Disaster Prevention and Management

Non-monsoonal landslides in Uttaranchal Himalaya (India): implications upon disaster mitigation strategy

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Disaster Prevention and Management, Vol. 15 No. 3, 2006,
 0965-3562

Disaster Prevention and Management, An International Journal, sets out to advance the available knowledge in the fields of disaster prevention and management and to act as an integrative agent for extant methodologies and activities relating to disaster emergency and crisis management. Publishing high quality, refereed papers, the journal supports the exchange of ideas, experience and practice between academics, practitioners, and policy-makers.

ISSN 0965-3562

Published in association with the Disaster Prevention and Limitation Unit, University of Bradford

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Non-monsoonal landslides in Uttaranchal Himalaya (India)

Implications upon disaster mitigation strategy

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Abstract

Purpose – Climatic conditions as also the agrarian economy of the Indian subcontinent is greatly affected by the monsoonal winds that are characterized by heavy rains between June and September. The paper is an attempt to break the myth that landslides are only confined to monsoonal months that normally have concentrated rains and can be expected in other seasons as well and, therefore, disaster alert levels cannot be relaxed during non-monsoonal season. The communication also attempts to identify slowly ongoing weathering processes that might cause to slope failure without rains and, therefore, paves way for identifying similar landslide prone areas.

Design/methodology/approach – The paper discusses two landslides of the recent past; Uttarkashi landslide of 23 September 2003 and Ramolsari landslide of 30 March 2005 that took place after the seizure of the monsoonal rains and is based upon the first hand field observations of the authors. The paper discusses the likely causes of the slides along with the implications of this new trend of landslides taking place in the non-monsoonal season upon the disaster management strategy of the state.

Findings – The investigations reveal that precipitation could be considered the trigger in case of Uttarkashi landslide but there exist no evidences to suggest that the Ramolsari landslide could have been triggered by increased pore water pressure. Slow ongoing and hard to observe processes of weathering seem to have initiated this slide.

Research limitations/implications – For the purpose of metrological parameters, the study relies upon the data of the state run rain gauges that do not have an appreciably good spatial distribution. Rainfall data of the nearest observation points is, therefore, taken as representative of the rainfall in the area under present focus. For Ramolsari, the rainfall data of Tehri is used while Uttarkashi has a rainfall recording observatory.

Originality/value – The paper highlights the importance of keeping the preparedness levels high for prompt post-disaster operations all through the year. This paper advocates redefining high alert period for landslide hazard and for following high alert all through the year particularly in areas prone to landslides.

Keywords Natural disasters, Landslides, India

Paper type Research paper

Disasters in the Himalayan terrain

Himalayan mountain belt emerged as a result of the north-northeasterly drift of the Indian plate, its consequent subduction beneath the Eurasian plate and its subsequent eventual collision with the same. As a result of this the rocks comprising the mountain belt have experienced severe metamorphism, deformation and large-scale dislocations

Disaster Prevention and Management
Vol. 15 No. 3, 2006
pp. 448-460

0965-3562
DOI 10.1108/09653560610669927

Support for the fieldwork by Disaster Risk Management Programme of the Government of India and United Nations Development Programme is acknowledged. The authors acknowledge support and cooperation from the Department of Disaster Management of the Government of Uttaranchal.

(thrusting). The Himalayan terrain exhibits traces of a large number of major and minor dislocation planes (faults and thrusts) of regional dimensions (Himalayan Frontal Fault, Main Boundary Thrust, Main Central Thrust, South Tibetan Detachment, Indus-Tsangpo Suture Zone). Evidences of recent movement (neotectonism) along these planes have been observed (Sati and Rautela, 1998; Wesnousky *et al.*, 1999; Kumar *et al.*, 2001; Thakur and Pandey, 2004) and continuing build up of strain in the region due to ongoing tectonic movements makes the Himalayan terrain prone to earthquakes and in the past the region has been devastated by a number of seismic events.

The tectonic movements have rendered the rocks of the terrain highly sheared, faulted, folded and these show large number of penetrative weak planes along which the rock mass is prone to fail. Landslides are thus a common feature in the region and cause loss of human interests essentially during the monsoon season. High relative relief, high and concentrated atmospheric precipitation further enhance the fury of these disasters. Flash floods, forest fires, avalanches and road accidents are other disasters common in this terrain.

The state of Uttaranchal represents essentially a Himalayan state that is located between Nepal and Himachal Pradesh (India) and the seismic risk in the state is evaluated to be high. Four of the 13 districts (Pithogagarh, Chamoli, Bageshwar and Rudgaprayag) of the state fall completely in Zone V of the seismic risk map of India (damage of > IX on MSK scale) while other five (Uttarkashi, Tehri Garhwal, Pauri, Almora and Champawat) and fall partially in Zone V and partially in Zone IV (damage of VIII on MSK scale). In the recent past, the state has experienced two major earthquakes (1991 Uttarkashi and 1999 Chamoli) and non-occurrence of a major earthquake ($M > 8$ on Richter scale) in the region for more than previous 200 years further enhances seismic risk in the region (Bilham *et al.*, 2001). In the past, the state has witnessed a large number of landslide and flash flood events (Table I) and almost all of these have been confined to monsoonal season. Landslides are, therefore, considered to be a monsoonal feature and landslide-related administrative preparedness is particularly geared up during this season to timely respond to these events so as to reduce human miseries.

In the year 2003, landslide, however, initiated at Uttarkashi on 23 September (Plate 1) with the withdrawal of the monsoonal rains and after quiescence all through the peak of the monsoons. In the year 2005, the landslide at Ramolrsari (Plate 2) struck on 30 March with the onset of the summer season and at a time when the administrative preparedness was being geared up to tackle the oncoming fire season (forest fires generally break out during summers in the region). The occurrence of landslides during non-monsoonal season in the previous some years, therefore, need to be taken up as warning signals given by nature and reorient the disaster management-related initiatives to avoid being surprised by a non-monsoonal landslide.

This paper discusses the above cited two non-monsoonal landslides and attempts to highlight the fact that rainfall is not the sole triggering force for landslides and, therefore, landslides should be expected in any season, though their frequency could increase during the monsoonal season.

Both Uttarkashi and Ramolsari are located in the catchment of Bhagirathi river, that meets Alaknanda at Devprayag to form river Ganga, and in adjacent district of Uttarkashi and Tehri Garhwal, respectively. These can be approached by Rishikesh-Gangotri National Highway; Uttarkashi being situated on the main road head while for Ramolsari Chaam-Mendkhal link road has to be followed.

1816	Pauri landslide
1842	Joshimath landslide
1857	Massive landslide blocked the flow of the Mandakini river
1868	Landslide at Chamoli Garhwal blocked Alaknanda river: swept two villages and killed 70 pilgrims
1880	Landslide in Nainital Town: massive destruction and killed more than 150 persons
1893	Landslide blocked Birahi Ganga and formed an artificial lake near Gohna village in Garhwal Himalaya
1894	Breach of Gohna lake causing "Birahi disaster" in Alaknanda valley
1906	Helang landslide
1945	Patalganga landslide
1963	Nainital landslide
1963	Kaliasaur landslide
1965	Karnaprayag landslide
1970	Landslides formed an artificial lake in the upper catchment of Alaknanda river: affected 101 villages, 25 buses of pilgrims Swept away, 55 persons and 142 animals dead District headquarter of Chamoli district devastated and subsequently shifted to Gopeshwar
1979	Okhimath landslide: 39 persons died
1981	Uttarkashi-Kedarghati landslide
1986	Landslides at Jakholi in Tehri Garhwal and at Devaldhar in Chamoli: 32 lives lost
1991	Gopeshwar landslide: 36 persons in 6 villages died
1996	Bhimtala landslide
1998	Massive landslides in Okhimath area formed an artificial lake blocking the course of Madhyamaheshwar river (tributary of Mandakini): 109 people dead, 1,908 families from 29 villages affected and 820 houses damaged
1998	Malpa landslide into river Kali: wiped out Malpa village near Dharchula in Pithoragarh, more than 300 people died
2001	Phata and Byung Gad landslides: around 20 persons killed and several houses damaged
2002	Landslides at Budhakedar and Khetgaon
2003	Uttarkashi landslide
2004	Amparav landslide
2005	Ramolsari landslide

Table I.
List of major landslides in Uttaranchal

Uttarkashi landslide affected the township of Uttarkashi that is also the district headquarter while Ramolsari is located in a remote area of Tehri Garhwal district. Apart from access and ease of mobilization of resources, the vulnerability of Ramolsari is enhanced by:

- sex ratio favouring females;
- high child ratio;
- low literacy rate; and
- high proportion of the marginal workers and non workers (Table II, *Census of India 2001*, 2004).

Geology

From south to north, the Himalayan mountain range is longitudinally divided into six tectonic zones; the Outer (Sub) Himalaya, the Lesser (Lower) Himalaya, the Higher (Great) Himalaya, the Tethys (Tibetan) Himalaya, the Indus Suture Zone and the Trans Himalaya (Gansser, 1974; Thakur, 1992). Himalayan Frontal Fault, Main Boundary

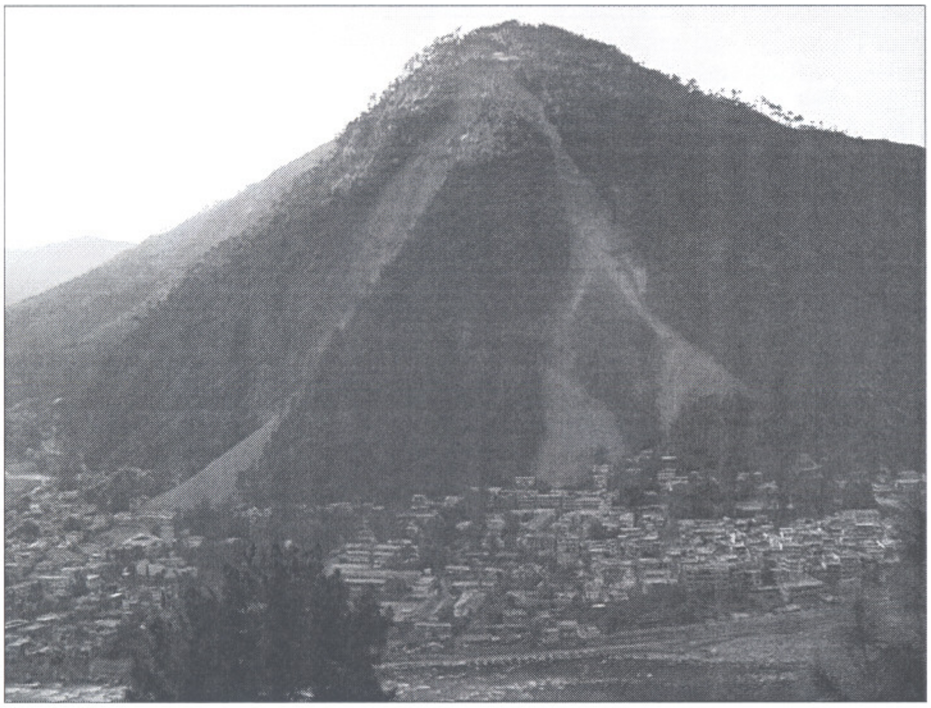

Plate 1.
View of the Uttarkashi landslide of September 2003 (Camera looking north) with Bhagirathi river in the foreground

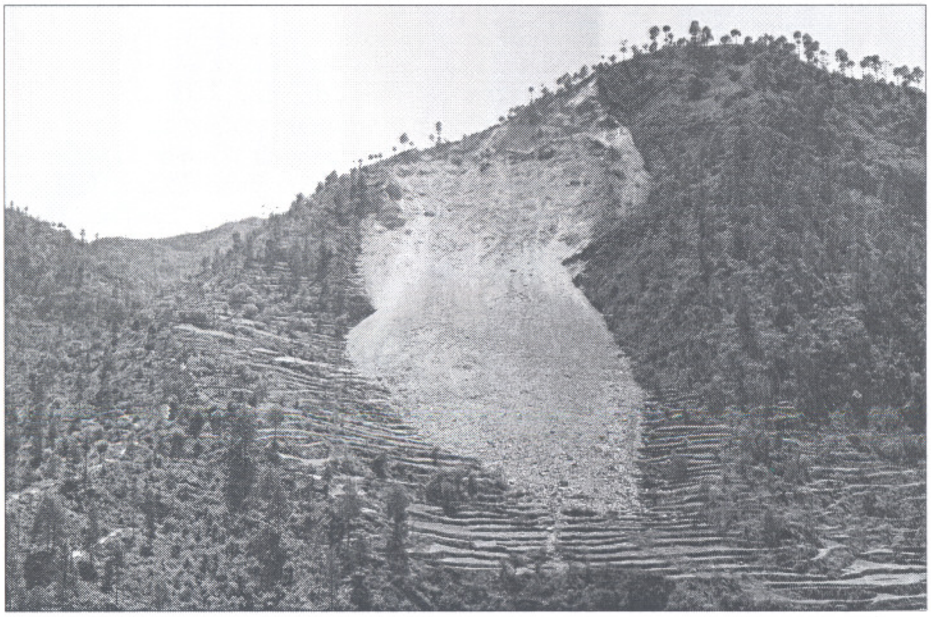

Plate 2.
View of the Ramolsari landslide of March 2005 (Camera looking south). Habitations of the Chawa Tok (hamlet of Ramolsari village are seen at the ridge to the east of the slide

Table II.
Demographic details of Ramolsari and Uttarkashi

	Total population	Sex ratio (females/1,000 males)	Child ratio (proportion of the children in the age group of 0-6 years)	Literacy rate (literates as proportion of the population)	Male literacy rate	Female literacy rate	Percentage of the marginal workers and non-workers)
Uttarkashi (MB)	16,218	750	12	77	82	70	70
Ramolsari	258	1,345	18	44	60	32	81

Source: *Census of India 2001*, 2004

Fault, Main Central Thrust, South Tibetan Detachment and Indus Tsangpo Suture are the discontinuities of regional dimensions marking boundaries of these zones.

Both Uttarkashi and Ramolsari landslide zones lie in the Lesser Himalayan Zone (Figure 1) that essentially consist of low grade meta-sedimentaries that are thrust over the sedimentary rock sequences of the Outer Himalaya along north dipping Main Boundary Thrust. The northern boundary of this tectonic unit is marked by north dipping Main Central Thrust that brings the crystallines rock sequence of Higher Himalaya Zone in juxtaposition with the meta-sedimentary sequence of rocks.

Uttarkashi and Ramolsari area is locally sandwiched between Srinagar Thrust and MCT to the south and north, respectively. The rocks constituting the Uttarkashi landslide are mainly phyllites and quartzites of Rautgara formation (Valdiya, 1980), dipping northerly into the hill at 30-35°. These are highly shattered, fragmented, fractured and thinly jointed. These are covered with 20-25 meters thick slided material. The rocks housing the Ramolsari slide are essentially phyllites of Chandpur formation (Valdiya, 1980) that show a number of penetrative weak planes. These rocks dip southwesterly at moderate angles (30-40°).

Comparison of the two slides

The Uttarkashi landslide of 23 September 2003 took place along the southern slopes of the hill (Varunavat Parvat) that rises above the river terrace level and along the lower slopes of the hill colluvium is observed to obliterate the river terraces. The township of Uttarkashi that is situated over the river terraces was threatened by this slide though timely administrative action averted loss of human lives in this incidence. This slide, however, caused immense loss of public and private property and the restorative works are estimated to cost the public exchequer around 2,853 million Indian rupees (1 US$ ~ 47 Indian rupees).

The Ramolsari landslide of 30 March 2005 took place on the northern slopes of a hill falling in the watershed of a fourth order stream, Malogi Gad (Figure 2) that flows in northeasterly direction to meet Bhagirathi river near Birkot. Near the confluence, extensive terraces of Bhagirathi are observed. Village Ramolsari is situated at the base of this hill and the slide has overrun vast expanse of agricultural lands of the village and depleted the forest resources.

Both these slides took place on sparsely forested hill slopes; in Uttarkashi, the hill had pine forest while in Ramolsari, there were oak apart from pine. Around the landslide zones, veneer of colluvial deposits is also observed. At both the places, lower slopes show

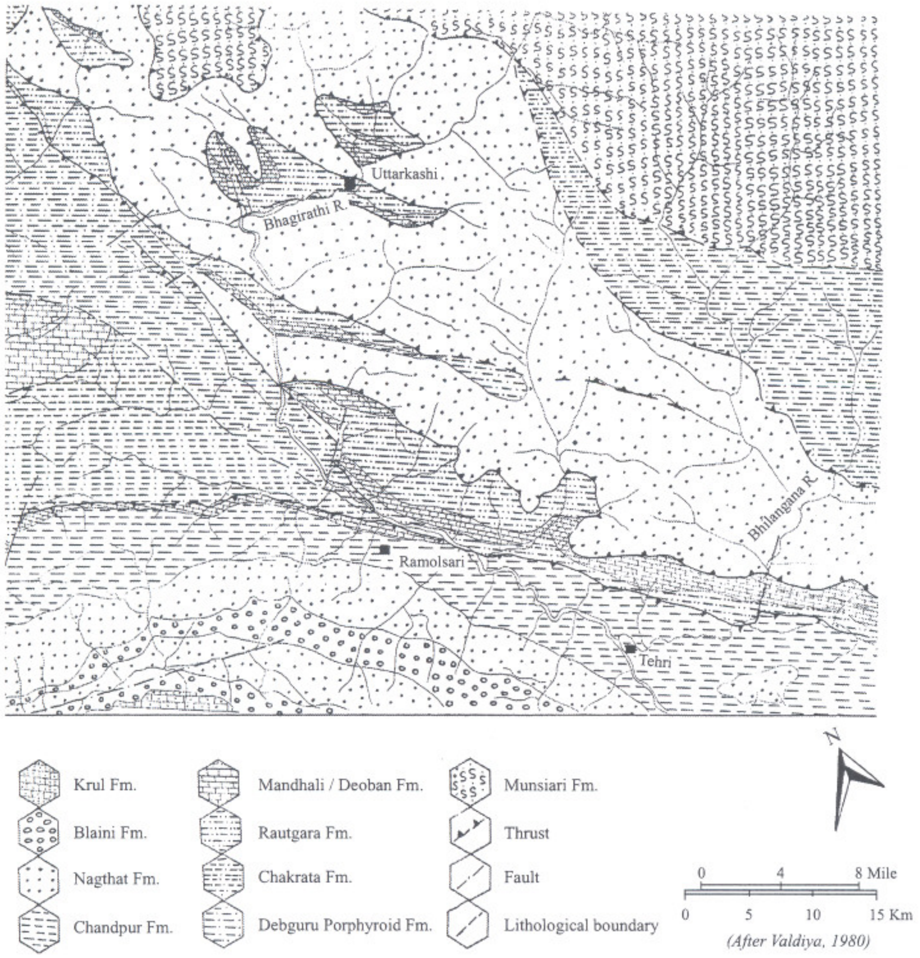

Figure 1.
Geological map of the area around Uttarkasi-Ramolsari (After Valdiya, 1980)

extensive terrace development along the course of Bhagirathi river. Both the landslides show characteristics of debris slide (debris slide in the crown portion, and rockfall and rockslide in the middle part) and in both the cases rolling down of the dislodged rock fragments and debris continued for more than ten days after the initiation of the landslide.

The crown of the Uttarkashi landslide is situated at an altitude of about 1,675 meters above mean sea level with the scarp of the active slide being 30 meters long and 150 meters wide and dipping in southeasterly direction (55/150°). It coincides with a prominent joint set (48-50°/110-120°) that is observed to be filled with 1-2 mm thick clayey material. The movement of the rock debris has produced sharp slikenslides plunging due 150-160°. The crown of the Ramolsari slide is located at an altitude of around 1,500 meters above mean sea level (Figure 3) and scarp of the active slide is about 100 meters wide and 40-60 meters long and dips steeply. The failure is observed to have taken place along one of the prominent joints dipping 70° due 020° along which clay development was noticed in the field.

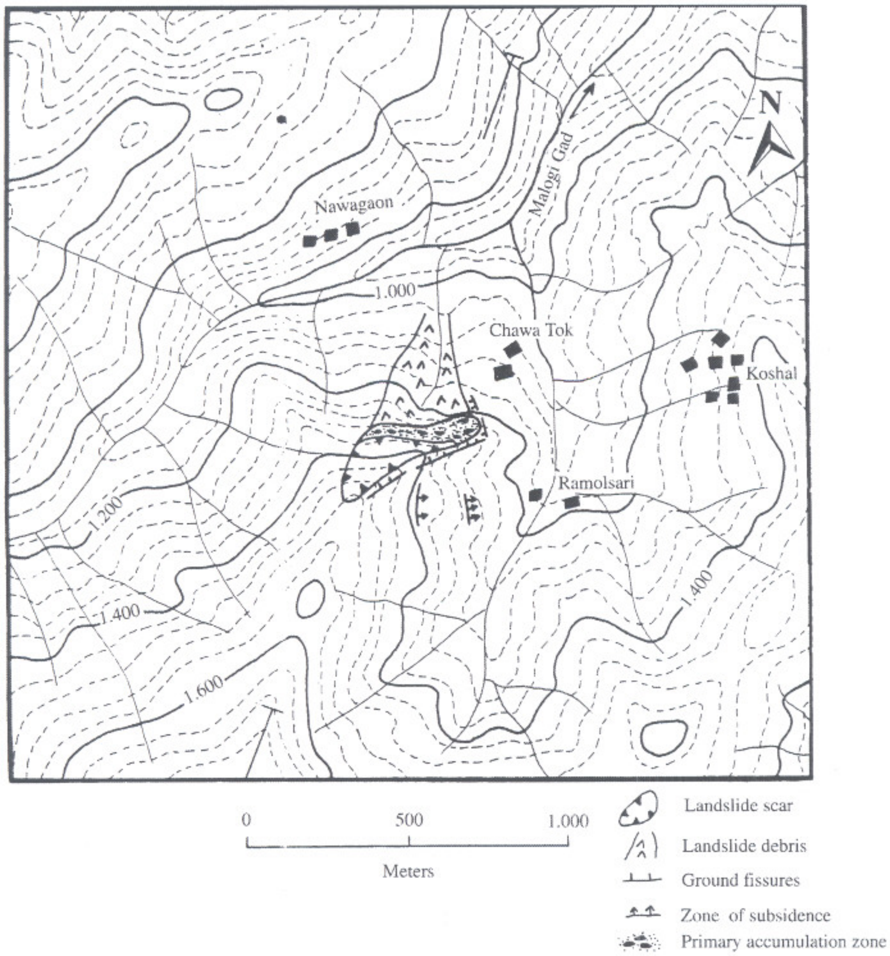

Figure 2.
Map showing topographic details of Ramolsari area together with the position of the slide scar, debris and the ground fissures together with the primary surface of deposition

Multiple joint sets are observed in the vicinity of both the landslides. In case of Uttarkashi slide, two sets of near vertical joints striking 40-220° and 140-320° apart from those dipping at moderate to steep angles are observed (48/120° 80/040° 80/140°). The foliation plane of the *in situ* rocks are observed to dip in northeasterly direction (40/045°). Lower hemisphere projection of these planes suggest that the intersection of the joint planes provide suitable conditions for failure to occur. The slip surface coincides with one of the prominent joint planes (48/120°) and the intersection lineations plunge in the direction of the mass movement (Figure 4). In the vicinity of the Ramolsari slide, the rocks dip westerly (38/277°) and show three prominent sets of joints (70/020° 65/065° and 70/125°). All the joints sets show dilation of millimeter scale. Lower hemisphere projection of the joint and foliation surfaces together with the slope suggest that the intersection of the penetrative weak planes provide ideal situation for mass wastage to take place (Figure 5).

Both the landslides are observed to have formed bench like surface of deposition (primary surface of accumulation) at 1,525 and 1,350 meters above mean sea level in

Uttarkashi and Ramolsari slides, respectively. Dislodged material from the slide scar has got accumulated in these benches from where it rolled downslope to the secondary zone of accumulation towards the base of the slope. In case of Uttarkashi landslide, two prominent debris chutes are observed and the slides material accumulated in distinctly identifiable accumulation zones. Though single debris chute and accumulation zone are observed in Ramolsari slide, initiation of ground fissures oblique to the main slide scar (trending 150-330° and oblique to 070-250° trending fissures that parallel the main scar) indicate possibility of the initiation of a new debris chute from the primary surface of accumulation. Failing of the ground along these ground fissures would initiate a new debris chute from the primary surface of accumulation and overrun the agricultural lands below.

Upslope tilted trees in the crown region are indicative of the rotational geometry of the slides. On the basis of the geometry of the exposed scarp of the raised benches at 1,525 and 1,350 meters in Uttarkashi and Ramolsari slides, respectively, the depth of these landslides are estimated to be 20-25 meters and 15-20 meters, respectively. According to the volume calculation formula based on the ellipsoidal geometry of the landslide mass as given by the IAEG Commission on Landslides (1990), the volume of the dislodged rock mass is given by $1/6\pi D_r W_r L_r$ (where D_r, W_r and L_r represent the depth, width and length of the surface of rupture, respectively). The volume of the dislodged rosk mass in case of Uttarkashi and Ramolsari landslides is estimated to be of the order of 50,000-60,000 m^3 and 30,000-60,000 m^3, respectively.

Wide open ground fissures running parallel to the slide scarp are observed over the slide zones. These are indicative of the slide engulfing still more land.

Landslide triggering mechanism

Landslides are known to have several causes, including geological, geomorphological, physical and human (Alexander, 1992; Cruden and Varnes, 1996), but only one trigger (Varnes, 1978). By definition, trigger is an external stimulus such as intense rainfall, earthquake shaking, volcanic eruption, storm waves, or rapid stream erosion that causes a near immediate response in the form of landslide by rapidly increasing the stresses or by reducing the strength of slope materials.

Excessive precipitation resulting in increased pore water pressure is normally considered to be the main cause of landslides and, therefore, rainfall record of the two areas was analysed. On an average, the area experiences annual rainfall around 2,000 mm and

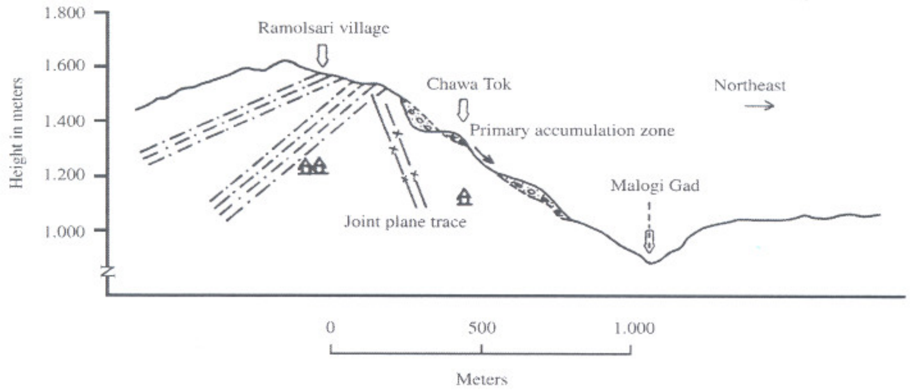

Figure 3. Cross section of the Ramolsari slide (for section line refer the topographic data given on Figure 1) showing the zone of depletion together with primary and secondary accumulation zones

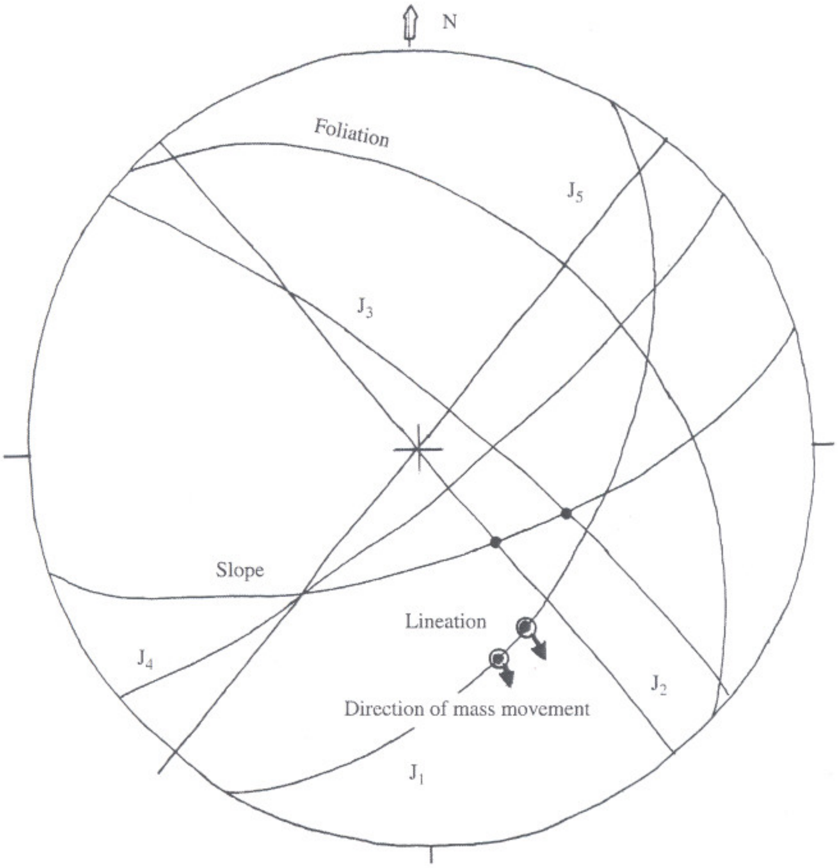

Figure 4.
Lower hemisphere projection of the joint plane and foliation in the Uttarkashi landslide zone

almost 60 per cent of it is confined to the months of July-September. Uttarkashi landslide of 2003 initiated immediately after the seizure of rains on 23 September. It is indicated by Gupta and Bist (2004) that due to rains in the preceding months, the groundwater pressure might have progressively increased; rains of the order of 1,545 mm being experienced in 60 rainy days between July and September. An unlined canal dug in the area by forest department over the landslide scarp might have further enhanced groundwater infiltration and facilitated failure of the highly jointed and fractured rock mass.

Rainfall data for the Ramolsari area suggests that the rainfall during the previous two years has been on the lower side being 1,209 and 1,470 mm during 2003 and 2004, respectively, against 2,225 mm during 2002. Though most rains are confined to the months of July-September some rains are experienced during the winter season but these are not significant. The winter rains spread over October and March are of the order of 300 mm and these were recorded to be 224 mm, 237 mm and 292 mm during 2002-2003, 2003-2004 and 2004-2005, respectively. During the year 2004, there was 156 mm of rain in October and the months of November and December did not witness any rain. In the year 2005, there was 32 and 101 mm of rain during January and February, respectively, and there was no rain during March. The rainfall data does not seem to indicate that the region

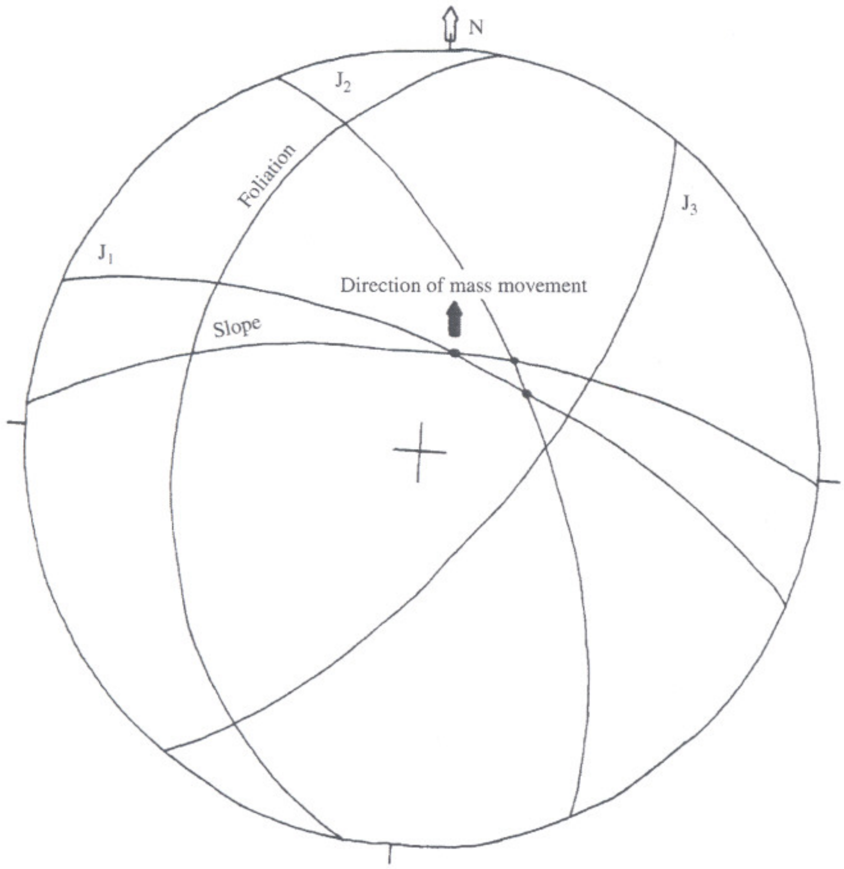

Figure 5.
Lower hemisphere projection of the joint plane and foliation in the Ramolsari landslide zone

experienced enough rainfall before the landslide event so as to trigger the Ramolsari landslide. There also does not exist any record of seismicity in the region that could be held responsible for triggering the slide. Malogi Gad does not flow in the immediate vicinity of the slide zone and, therefore, possibility of toe erosion triggering the slide is also ruled out. Cause of the clide in case of Ramolsari landslide could not, therefore, be established.

Instances of similar slides where the mass movement seems to occur without an apparent attributable trigger have been reported (Wieczorek, 1996) and these generally occur due to a variety or combination of causes, such as chemical or physical weathering of materials, that gradually bring the slope to failure (Wieczorek, 1996). Ramolsari landslide of March 2005 is an example of one such slide where the landslide trigger mechanism could not be established and perhaps slowly and continuously acting denudational forces were responsible for triggering the slide.

Implications of Ramolsari landslide

Landslides are generally understood to accompany monsoonal rains and, therefore, it is a common practice amongst the disaster management-related organizations in the region to gear up their landslide response-related preparedness during this season.

Other seasons are generally considered to be safe from landslides and during these periods other disaster management-related activities are generally carried out. The Ramolsari landslide of 2005, however, indicates that slowly and continuously operating physio-chemical and mechanical weathering processes have the potential of initiating landslides at locations that satisfy other geological conditions for the downslope mass movement even in the absence of rainfall. Geotectonic evolutionary history of the terrain makes the rocks of the terrain highly fractured and jointed and many a slopes in the region show high landslide hazard potential (NRSA, 2001).

Human miseries in the event of these landslides occurring in non-monsoonal period would be greatly compounded by the relaxed landslide preparedness norms of the agencies responsible for undertaking post disaster operations. It, therefore, becomes imperative to redefine the landslide period and keeping the landslide-related preparedness on high alert all through the year.

Where ever human habitations and critical infrastructure are located in the vicinity of the landslide hazard prone slopes special attention needs to be paid. Experiences suggest that more than anything else mass awareness and preparedness have the potential of greatly reducing human miseries and trauma in the event of any disaster. The masses, therefore, need to be communicated the potential threats they are exposed to, together with the essential do's and do nots during a disaster. Capacity building of the local volunteers needs to be carried out for making them efficient and effective relief workers well versed with search and rescue and first aid fundamentals. In the rugged and inaccessible mountainous terrain, these efforts become all the more important because despite the best efforts and intentions, the constrains put forth by topography, relief and accessibility are bound to delay the formal response.

The State Government of Uttaranchal through its Disaster Mitigation and Management Centre (DMMC) has already started working on these lines and village disaster intervention teams (VDIT) of local volunteers have been raised in more than 300 disaster prone remote villages. These teams are helping in bringing mass awareness, undertaking resource appraisal and risk assessment, as also in the formulation of village disaster intervention plans. Apart from the personnel of the regular police services who have the responsibility of carrying out post disaster interventions the VDIT members are also being imparted rigorous training in search and rescue as also first aid by the State Government. These together with the training of the masons in earthquake resistant construction, construction of demonstration houses and awareness of the school children and staff would help in greatly reducing human miseries in the event of any disaster.

Recommendations

Treatment of the Uttarkashi landslide of 2003 has already been initiated and in case of Ramolsari landslide debris is still observed to be continuously rolling down from the primary surface of accumulation. Even slight perturbations caused by strong winds are inducing the mass to roll down. Unlike the Uttarkashi landslide that took place in the heart of a major township, this landslide does not create a major threat for a large population group and, therefore, the administration is unlikely to muster funds for its elaborate treatment. The restoration work would at the same time involve erection of heavy engineering structures and this is a long-term strategy requiring mammoth financial and technical resources. Till this strategy is implemented avoidance of the slide zone is the best remedy for the Ramolsari landslide. Any kind of anthropogenic intervention in the slide zone together with the buffer marked around it, on the basis of the surface expression of ground fissures and the strike continuity of the same, needs to be avoided. Devoid of human intervention the slide zone is expected to be stabilized by natural regenerative processes in due course of time.

The agricultural land between Chawa Tok (a hamlet of Ramolsari village) and the toe of the slide also needs to be made free of anthropogenic interventions. Initiatives to restore the agricultural fields in this zone would only amount to destabilization of the toe and initiate further downslope movement of loose rock mass. The village routes have to be realigned for making the access to forest and school convenient for the masses. This could be done by the constructing bridge across Malogi Gad at a suitable site so as to avoid the slide zone.

Though the Ramolsari village seems to be free of immediate threat of landslide there is every likelihood of the initiation of landslide and consequent debris chute to the south of Chawa Tok, between Ramolsari and Chawa Tok. This would adversely affect the life support strategy of the masses as it would engulf most of the productive land of the village. The following mitigative measures, therefore, need to be undertaken urgently for ruling out possibility of initiation of this slide:

- Provision for the diversion of water away from the head of the slide zone.
- Construction of restraining structures at suitable sites.
- Slope modification wherever required.
- Safe disposal of the loose debris at the primary surface of accumulation that is inclined to escape through this new slide zone. This debris can be manually disposed off through the existing debris chute.

Initiation of this slide would totally isolate the Chawa Tok that would then be engulfed by landslide chutes on all its sides. Any attempt to cross these could result in human casualties and, therefore, the masses need to be conveyed the threat posed and together with basis dos and do nots.

Evidences of creep and ground subsidence have been observed in the upper slopes of Ramolsari village that is located in a small pocket at the base of the cliff and the slides in this zone would pose a grave threat to human lives. Avoidance of the hazard prone areas is the best remedy for minimizing risk and, therefore, the masses should be encouraged to voluntarily rehabilitate at other safe locations by communicating the risk posed to their present habitations by the landslide. Incentives by the State for those who choose to rehabilitate would facilitate this process. If the new habitation site is not far off the masses can continue cultivation of their lands around Ramolsari.

Awareness needs to be brought about amongst the masses regarding the possible threats that the mountain ecosystem generally poses to the habitations and they should at the same time be trained in search and rescue, together with first aid. During the monsoon season regular surveillance of the upper slopes should be resorted to by the villagers and any abnormal observation should be reported to the authorities.

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Further reading

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