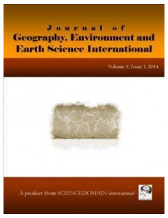

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Inventory of Active Landslides and Landslide Hazard Assessment Using Field Techniques and Remotely Sensed Data: A Case Study from Balkhila Sub-Watershed (Uttarakhand, Himalaya)

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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Case Study

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ABSTRACT

This paper presents landslide hazard assessment in and around Balkhila sub-watershed of Uttarakhand, Himalaya using remote sensing data and Geographical Information System. IRS-IC LISS III, RESOURCESAT LISS-IV remote sensing data products along with Survey of India (SOI) topographical sheets accompanied by field investigations were used to generate a landslide inventory map of the study area. Such type of information on slope stability of the area could be useful for explaining the known existing landslide, helping to make emergency decisions and relieving the efforts on the avoidance and mitigation of future landslide hazards in the area.

Keywords: Balkhila watershed; active landslide; landslide hazard assessment; inventory of landslide; remote sensing; geographic information system.

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1. INTRODUCTION

Garhwal and Kumaun regions of Uttarakhand Himalayas are seismically and ecologically very sensitive domains. The variety of ecosystem that it supports is, therefore, fragile so that even a very small disturbance triggers changes that rapidly assume large scale disaster. Among various natural hazards, landslide has become a frequent threat, invariably associated with deforestation and road building activity [1,2]. It has been observed that watersheds proximal to Main Central Thrust (MCT) are most terribly affected by recurring incidences of landslides. This is a zone of crushed and pulverised lithology with gigantic cones and fans of old landslide debris resting on the steep slopes on either side of it [3].

The Balkhila Watershed of Chamoli District in Uttarakhand, Himalayas has high landslide hazard and creates a major disaster in the area every year. However, the available information on the landslides in the Balkhila region is still limited. Gangolgaon-Ghingran cloudburst event (August, 1991), Bandwara landslide (August, 2007) (Plate1) and Siron landslide (July, 2017) are some of the burning examples that have caused large-scale human tragedies, material damage and associated environmental and social hazards in this region.

Landslides are a type of “mass wasting” which denotes any downslope movement of soil and rock under the direct influence of gravity. The term “landslide” encompasses events such as rock falls, topples, slides, spreads, and flows [4]. Landslide maps are very important for documentation of the extent of landslide phenomena in a region. Investigation of the landslide covers distribution, types, pattern, recurrence and statistics of slope failures. It is useful to determine landslide susceptibility, hazard, vulnerability and risk, and to study the evolution of landscapes dominated by mass-wasting processes [5].

1.1 Study Area

Balkhila River constitutes an important watershed of Alaknanda basin situated between Tungnath and Rudranath in the Garhwal Himalayan range and forms a part of District Chamoli Garhwal. It lies between 30°23′ N to 30°33′ N and 79°10′ E to 79°23′ E (Fig. 1). It drains water from Amrit Ganga, Vir Ganga, Bhaus Gad, Gabni Gadera, Bhuranshi Gadera, Bhrigu (Veer) Ganga, Dewariya Gad, Paseli Gad and Bhaunta Gad. Balkhila River highly influences the geographical, physiographic and environmental variability of the entire watershed. The average altitude varies from 945m to 4700m above sea level with steep hills covered with oak and conifer mixed forests. The watershed covers an area of approximately about 160 sq. km with lush natural resources affecting the socio-economic and cultural lifestyle of the local people.

Plate 1. Impact of Bandwara landslide (August 2007) on agriculture and settlement

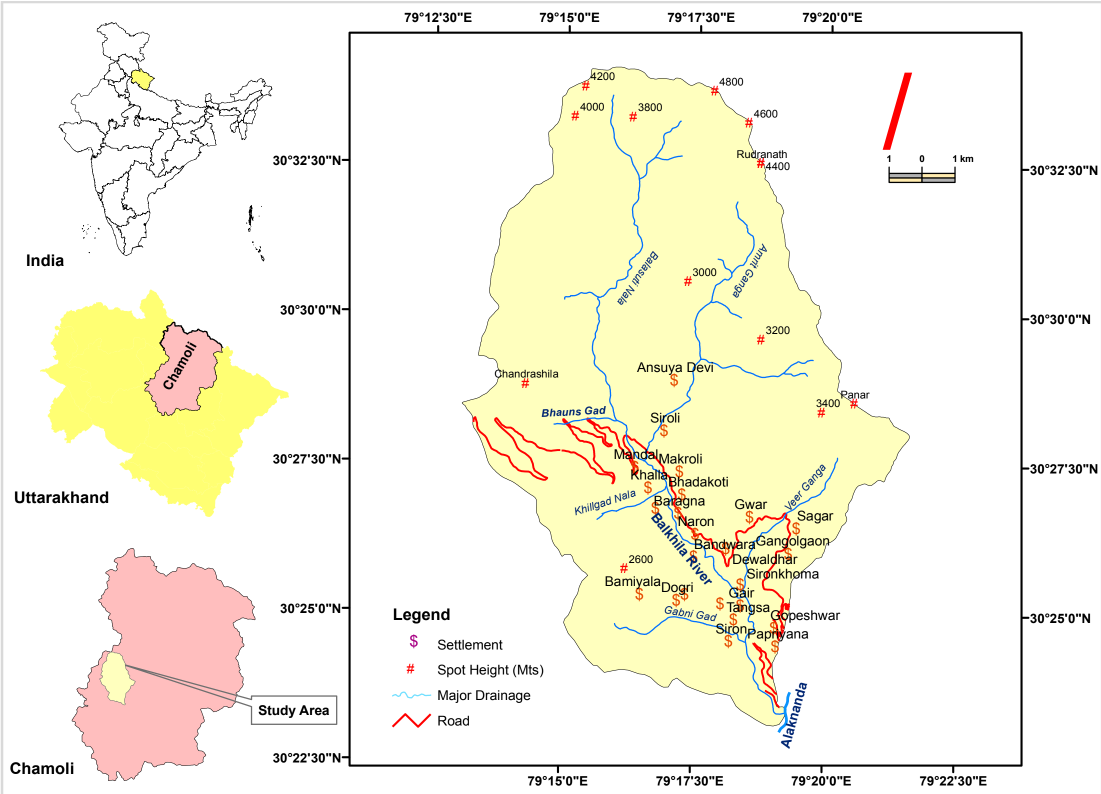

Fig. 1. Location map of the study area

1.2 Geological Setting

The study area lies in the north central part of the Garhwal Himalaya and geologically it has been studied in detail [6,7,8,9,10,11].

The Balkhila River flows through different litho-tectonic units from NE-SW direction. The study area is structurally highly complex with several thrust-faults and folds. The MCT passes across the central part of the study area. The MCT zone separates the Lesser Himalayan Formations from the overlying Higher Himalayan Central Crystallines. The rocks exposed in the region belong to the Garhwal group of rocks, which are thrusted over by central crystalline along the MCT zone, in the north. The rocks of Garhwal Group are low-grade in terms of metamorphic and mainly comprise of slate, phyllite and quartzite.

2. DATA USED AND METHODOLOGY

The spatial distribution of the presently active landslide of the area was mapped using satellite supported by field verification and GPS recording for precise location. Interpreted maps were verified on the ground and mapping of landslide zones was carried out. Correlation of data regarding ground conditions of major lithological units, geological structure, geomorphological features Land use features and other parameters was done as derived during pre-field interpretation. Ground truth data with respect to physical properties of various rock units and structural features were collected.

Topographical Sheets at 1: 50,000 (53N/3, 6, 7) and 1: 25000 (53 N7/NW, SW) from Survey of India were used for ground survey and preparation of base maps viz., road, settlement, drainage, topography etc. IRS-IC LISS III (24-meter resolution), RESOURCESAT LISS-IV remote sensing data products, existing geological map. Field data collected from field checks were used for the assessment of Landslide hazard in the area. Erdas Imagine 9.2 and ArcGIS 9.2 were used for the image processing.

2.1 Inventory of Landslides

A "landslide" is the movement of a mass of rock, debris, or earth down a slope, under the influence of gravity [4]. A landslide inventory map records the location and, the date of occurrence and the types of mass movements that have left discernable traces in an area [12,13,14,15]. Landslide maps can be prepared using different techniques [16]. Landslide inventories are the basis for assessing landslide susceptibility, hazard and risk [17,18,19,20] detection and identification of landslide zones are the key in any study dealing with landslides hazard assessment. Landslide hazard zonation is the first step towards Disaster Mitigation in the event of landslide [21]. For this, identification of the landslide zones and landslide inventory is an essential part of the landslide hazard and risk assessment.

2.2 Identification of Landslides on Remote Sensing Data

Landslides were identified from the remote sensing data. It is demonstrated that the visual observation of the landslides and associated features holds the key and it can be explained in terms of morphology, vegetation and drainage conditions of terrain in a systematic manner [22]. This highlights the fact that techniques developed on aerial photographs can be extended to a great extent by using high-resolution data sets and multispectral as well as temporal observation, which was not possible with aerial photography in the past. Therefore, it is essential to analyse all visual interpretation keys and technique, generic as well as specific for landslides using satellite datasets. Digital remote sensing products are proved to be beneficial in mapping landslides in remote and inaccessible areas due to high resolution [23].

Landslide identification keys consist of a large set of parameters that contribute to identify a landslide and map its extent. These keys consist of a set of parameters that are related to purely spectral properties. Different types of landslides characterised by different movement (fall, topple, slide-rotational/translational, flow, spread and complex) and material types (rock, debris etc.) can be identified on satellite imagery to a varying extent.

2.3 Satellite Data Analysis

Satellite data analysis was carried out for identification of the active landslides in the region. The base map was first georeferenced in ERDAS Imagine 9.2. Similarly the LISS-III image was geo-referenced with respect to the base map into UTM projection system with the unit expressed as meters. The projection system used in the layers was UTM, zone 44; spheroid – UTM WGS 84 North and datum-UTM WGS North. A subset of the study area was made after georeferencing these layers. Digital Image processing was carried out for mapping of landslides from the image in GIS environment. Some common digital image processing techniques like image enhancement, filtering, data scaling and principal component analysis were deployed for smooth visual interpretation of the image. Image enhancement improved the information content of the Satellite image. One of the important tasks was to delineate the various linear features in the study area. The 7x7 edge enhancement (Fig. 4) and 3X3 high pass filter were performed in ERDAS Imagine 9.2. In the present work principal component analysis for red, green, and the blue band was derived. This helped in identifying the active landslide zones and preparation of active landslide distribution map (Fig. 4).

2.4 Visual Interpretation and Field Work

First of all, each landslide type was characterised with a peculiar diagnostic feature of known landslide and then those recognised features were applied to identify landslides of the remaining parts of the study area. The diagnostic features include shape, size, colour, tone, texture, pattern and topography of landslides. A total of 62 small, medium, and large landslides were identified on the basis of visual interpretation of satellite data.

Visual interpretation of the LISS III data (Fig. 2) and extensive field check of the landslides throughout the area has been carried out with the help of Global Positioning System (GPS) for identification and mapping of active landslides. Out of 52 landslides identified on the satellite data, only 26 prominent and accessible landslides were taken under consideration for detailed inventory (Fig. 3).

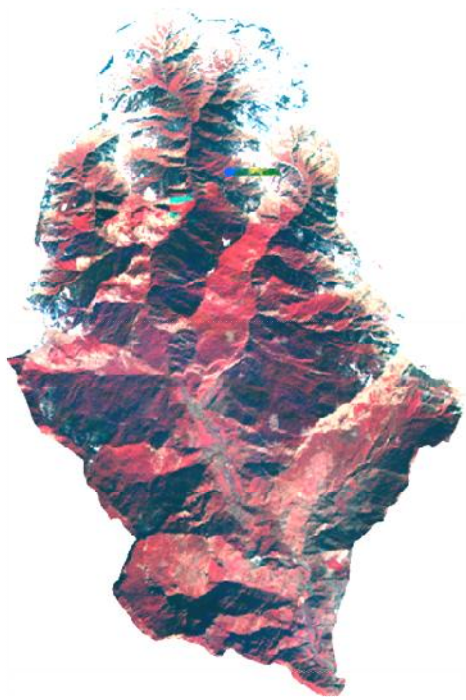

Fig. 2. Satellite imagery (LISS III) of the study area

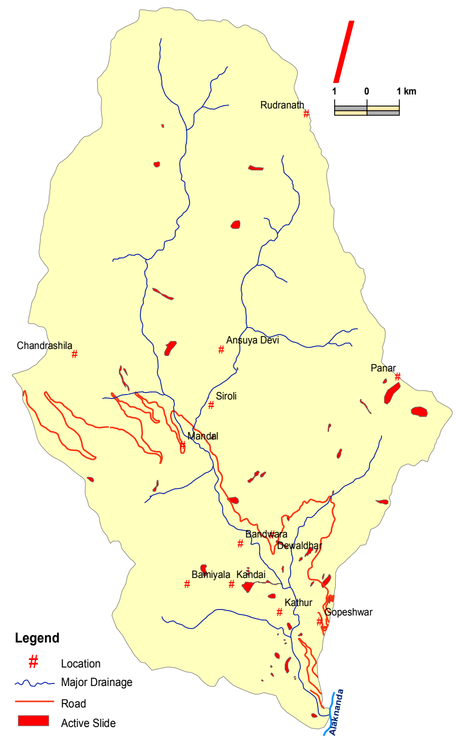

Fig. 3. Landslide distribution map of the study area

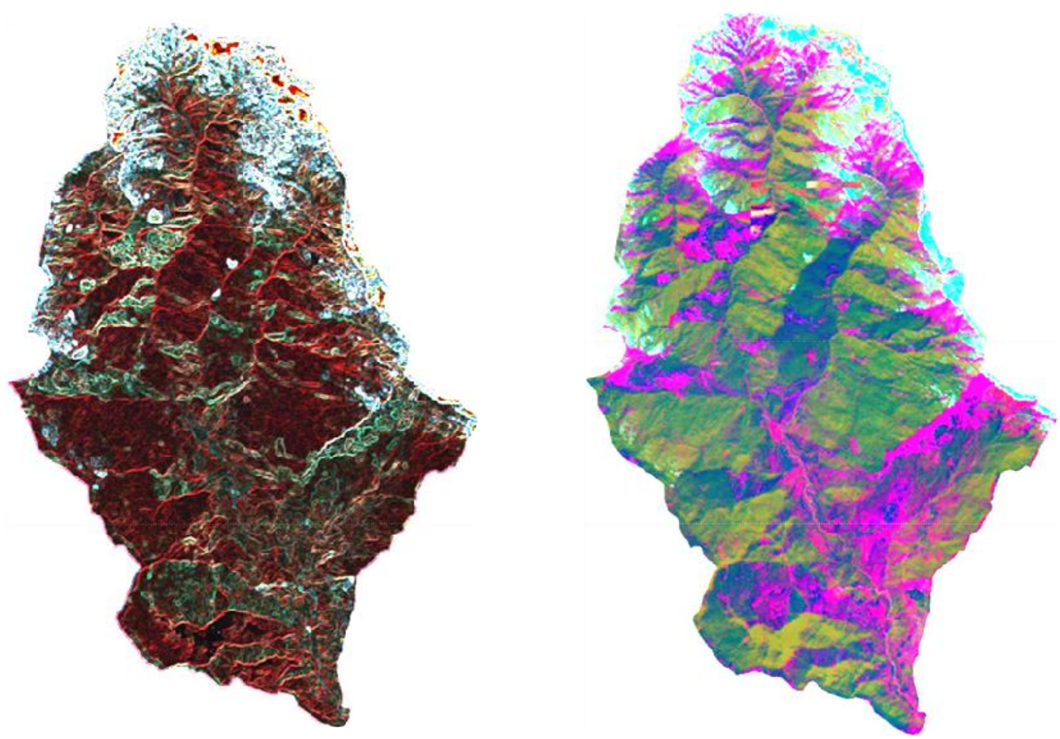

Fig. 4. Digital image processing techniques applied in LISS-III image of study area

Table 1. Inventory of Landslides in Balkhila catchment area, Uttarakhand

Sl. no.	Location	Lithology	The attitude of the bed	Joint plane	Slope, Aspect, Morphology	Landslide dimension (H-Height W-width in meter)	Causes of failure / Affect
1.	30°24′06″ 79°19′47″ 987 amsl Chamoli 1km milestone	Highly weathered quartzite	N 170°/ 10	N 30°/ 48 N 89°/33	> 60° N 85° Concave	H-25 W-10	Both the joints are responsible for the failure. Active rock fall-wedge failure, seepage and road cutting affecting the road section.
2.	30°23′49″ 79°18′54″ 1165 amsl 0.5 km from kothiyal Sain	Mainly debris material surrounding rock type is quartzite.			45-60° N280° Straight	H-25 W-10	Both the joints are responsible for failure, active rock fall “wedge failure”, affected road length is 25mt.approx.
3.	30°23′51″ 79°18′52″ 1148 amsl	Moderately weathered quartzite	N 320°/ 25	N 155°/ 85	> 60° N 250°	H-35 W-20	Joint and weathered material responsible affecting nearly a road length approx. 30 mt.
4.	30°24′08″ 79°18′48″ 1179 amsl nearGweelon	Highly weathered quartzite	N 295°/ 50	N 110°/ 59	80° N 210° Straight	H-20 W-35	Slope more than dip, active rockfall, joint, weathering and Chamoli earthquake, affecting Chamoli–Gopeshwar road
5.	30°24′10″ 79°18′47″ 1187 amsl	Highly weathered Quartzite	N 275°/ 39	N 130°/ 85	N 285° Straight	H-25 W-65	Active rock fall due to 1999 earthquake, road cutting at Pokhri bend.
6.	30°26′42″ 79°21′54″ 1875 amsl	Debris material with fragments of phyllite & quartzite.			45° N 280° Straight	H_1 -20 W-10	Active debris slide, seepage and accumulated debris material is the main cause of the landslide.
7.	30°26′22″ 79°21′31″ 1650 amsl	Debris material fragments of phyllite, quartzite and schist			45-60° N 125° straight	H-15 W-50	Active, debris slide, road cutting, weathered material
8.	30°25′44″ 79°20′59″ 1640 amsl	Debris material consisting of fragments of phyllite, quartzite and schist			25-35° N 170° concave	H-100 W-100	Active debris slide weak weathered material
9.	30°25′14″ 79°19′46″ 1518 amsl	Debris material consisting of fragments of phyllite, quartzite, gneisses			30-60° N 170° straight	H-50 W-40	Active debris slide affecting road length ~70mt

Sl. no.	Location	Lithology	The attitude of the bed	Joint plane	Slope, Aspect, Morphology	Landslide dimension (H-Height W-width in meter)	Causes of failure / Affect
10.	30°23′18″ 79°18′33″ 1469 amsl	Moderately weathered Quartzite	N 190° / 32	N 95° / 50	45° N 145° straight	H-20 W-25	Active Rockfall, joint and fissured rock is the main cause of slide.
11.	30°23′45″ 79°18′08″ 1389 amsl	Highly weathered quartzite	N 205° / 32	N 35° / 90	80° N 50° straight	H_1-25 W-30	Active rock fall, Joint and fissured rock is the main cause of the slide
12.	30°22′22″ 79°18′19″ 1010 amsl	Mainly debris material surrounding highly weathered low grade metamorphics			> 60° N 190° straight	H_1-20 W-60	Active debris slide/ rock fall weak and weathered material.
13.	30°22′35″ 79°18′26″ 1051 amsl	Phyllites and slates			30-45° N 150° straight	H_1 -25 W-30	Active rock/debris slide blocking local nala and affecting 100 mt of road length, the cause is weak & weathered material.
14.	30°22′38″ 79°18′26″ 1051 amsl	Debris/loose material consisting of low grade metamorphics			45-60° N 145° straight	H_1 -15 W-100	Active debris slide affecting 150 mt. of road length, the main cause is weak & weathered material.
15.	30°25′47″ 79°18′14″ 1220 amsl Pipalkana-Kathur	Debris/loose material consisting of slate and phyllites			> 60° N 80° straight	H -50 W-35	Active debris slide due to seepage from Pilang canal. weak weathered material
16.	30°22′47″ 79°18′31″	Moderately weathered quartzite	N 170° / 22	N 342° / 72	45-60° N 225° concave	H -25 W-40	Active “wedge failure” the joint plane, road cutting is the cause of landslide affecting road
17.	30°22′50″ 79°18′47″ 1107 amsl	Low weathered quartzite	N 270° / 55		> 60° N 230° straight	H-25 W-50	Active debris, slide affecting road length around 100 mt
18.	30°22′52″ 79°19′05″ 1072 amsl	Debris/loose material consisting of slate and phyllites			> 60° N 78° straight	H-20 W-35	Active debris slide, weak weathered material, affecting nearly road length of 40 mt.

Sl. no.	Location	Lithology	The attitude of the bed	Joint plane	Slope, Aspect, Morphology	Landslide dimension (H-Height W-width in meter)	Causes of failure / Affect
19.	30°22′56″ 79°19′04″ 986 amsl	Debris/loose material consisting fragments of quartzites, phyllites			25-30° N 128° straight	H -15 W-65	Active debris slide, weak/weathered material causing the slide
20.	30°23′16″ 79°19′05″ 985 amsl	Debris/loose material consisting fragments of quartzites, phyllites			25-30° N 80° straight	H-20 W-30	Active debris slide, weak/weathered material is cause affecting nearly 40 mt of road.
21.	30°25′57″ 79°17′59″ 1538 amsl	Low grade metamorphic mainly mica schist	N 290° / 20		25-30° N 198° straight	H-15 W-10	Active debris slide jointed and weak material affecting 25 mt of road length
22.	30°25′51″ 79°18′13″ 1571 amsl	Debris material consisting of fragments of quartzites, slates			25-35° N 145° straight	H-30 W-40	weak material affecting 50 mtr of road length
23.	30°25′58″ 79°18′16″ 1585 amsl	Debris/loose material consisting fragments of quartzites, phyllites			25-35° N 123° straight	H_1 -35 W-100	The road is subsiding around 1 mt per year. Affecting agriculture fields and road.
24.	30°26′31″ 79°19′03″ 1681 amsl	Debris/loose material consisting of low grade metamorphics			40-60° N 178° straight	H-40 W-20	Weak weathered materials are responsible for the slide. affecting road.
25.	30°25′39″ 79°18′59″ 1701 amsl	Highly weathered quartzite	N 350° / 30	N 215°/59	15-30° N 250° Straight	H_1 -40 W-50	Joint weathered and fissured material affecting road length about 60mt
26.	30°25′24″ 79°18′52″ 1643 amsl	Highly weathered quartzite	N 350° / 10	N 160° / 49	>45° N 160° Straight	H_1 .100 W-500m	Affecting road, vegetation, agriculture field and rehabilitation

3. DISCUSSION AND CONCLUSION

The present study was carried out with the objective for investigating the problem of landslides and other mass wasting movement in Balkhila catchment encompassing a geographical land surface of about 160 km^2 in the district of Chamoli of Garhwal Himalaya. Remote sensing technique with field investigation was used for generation of inventory of landslides in the present study. Both the techniques in combination were proved to be useful as it saved lot of time as well as man-hours.

The LISS III satellite imagery is composed of blue, green, red, and near-infrared wavebands. The landslide has a stronger reflectance than other land covers in the green and red wave bands. However, in the near-infrared wave band, vegetation reflects the near-infrared more strongly than bare soil (landslide). It has been found that LISS III data is quite useful for terrain feature extraction, analysis and synthesis. Active Landslide distribution map and inventory of landslides are quite useful for assessing the hazard associated with landslides in the region.

Geologically, the study area represents the complex structural pattern. Tectonic activities have lead to adversely oriented structural discontinuities including faults, unconformities, flexural shears and adversely oriented mass discontinuities (including bedding, schistosity, cleavage) that form the main cause of frequent landslides in the area. The structure includes bedding, joints, foliation, fault and thrusts. The structural discontinuities in relation to slope inclination and direction have a great influence on the stability of slopes.

Lithology plays a major role in slope stability. Weaker and fragile rocks such as phyllites of Chamoli group exposed around along the road of Gopeshwar-Kathur and Devaldhar sections are more susceptible to slope failure as compared to the hard rocks of Mandal and Chopta area. It has been observed that most of the landslides occur in the study area on the old debris material followed by the weak and highly fractured and jointed lithological units.

Water received as precipitation, either evaporates or flows down as surface or subsurface flow. The subsurface flow penetrates the joints or cracks present in the bedding plane thus making them fragile. Even the surface flow leads to erosion of surface and undercutting making slopes more susceptible to failure. Intense, short period of rainfall, rapid melt of snow, or the prolonged high precipitation is the reason of the higher number of landslides during or immediately after monsoons i.e., during June, July, August and September. Breaching of natural dams has also often led to severe floods and landslides.

Anthropogenic factors are also playing important role in the area causing landslides. It includes deforestation, modification in natural slope conditions, loading of the slope or its crest, water leakage from services, mining and quarrying (e.g., Gair landslide), dumping of the excavated debris material from road cut section, along with the downslope etc.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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