for effective planning in disaster relief events. The occurrence of the landslide is also dependent on seismic activities. It is observed from the map that the population around the landslide susceptible area is meager. The last seismic activity in the study area was observed in the year 1999. The influence of the seismic activities was not considered while processing the information.

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