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Key Landslide Triggers: A Case Study of Upper Alaknanda Valley, Uttarakhand Himalaya, India

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INFORMATION

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ABSTRACT

Heavy rainfall in June 2013 triggered landslides together with river erosion across the state of Uttarakhand in India that culminated in a major disaster. Detailed investigation was carried out in the upper Alaknanda Valley of Uttarakhand Himalaya that was adversely affected by landslides, with an aim to identify key factors triggering slope instability. Correlation of the spatial distribution of landslides with land use, road and streams suggests that proximity to road and drainage network have the strongest influence on landslides occurrence in the area. Ill maintained farm terraces on the slopes and alignment of the road network in proximity of the drainage channels are observed to further influence landslide occurrences. Aligning the road network at a safe distance from drainage network, with provision of rainwater disposal and slope stabilisation measures is therefore recommended. Geological surveys should at the same time precede road construction to avoid unstable and weak zones and proper care should be taken to ensure maintenance of farm terraces on the slopes.

1. Introduction

Reduced strength or cohesion of rock mass or unconsolidated material along the hill slope often promotes these to slide downslope under the influence of gravity, which is identified as a landslide. Instability of in-situ rocks is generally governed by structural configuration, and relationship with slopes.

According to USGS, landslides could be initiated on slopes already on the verge of movement by rainfall, snowmelt, change in water level, stream erosion, change in ground water, earthquake, volcanic activity, disturbance by human activities, or a combination of these. Losses occur when people and their associated structures are exposed to landslides (Froude and Petley, 2018). According to Geological Survey of India (GSI), economic loss due to landslides is estimated to be 1-2% of the gross national product and 80% of the reported landslide fatalities occur in developing countries.

The Himalayan region, particularly the state of Uttarakhand is highly vulnerable to landslides and previous devastating landslides include Sher-ka-danda landslide of 1880, Brewery landslip of 1898, Birahi valley rock fall of 1893, Malpa and

Okhimath landslides of 1998, Phata landslide of 2001, Munsyari landslide of 2010, Okhimath and Uttarakashi landslides of 2012, Uttarakashi, Rudraprayag, Chamoli, Bageshwar and Pithoragarh landslides of 2013 (Atkinson, 1882; Middlemiss, 1898; Rautela and Thakur, 1999; Naithani et al., 2002; Sarkar and Kanungo, 2010; Khanduri, 2018; Rautela, 2018; Khanduri, 2021).

These caused immense losses of human lives, property and infrastructure in the region. Disaster of June 2013 was one of the worst natural disasters faced by the region in recent times. Interaction of SW monsoon with the Westerlies causes exceptionally heavy rainfall in the higher reaches of the state on 16/17 June, 2013.

According to Indian Meteorological Department (IMD), the rainfall in the state between 15 and 18 June, 2013 was 385.1 mm against the normal of 71.3 mm; augmented by 440 percent (IMD, 2013). All the rivers and their tributaries were in spate resulting in damage and destruction along their banks. The most affected districts were Uttarakashi, Rudraprayag, Chamoli, Bageshwar and Pithoragarh.

Temple township of Kedarnath in Rudraprayag district was worst affected by flash food which caused by breach of Chorabari lake situated on the uphill side to the NNW of the town (Dobhal et al., 2013, Rautela, 2013). More than 4000 people died or went missing in this incidence (Rautela, 2013; Khanduri et al., 2018).

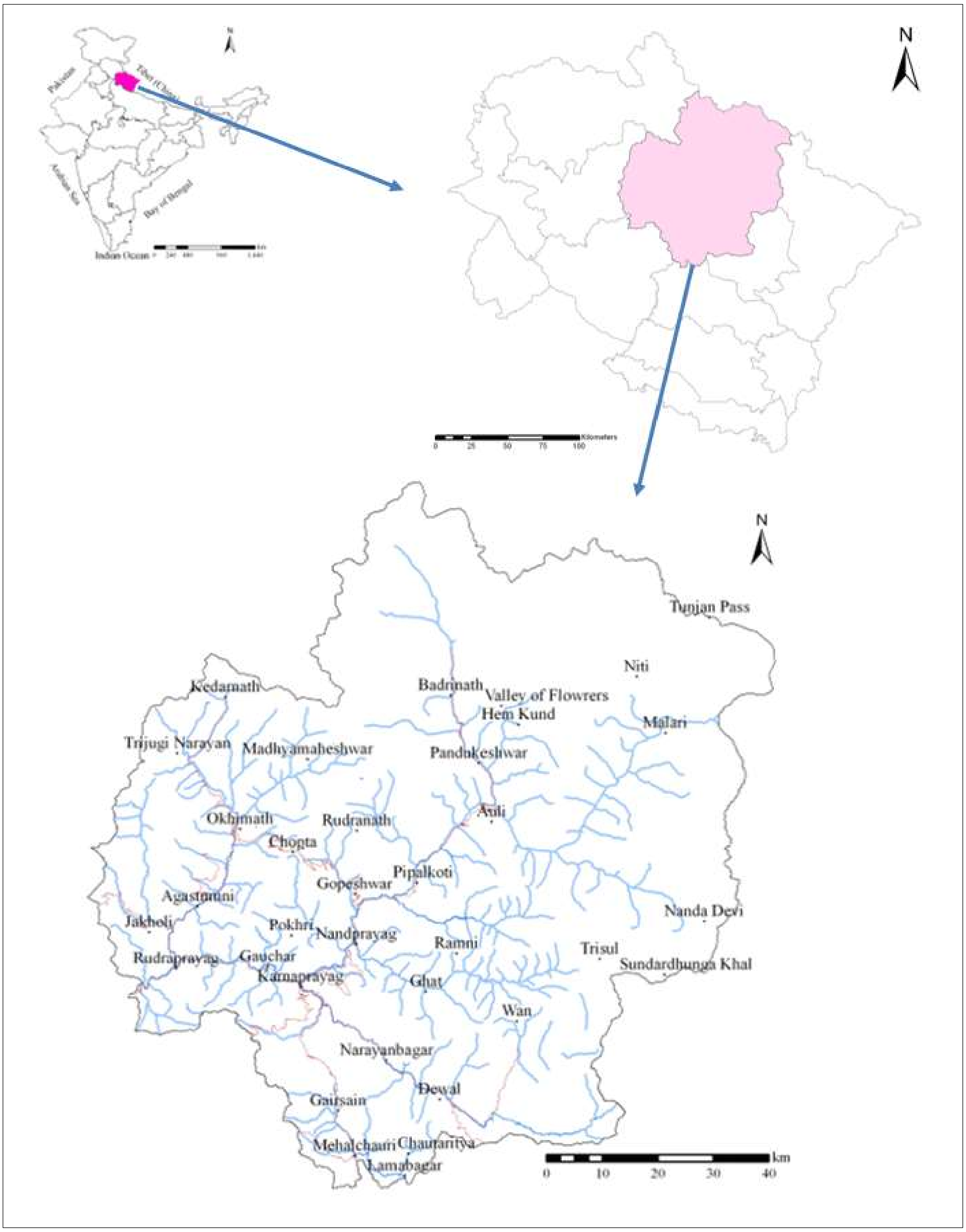

Fig. 1. Location of the study area

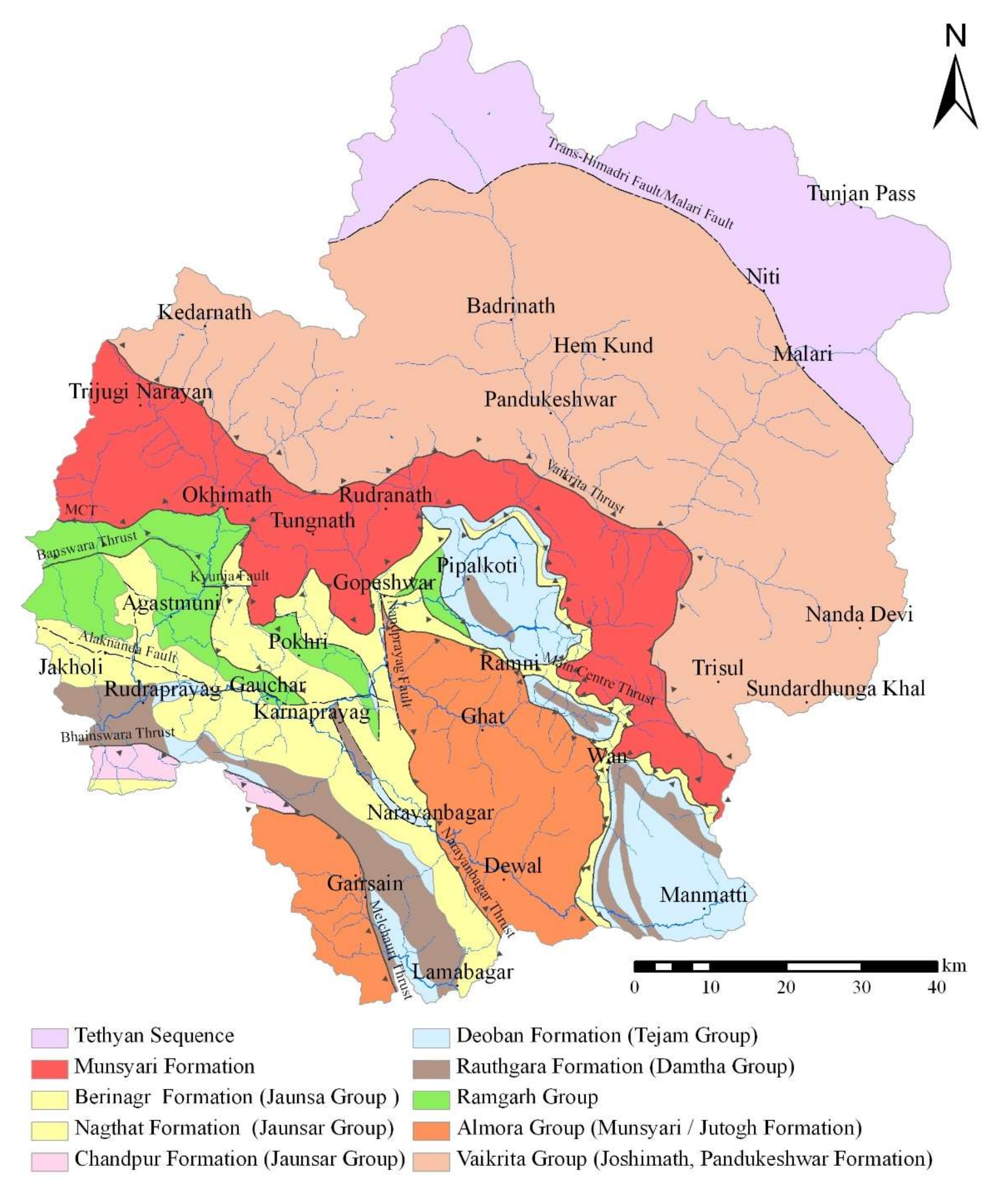

Fig. 2. Map showing geology of the area

Heavy rains and associated floods triggered a number of landslides in the region. In view of landslides vulnerability in the upper Alaknanda Valley, field investigations were carried out for identifying factors influencing slope instability. A total of 510 landslides were identified through field investigations in the upper Alaknanda Valley and these were correlated with drainage, landuse and road network.

Geographical Information System (GIS) is an effective tool that has been utilised for analysis and correlation of various thematic layers (Rautela and Thakur, 1999; Zhou et al., 2002; Ercanoglu and Gokceoglu, 2002; Saha et al., 2005; Pradhan et al., 2012; Sarkar et al., 2013; NIDM, 2014; Khanduri, 2017; Anis et al., 2019; Zhang et al, 2021). Landslides in the upper Alaknanda Valley have been mapped under the GIS environment and correlated with different natural and man-made factors to assess their influence on landslide occurrence.

2. Materials and Methods

2.1. Study area

Present study covers upper Alaknanda Valley that falls in Lesser and Higher Himalaya and is bound by 78° 47’ 45” E and 80° 06’ 41” E longitudes and 31° 05’ 28” N and 29° 55’ 29” N latitudes (Fig. 1). The area covers Rudraprayag and Chamoli districts of Uttarakhand and falls in Zone V of Earthquake Zonation Map of India (IS 1893, 2002).

Being strategically important the area is well connected by road network of which Rishikesh-Badrinath (National Highway 58) and Rudraprayag-Kedarnath (National Highway 107) are an integral part. Major townships of the area include Rudraprayag, Karanprayag, Nandprayag, Chamoli, Gopeshwar, Joshimath and Badrinath are situated along the National Highaway 58 while Tilwara, Agastmuni, Chandrapuri, Guptkashi, Sitapur, Sonprayag and Gaurikund along the National Highway 107. Rishikesh is the nearest rail head while located in close proximity of Dehradun, the capital of Uttarakhand state, Jolly Grant is the nearest airport. The study area also has an air strip at Gauchar.

2.2. Geology and geomorphology

Higher Himalayan Central Crystalline rocks are thrust over Lesser Himalayan Garhwal Group of rocks along a north dipping Main Central Thrust (Fig. 2). The Garhwal Group of rocks of Lesser Himalaya are observed to comprise of low-grade meta-sediments that are intruded by acidic and basic igneous rocks. To the north of MCT zone, Helang Formation represents low to medium grade rocks of green schist facies whereas Joshimath, Pandukeshwar and Badrinath formations constitute medium to high grade rocks of amphibolite facies which are separated by Vaikrita Thrust. Sedimentary rocks of Tethyan Sequence are exposed over the rocks of Central Crystallines across Trans - Himadri Fault/ Malari Fault (Auden, 1949; Heim and Gansser, 1939; Valdiya, 1980; Valiya and Goel, 1983; Valdiya, 1989).

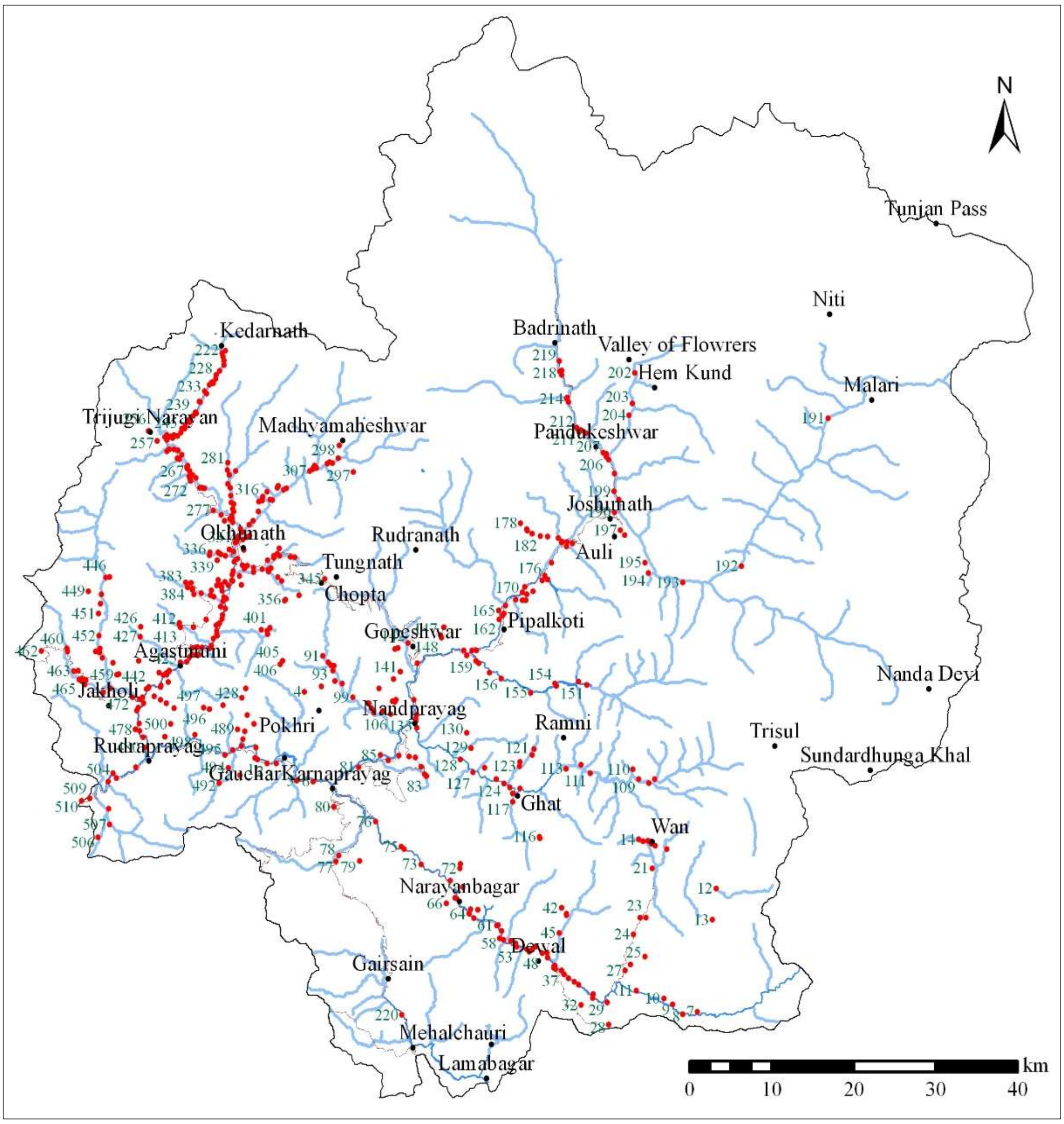

Fig. 3. Map showing distribution of landslides in the study area

Alakanda river originates from Satopanth Glacier and flows from NW-SE direction till Vishnupryag where it has confluence with Dhauliganga that originates from Niti Pass and flows northwest. Nanda Devi peak with an altitude of 7817 m asl in the Dhauliganga Valley is the second highest peak of India. From Vishnuprayag to Gauchar, Alaknanda river flows NE-NW and thereafter flows East till Rudraprayag where it has confluence with Mandakini river that originates from the glaciers of Chorabari and flows NNE-SSW course. Alaknanda has confluence with Bhagirathi at Devprayag and thereafter the river is known as Ganga. Upper Alaknanda Valley has rugged mountainous topography showing high relative relief with altitudes varying between 550 m and 7817 m asl. The topography is intervened by narrow along with "V" shape valleys and gorges particularly in upper reaches whereas wide valleys and meanders channels in lower reaches that appears to be controlled by geology and structural setup.

2.3. Procedures and tools

Under the present study the distribution of landslides observed in the upper Alaknanda Valley have been correlated under GIS environment with various factors influencing their occurrence.

i. Handheld GPS has been utilised for accurately geopositioning the observed landslides.
ii. Survey of India toposheets have been utilised for elevation data and preparing slope map and digital elevation map.
iii. Road network data of Survey of India toposheets has been updated from Public Works Department of the state government that is responsible for planning of construction of roads in the state.
iv. Survey of India toposheets have been utilised for preparing drainage network as well as landuse maps of the area.
v. Geological and tectonic maps of the area compiled from various published sources have been updated on the basis of the relevant data collected by fieldwork.
vi. Arc Info 9.3 software has been utilised for GIS based correlations.

3. Landslides and Their Correlation with Key Factors

3.1 Landslides

510 landslides; 290 in Rudraprayag district and 220 in Chamoli district have been identified and studied through field investigations in upper Alaknanda Valley (Fig. 3). On the basis of movement and rigidity of material comprising the slide mass, bed rock, debris and earth, these are classified as debris/bouldery debris slide, rock cum debris slide and rock slide/fall (Varnes, 1978; Cruden, 1991). Of the identified slides 68 percent are observed to be debris/bouldery debris slide (Table 1). This suggests that saturation of overburden or debris material by prolonged heavy rainfall and associated flood is responsible for initiating most slides of the area.

Table 1. Summary of different type of landslides observed in the study area

No	Landslide type	Number of slides
1	Debris/bouldery debris slide	346
2	Rock cum debris slide	141
3	Rock slide / fall	23
	Total	510

Spatial distribution of landslides is correlated with various layers to assess their influence on the occurrence of landslides in the area. For this the relationship between distribution of landslides in absolute numbers and their density within individual parameter class of the thematic layers is considered.

3.2. Land use

For the purpose of present study land use map of the area is classified into eight simple classes; agriculture, barren land, open forest, dense forest, scrub forest, built up area, water body and glaciated area. Large portion of the study area (28.4 percent) is observed to be glaciated while 24.6 and 11.6 percent respectively fall under dense and open forest cover. Agriculture and barren land in the study area account for 9.6 and 12.1 percent of the area respectively.

As is expected none of the slides fall in water body, built up area and glaciated area. Most landslides (35 percent) are observed to fall under the land use category identified as agriculture land and only 12 percent fall under scrub forest and barren land classes. An overwhelmingly large proportion of landslides (> 50 percent) fall under open and dense forest classes. Density of landslides in different land use classes is also observed to follow this trend and only dense forest class with high number of landslides and low landslide density deviates from this trend (Fig. 4).

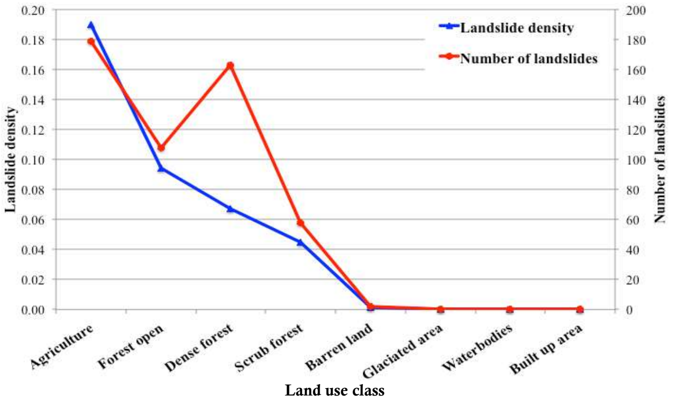

Fig. 4. Diagram showing distribution of landslides and landslide density (number of landslides/sq km) in various land use classes in the study area

3.3. Drainage

Toe erosion by streams is often cited as one of the most common causes of landslide initiation and therefore distance from the streams is taken as an important parameter while assessing landslide susceptibility of any area. Under the present study buffers of 50 meters each are drawn around the trace of streams and the distribution of landslides with increasing distance from the trace of the drainage is studied. It is observed that number of landslides show continuously decreasing trend with increase in distance from the trace of the streams (Fig. 5) and almost 68 percent of the landslides are located within 100 meters from the stream.

3.4. Road network

Interaction with the masses in the field brought forth an important fact that many areas that were hitherto not affected by landslides have become chronically prone to landslides after the construction of roads in the area. It was therefore imperative to study the relationship of landslides with the road network in the study area. Buffers of 50 meters each are therefore drawn around the trace of the roads and the distribution of landslides is accordingly studied.

Almost 42 percent of the landslides are observed to be located in proximity of the road, i.e., within 50 meters. Both landslides in absolute numbers and landslide density show strong positive correlation and show a decreasing trend as one moves away from the road (Fig. 6).

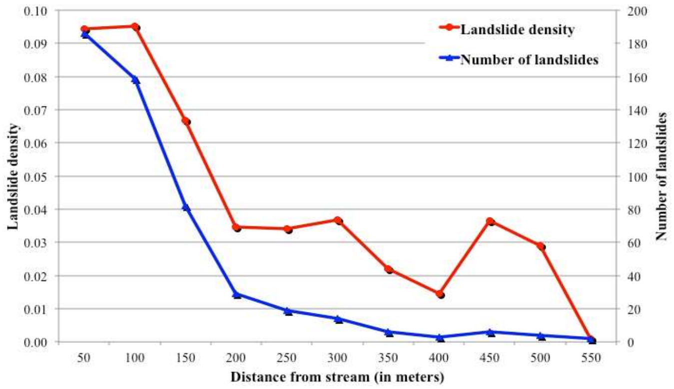

Fig. 5. Diagram showing distribution of landslides and landslide density (number of landslides/sq km) with increasing distance from the trace of the streams

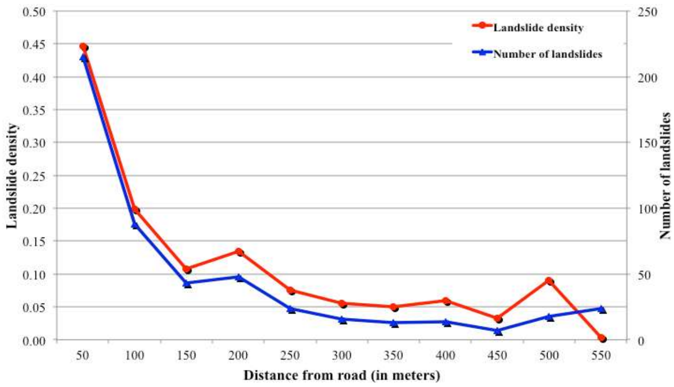

Fig. 6. Diagram showing distribution of landslides and landslide density (number of landslides/sq km) with increasing distance from the trace of the roads

Based upon this observation it is concluded that landslide occurrence in the area is highly influenced by spatial distribution of roads and going away from the road probability of getting affected by landslides diminishes. Both, landslides in absolute numbers and landslide density, show positive correlation and show a decreasing trend as one moves away from the streams. Based upon this observation it is concluded that landslide occurrence in the area is highly influenced by spatial distribution of streams and going away from the stream the probability of getting affected by landslides diminishes.

4. Results

In the present study spatial distribution of 510 landslides identified and mapped in the upper Alaknanda Valley of Uttarakhand is correlated with land use, stream and road network with a premise that both landslide density and landslide numbers should show a strong positive correlation in case the said parameter has overwhelming impact on the occurrence of landslides.

Individual layers pertaining to land use, road, drainage and landslide are prepared under GIS environment and the correlations are subsequently undertaken. These suggest that the land use categories showing maximum landslide occurrences and density are represented by agriculture and forest classes and the barren land that is generally conceived to host most landslides accounts for insignificant numbers. The reasons thereof might well be local and are therefore required to be investigated.

As regards landslide and landslide density relationship with stream and road network are concerned both show a positive correlation and particularly strong correlation is observed with road alignment. It is therefore concluded that these parameters are largely responsible for landslide occurrence in the area.

5. Discussion and Conclusion

Field observations and inputs of the masses, as also correlations undertaken suggest that large proportion of the landslides in the recent times are getting initiated from the unmaintained and damaged agricultural terraces. Rainfall induces high-density flow from these damaged fields that attain damaging proportions in the downslope areas. Incentives to the masses by way of effective forward and backward linkages for the marketing of the agro-produce could help in routine maintenance of the agricultural terraces.

The landslides in the study area are largely concentrated in proximity of the road and river/stream. The relationship of these two parameters on the distribution of landslides therefore requires special attention. Field observation suggests that most roads are aligned parallel to and in close proximity of the drainage network. The same is corroborated by the correlation of the two parameters that shows that more than 50 percent of the total road length in the area is located within 100 meters of the drainage channel (Fig. 7).

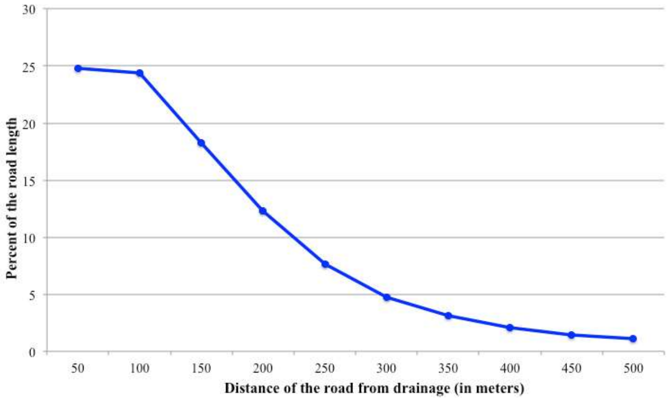

Fig. 7. Figure depicting the relationship of percent of the road length of the study area with increasing distance from the drainage

The study reveals that road construction is the major contributor to the menace of landslides in the study area and therefore the solution to this problem has to be searched in the current practice related to road building. It is recommended the disposal of all excavated material in the hills be regulated and ensured that the same is disposed of only at pre-identified and duly notified sites. For this putting in place a robust and legally binding debris disposal policy is suggested. Measures for slope stabilization and rainwater disposal should also necessarily accompany road construction.

Based upon the findings of the present study it is highly recommended that, to the extent feasible roads should be aligned away from drainage channels and at higher elevations.

These measures if put to practice in letter and spirit would help in minimizing the problem of landslides in the area. In the beginning implementation of these measures would certainly require additional financial resources that might seem burdensome but these are sure to fetch rich dividends by way of savings in terms of road maintenance, manpower, environment and resources.

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