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Photographic Feature

# Varunavat landslide disaster in Uttarkashi, Garhwal Himalaya, India

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**Abstract:** Uttarkashi town, Garhwal Himala, India was severely affected by the Varunavat hill landslide, which occurred on 23 September 2003. The houses situated at the foot of the hill were completely destroyed; however, there were no casualties. The paper describes the landslide, its features, probable causes and associated risk as observed by the authors.

Landslides are one of the major geological hazards in the Himalaya, in the northern part of the Indian subcontinent. The Himalaya are characterized by rock types, tectonic zones, topographic relief and slopes of diverse nature. The structurally deformed rocks have been subjected to severe erosion and toe cutting by the action of rivers and streams. These characteristics contribute to making the terrain highly susceptible to landslides. In recent years, the human influences of a number of hydro-electric schemes as well as indiscriminate mining and quarrying have aggravated the problem.

A large number of landslides have previously affected the main highways of Uttarakhand State of the Himalaya. Some of these highways are strategically important as these are the routes for pilgrims to reach religious sites. The traffic along these routes is at risk from landslides particularly during the monsoon period (Sarkar *et al*. 2005). In the recent past there have been a number of landslide disasters in Uttarakhand State. These include the landslide disaster at Malpa in the Kali valley on 18 August 1998, which completely destroyed the village and wiped out temporary shelters for pilgrims going to Kailash–Mansarovar, causing more than 200 fatalities. Another example includes the Mandakini Valley of Rudraprayag district, which was struck by several landslides as a result of heavy precipitation in the third week of July 2001; these include the Phata and Byung Gad landslides, which killed 20 people. The landslide that occurred at Varunavat hill of Uttarkashi town, Garhwal Himalaya, on 23 September 2003 affected part of the town, destroying many properties. The Varunavat hill before and after the landslide is shown in Figure 1. This paper describes the landslide information gathered shortly after the event in the last week of September 2003 and assesses the present condition following the installation of control measures in 2008–2009.

(a)

(b)

**Fig. 1.** (**a**) Pre-landslide scenario and (**b**) post-landslide scenario of the Varunavat hill.

## Geology

Uttarkashi town is situated at the foot of the Varunavat hill on the right bank of the river Bhagirathi in Uttarakhand State of India. Geologically, Uttarkashi and its surrounding region are characterized by Higher Himalayan Crystallines and Lesser Himalayan sediments. The higher Himalayan Crystallines are thrust over the Berinag Formation of the Lesser Himalaya along the Main Central Thrust. The Berinag Formation is underlain by the Damta Group of rocks (Valdiya 1980). The area is sandwiched between the Main Central Thrust to the north and the Srinagar Thrust to the south


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**Fig. 2.** Main escarpment of the landslide.

**Fig. 3.** Slip surface showing striations caused by sliding.

(Agarwal & Kumar 1973) and lies in a highly seismotectonically active zone. The epicentre of the 1991 Uttarkashi earthquake (6.1 magnitude on the Richter scale) was in the vicinity of Uttarkashi town, which was subjected to tectonic movements leading to the development of several faults and weak planes. The earthquake originated from slipping of segments of faults in the active zone of the Main Central Thrust (Valdiya 1991). The maximum peak ground acceleration was 0.29*g* at Uttarkashi.

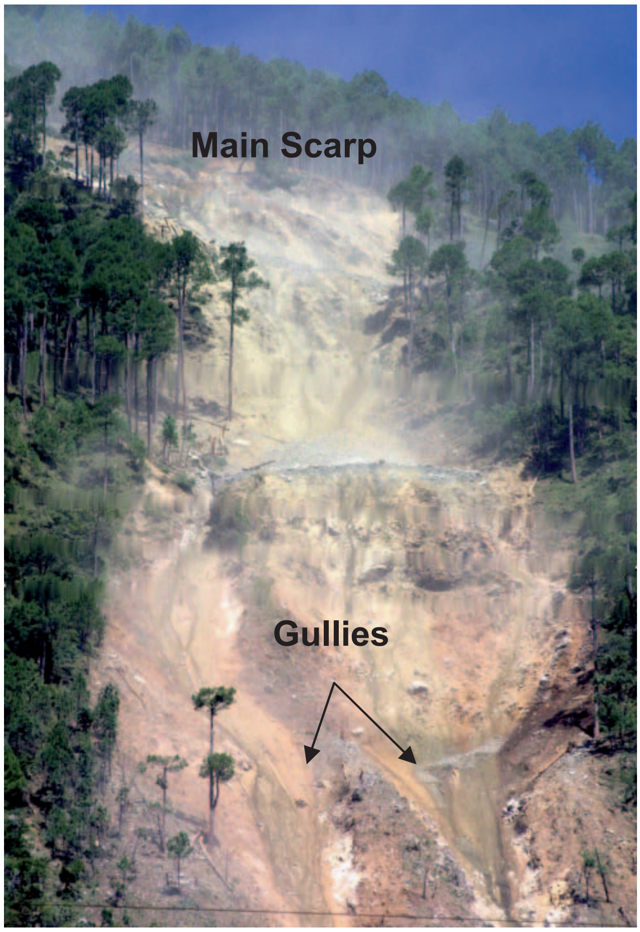


**Fig. 4.** Continuous debris slide and rock fall.

The form of the September 2003 landslide at the Varunavat hill was characterized as a rock–debris slide and Uttarkashi town was exposed to a severe landslide risk for many days. The rocks in the landslide-affected area of the Varunavat hill are thinly bedded quartzites and phyllites of the Damta Group, which are highly weathered, jointed and fractured. The rocks are overlain by a 1–2 m thick soil cover on the uphill slope. The beds dip at 15–30° towards N350° into the hill slope. There are three sets of major joints. One of the joint sets, dipping at 50° southwards, is parallel to the slope, favouring instability. The main scarp of the landslide coincides with this joint plane. The other two joint sets dip obliquely to the slope. The ridge of the hill is covered with pine forest whereas the lower slopes are covered by scrub.

## Slope instability and causes

Slope instability of the Varunavat hill has been documented by Pandey & Uniyal (2007), who described two *Q1* previous landslides (Fig. 1). The Gyansu slide occurred in June 1980 and since then debris comprising boulders and loose unconsolidated material has frequently been mobilized down the Gyansu drain into the Bhagirathi

**Fig. 5.** Debris accumulation at road through the main channel.

river. The 1980 slide was confined to the drain and was about 1 km in length, and before the landslide of September 2003 active instability was observed at the mouth of the Gyansu drain, which had become widened as a result of natural erosion and undercutting. The other slide, called the Tambakhani slide, was also developed on the same hill slope and had a 60 m wide scarp and a length of about 700 m. This slide was narrower in its lower section and was only 6 m wide at road level. The slide debris comprised boulders and loose rock fragments and was observed to be active for several years prior to 2003. Hence it can be stated that the Varunavat hill already showed evidence of unstable conditions.

The Uttarkashi earthquake of 1991 induced slope instability and caused the development of many cracks in the hills of the region. The instability was further aggravated by anthropogenic activities at the toe of the hill slope resulting in disintegration of the rock mass and increase in slope gradient and shear stress (Sarkar *et al.* 2004). Another contributory cause was a forest fire on the uphill slope, which partly destroyed the vegetation preceding the event. All these factors potentially contribute to slope instability pre-conditioning of landslides.

The causal factor associated with the landslide initiation was the continuous rainfall that occurred for several days before the slide was triggered on 23 September 2003. The jointed and fractured rocks acted as pathways for water percolation and thereby developed high pore pressure leading to failure. From the rainfall data of 1990–2003 it was observed that the annual total rainfall in the area was about 1350 mm, with 60% of rainfall falling in the months of July–September (Gupta & Bist 2004). The average annual rainfall in the area for the year 2003 was above normal. In July and August 2003 there was continuous rainfall with a peak of 140 mm on 5 July. In September 2003 continuous rainfall fell for 13 days before the landslide was triggered but the intensity was not especially high. On 23 September, the day on which the slide was triggered, the rainfall was only 35 mm. This indicates that cumulative rainfall over a period of days was primarily responsible for triggering the landslide rather than high-intensity rainfall.

## Landslide features and activity

The 2003 Varunavat hill landslide is a lateral extension of the old Tambakhani slide, which was enlarged upslope with small-scale local slips. A reconnaissance survey of the slide area was carried out by the authors within a week after the occurrence of the slide. At that time the slide was still active, and activity continued for the next 15 days. The area was in a very unstable condition. Rainwater ingress through the jointed and fractured rock mass is interpreted to have developed high pore pressure leading to detachment of part of the hill mass at the extended portion of the Tambakhani landslide scarp. Initially, the failure was of rotational type, as indicated by a prominent slip surface at the crown and back-tilted trees. Later it broke down into a rock–debris slide on downhill slope.

The main scarp of the slide was about 60–70 m wide and 650 m above the road level (Fig. 2). The exposed slip surface was 100 m or more in length with a dip of up to 40° (Fig. 3). The striations caused by the movement on the slip surface were distinctly visible. The runout distance from the exposed slip surface to the zone of accumulation in the town was more than 900 m. The slope was steep in the lower portion of the hill. Once the slide was triggered the impact of boulders on rock outcrops and soil overburden resulted in entrainment of more landslide debris. The debris material comprised boulders and rock fragments of various sizes along with mixed sandy and silty clay. Several cracks were observed in the main body of the landslide. A few of these were more than 1 m deep. Most of the cracks were transverse in nature, and there were a few longitudinal cracks. Cracks were also observed on the slopes along the left flank beyond the limit of the landslide. This indicated the possibility of further lateral extension of the landslide on the left flank. The volume of displaced debris


**Fig. 6.** Uprooted trees on uphill slope.

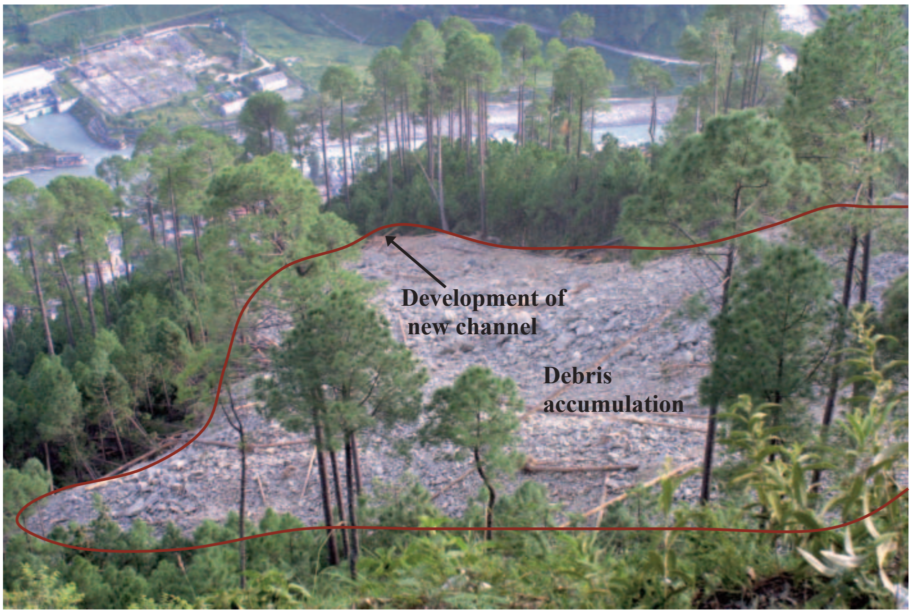


**Fig. 7.** Development of new channel for debris slide and rock fall.

resting on the upper part of the slope was estimated to be about 40 000–50 000 $m^3$. At the time of survey, debris was observed to be continuously rolling down the slope and posing a threat to the houses situated in its path (Fig. 4). A huge quantity of debris accumulation at the toe of the slide in the form of a colluvial fan destroyed several structures including residential, shopping and hotel buildings (Fig. 5).

The movement of debris also affected the forest in its path, resulting in the uprooting of trees. Two breaks in slope with gentler slope angles between 15 and 20° were observed along the flow path, and served as temporary accumulation zones for the sliding mass and uprooted trees (Fig. 6). Thus the accumulation of slide debris along with uprooted trees at various elevations on the slope locally increased the gravitational load and aggravated the slope instability. Because of the accumulation of debris in the main path a new channel formed down the left flank of the slide (Fig. 7). This new channel threatened a large number of houses in the town. The local administration was advised to evacuate these houses immediately.

In view of the loose debris resting on the slope above the steep foot-hill slope, it was recommended that a buffer zone of about 100–150 m width and 1 km length along the foot hill be created to avoid any further damage, particularly that owing to rock fall. The extent of the buffer zone was decided keeping in mind the

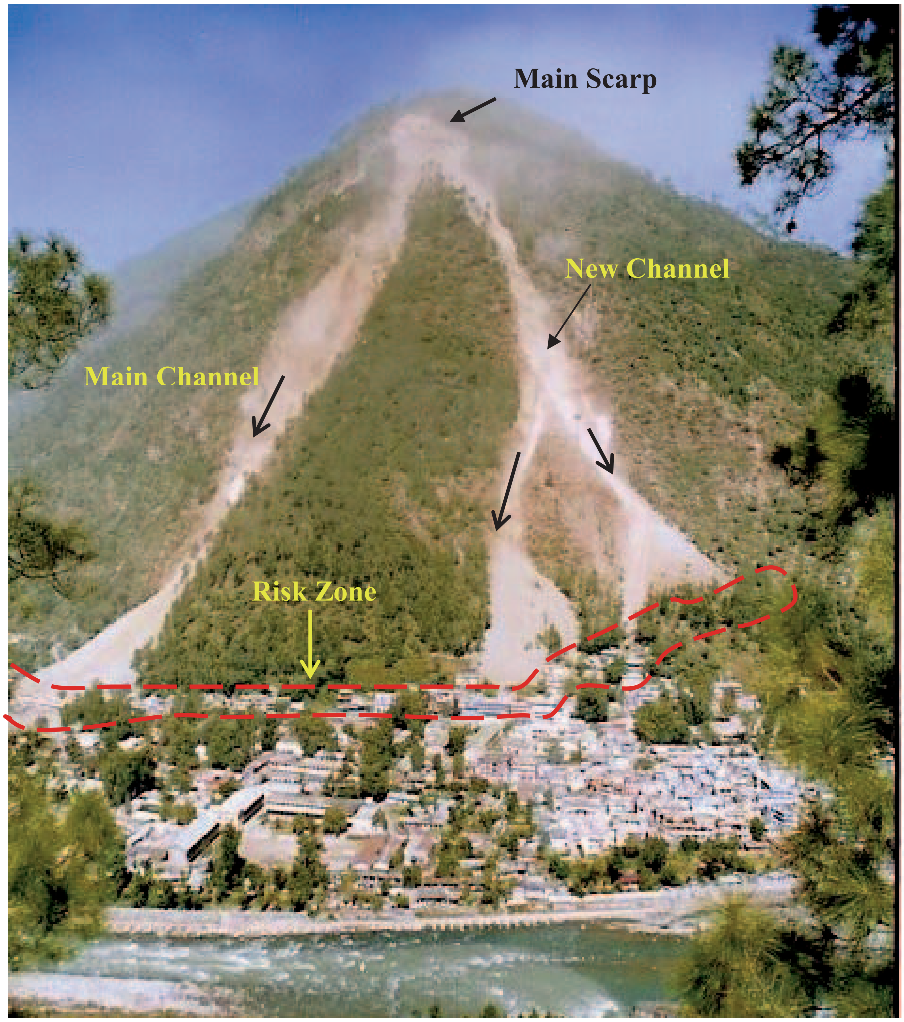


**Fig. 8.** Suggested buffer zone at risk owing to landslide.

**Fig. 9.** Buildings that were later buried by debris.

volume of debris and the flat topography at the foot hill. It was advised that no development or construction activities should be allowed in the buffer zone, which should remain under strict vigilance until the sliding activity completely stops and the hill slope can be declared safe. The administration took prompt action

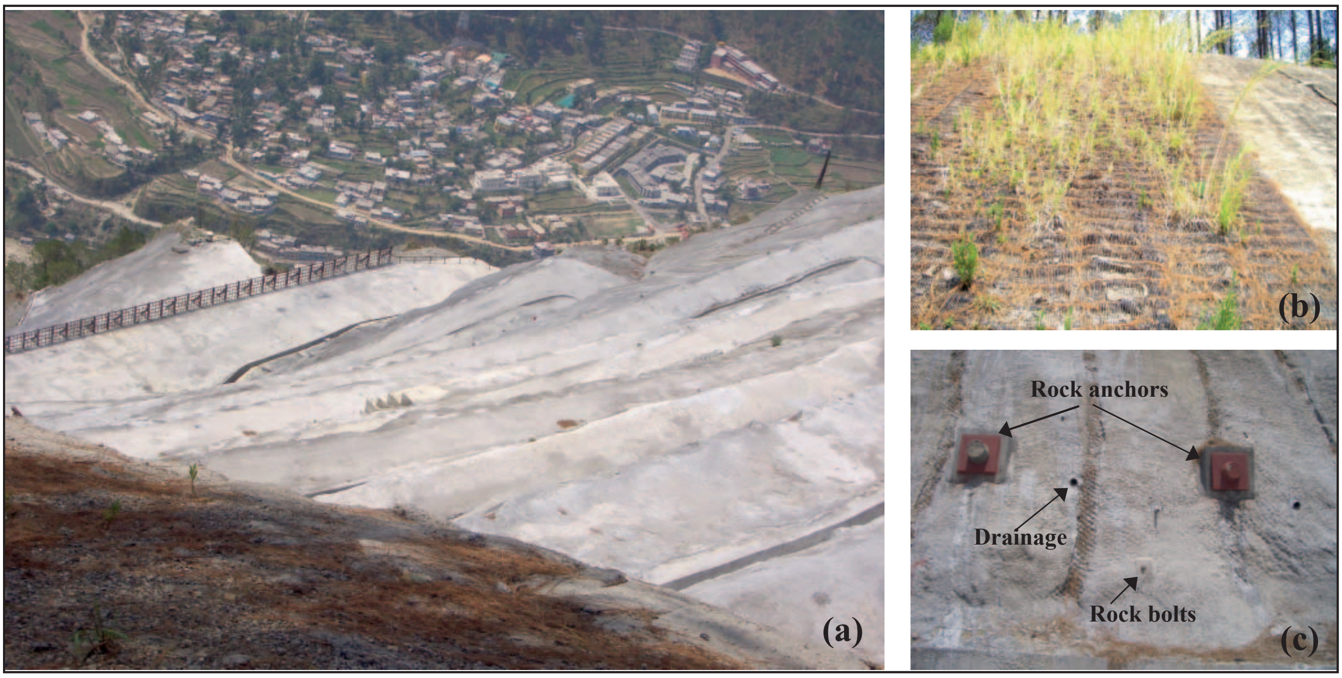


**Fig. 10.** Present scenario after implementation of control measures. (**a**) View of landslide from top. (**b**) Bio-measures at main scarp. (**c**) Rock anchors, rock bolts and subsurface horizontal drains.

and followed the recommendations. As predicted by a team of experts (formed by the Ministry of Home Affairs, Government of India) including the authors, a huge quantity of debris was displaced down the left flank within a week after the new channel formed (Fig. 8). It was also suggested that remedial measures such as sealing of cracks, slope grading, construction of retaining walls, proper drainage measures, soil reinforcement and biotechnical measures should be designed and implemented once the sliding activity stopped.

## Consequences

The landslide has destroyed many structures. About 360 houses were completely or partly damaged by the landslide (Fig. 9). Hotels and tourist lodges located along the National Highway (108) were completely buried under the thick cover of landslide debris. Residential houses and government buildings were also affected. The National Highway was blocked for a month over a 1 km road length. There was also loss of forest on the uphill slope of the hill owing to the movement of boulders and debris material. However, there were no casualties, as the district administration along with scientific organizations worked together to evacuate the houses in time. This avoided a potential major disaster.

## Control measures

The Geological Survey of India recommended control measures to arrest the sliding activity. These are mainly slope grading, shotcreting, surface drainage and rock anchoring. To implement these measures a vehicular track was made to reach the uphill slope. The accumulated debris resting on the middle of the slope and at the road level was removed and disposed of in an adjacent valley, and covered with biodegradable jute mesh to avoid erosion and debris flow.

The control measures were implemented during 2008–2009 (Fig. 10). The slope has been modified and shotcreting has been applied with wire mesh reinforcement on the entire slope. Rock anchoring and rock bolting has been implemented to strengthen the weak jointed and fractured rocks. After covering the main landslide scarp at the crown portion with geo-grid, bio-measures have been adopted to protect the slope from erosion. Special grass has been planted to stabilize the slope through root reinforcement. Subsurface horizontal drains have been installed at various levels to drain groundwater. Surface drainage has also been constructed at various levels to drain surface runoff from the slope. At the toe, a retaining wall was constructed to provide support to the slope. At present, the slide appears to be stabilized and no activity was reported after the implementation of the above control measures.

## Conclusions

There are many examples of large landslides affecting various parts of the Indian Himalaya about which little is known. When landslides of this nature threaten towns and populated areas they are of serious concern. It is always advisable to avoid hazards if possible. A key lesson learnt from this case is that townships should not be built below foot hills subject to instability from above; in such cases consideration must be given to establishing a buffer zone along the foot-hill slope in which development and construction should not be allowed. The extent of the buffer zone should be assessed by a competent geologist based on full knowledge of the potential landslide type, slope morphology, debris material and volume. There is also a need for large-scale landslide hazard mapping and risk evaluation that will lead to efficient landslide disaster management. However, in unavoidable circumstances, geological and geotechnical investigations should be carried out and if necessary adequate remedial measures must be planned for safe construction and civil protection.

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**Specific Queries (see Q? in margins)**

Q1. (Pandey – spelling not as in ref. list. Please make consistent)
Q2. (Valdiya 1980 - please add book or report title)
Q3. (Valdiya 1991 - please add page numbers of paper)