Geological factors contributing to landslides: case studies of a few landslides in different regions of India

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Abstract. Landslides – mass movements of rock, debris or earth down a slope – are worldwide phenomena which cause significant damage and an estimated 5000 fatalities each year. They are caused by the interplay of various natural and anthropogenic factors and occur under diverse geoenvironmental conditions. In India, landslides occur primarily in the Himalayas of North India and in the Western Ghats of South India. This paper reports the results of field investigations for six landslide sites in North, Northeast and South India. We provide explanations as to why several landslides occurred at each of the sites. Our goal is to gain a deeper insight into the causes and precursors of landslides, which will facilitate more accurate identification of landslide-prone locations and enable early detection of landslide events.

1. Introduction
Landslides, mass movements of rock, debris or earth down a slope, are natural processes that have shaped much of the earth’s landscape. However, with increased human settlement in unstable terrain, landslides pose a more serious threat to humans than ever before, causing an estimated 5000 fatalities each year [1].

Landslides occur when the downward forces, including the force of gravity, exceed the cohesive forces holding the landmass together, and a failure of the slope-forming material results. Several factors contribute to a landslide occurrence – geological factors such as weak, sensitive and sheared material, the presence of fissures and joints, and contrasts in permeability or stiffness of the slope forming material; morphological factors such as tectonic uplift, glacial rebound and erosion of the hill slope or toe; physical factors such as heavy rainfall, rapid snow melt and earthquakes; and anthropogenic factors such as mining, deforestation and excavation of the hill slope or toe [2].

As part of a larger study [3], we visited and conducted field investigations on several landslide sites in the Himalayas of North India; the Sikkim Himalayas; the Patkai hills of the Northeast Himalayas; and the Western Ghats of South India. The sites have varying geologies, topographies, drainage patterns and geotechnical characteristics, but have nevertheless experienced quite a few landslides. In this paper, we report the results of reconnaissance studies of the following sites (please refer figure 1):

- Bhatwari, Uttarkashi Town, Uttarakhand State, Himalayas, North India
- Chandmari, Gangtok City, Sikkim State, Himalayas, Northeast India
- Old Mangan Bazaar, Mangan Town, Sikkim State, Himalayas, Northeast India
- Ramhlun Sports Complex, Aizawl City, Mizoram State, Patkai hills, Himalayas, Northeast India
- Laipuitlang, Aizawl City, Mizoram State, Patkai hills, Himalayas, Northeast India
- Anthoniar Colony, Munnar Town, Kerala State, Western Ghats, South India

2. Methods
We walked over each of the sites and neighbouring slides, accompanied by local geologists. Predominant rocks, minerals and geologic formations were identified. The presence of rivers, streams, and underground water sources was noted. Specific attention was paid to landslide indicators such as tilted trees, jammed doors and windows, and cracks on the ground and on structures. Old records of rainfall, land use, and landslide occurrence were consulted. The residents and local administration provided additional information. We present the results of these studies in this paper.

We have also conducted laboratory and in-situ soil tests [3], [4], and installed piezometers and inclinometers at some of the sites [4], the results of which are beyond the scope of this paper.

3. Bhatwari Landslide, Uttarkashi Town, Inner Himalayas, North India
The Bhatwari hill/village (30°49' N, 78°37' E, elevation 1610 m, figure 2), like numerous nearby hills, lies in Uttarkashi Town, along the banks of River Bhagirathi (one of the two headstreams of the Ganges river). The national highway NH 108 passes through these hills. Bhatwari, and the other hills in Uttarkashi, have experienced several landslides, particularly during the monsoons [5].

Uttarkashi is bounded by two major thrust faults – the Main Central Thrust (MCT) and the Srinagar Thrust, and is in a seismically active zone. The MCT separates two groups of rocks – the highly metamorphosed Central Crystallines (schists, gneisses, amphibolites, migmatises) that thrust southward over the less metamorphosed Garhwal Group (quartzites, epidiorites, slates). Bhatwari Hill has loose unconsolidated overburden of fluvioglacial material, while its bedrock consists of foliated mica schist sandwiched between massive jointed gneissic rocks.

Subsidence has been observed since 2009 [5]. A rainfall-triggered landslide occurred on the night of
12–13 August 2010, and another slide occurred on 16 June 2013 during the 2013 Uttarakhand floods [5]. The factors that contributed to these landslides include erosion of the hill’s toe by the Bhagirathi, saturation of the loosely-consolidated overburden, the steep slope of the hill, the highly jointed bedrock, the presence of thin mica schist foliations between the jointed gneissic rocks, and the presence of water leading to the removal of fines at the overburden-rock interface.

Figure 2. Bhatwari Landslide

Figure 3. Chandmari Landslide

4. Chandmari Landslide, Gangtok City, Inner Himalayas, Northeast India

Chandmari Hill (27°20’ N, 88°33’ E, elevation 1459 m, figure 3) is located in the Eastern Himalayan mountain ranges of Gangtok city, the capital of Sikkim State.

The Daling Group of rocks (quartzites, phyllites, dolomites) occurs commonly, along with foliated augen gneisses having streaky character, such as the Lingtse Gneiss [6]. Bands of weathered biotite-muscovite schist are also frequently encountered. There is thick soil overburden mixed with boulders and weathered mica gneiss. The predominant minerals include quartz, feldspar and mica.

Subsidence was first observed in 1966 [7]. The landslide was fairly active during the period 1975–1976, but thereafter, it remained relatively stable until its reactivation in June 1984 as a landslide and subsidence zone [8]. A rainfall of 211 mm in 4 hours on the night of 8–9 June 1997 triggered at least nine landslides in and around Gangtok, including one at Chandmari. Rainfall-triggered landslides occurred in July 2007 and June 2011, while an earthquake on the Sikkim-Nepal border on 18 September 2011 triggered minor debris slides. Currently, downward creep is observed here.

The factors contributing to landslide occurrences include heavy rainfall, the presence of weathered rocks, the contrast in permeability in adjacent soil layers, seismic activity, and anthropogenic factors such as improper construction activities.

5. Old Mangan Bazaar Landslide, Mangan Town, Inner Himalayas, Northeast India

Mangan is the headquarters of North Sikkim District. Old Mangan Bazaar (27°30’ N, 88°32’ E, elevation 1137 m, figure 4), the local market place, has experienced landslides in the past [9].

Mangan is dominated by three rock types – quartz-biotite schist, biotite schist and garnetiferous mica schist. Schists are characteristically foliated and hence easily eroded. The river Teesta flows at about a kilometre away from this area and erodes the toe of the hill, leading to further instability.

The most recent landslide occurred after a rainfall of 196.6 mm on 20 September 2012. Heavy rainfall during 19–23 September 2012 triggered many more landslides in the region. Old landslides were reactivated due to heightened erosion by Raffong Khola, a tributary of River Teesta.
6. Ramhlun Sports Complex Slide, Aizawl City, Patkai hills, Inner Himalayas, Northeast India

Aizawl, the capital city of Mizoram state, is set on a narrow, elongated, north-south trending anticlinal ridge, and has an average elevation of 1132 m. Ramhlun Sports Complex (23°45' N, 92°43' E, elevation 963 m, figure 5) is a densely populated locality in Aizawl City, with an escarpment to its east, and Bangla Lui, a tributary stream of Chite Lui River, flowing along its northern border.

Only sedimentary rocks are found in Mizoram. The rock formation at Ramhlun Sports Complex consists of a thin bed of fine-grained silty shale underlying a relatively thick bed of silty sandstone/siltstone, which in turn underlies well-bedded sandstone. Several joint sets, as well as fractures, are present in the rock bed. The overburden consists of sandy soil with soft shale fragments.

Creep movement has been observed since 1994. Rainfall-triggered rock falls–debris slides occurred on 19 July 2004, 14 September 2007, and during the period 10–20 August 2012. More recently, in August 2013, several houses collapsed due to land subsidence. The joints, fractures and cracks in the rock bed play a critical role in destabilising the slope. Other factors that contribute to slope instability include the abrupt escarpment to the east, the presence of pronounced bedding planes in the bedded sandstone, heavy rainfall, erosion by Bangla Lui Stream, and an improper drainage system that allows water to seep through the joints and cracks, leading to saturation of the overburden material.

7. Laipuitlang Landslide, Aizawl City, Patkai hills, Inner Himalayas, Northeast India

Laipuitlang Hill (23°44' N, 92°43' E, elevation 1134 m, figure 6) is another densely populated locality in Aizawl City. The bedrock consists of shale underlying bedded sandstone, while the overburden consists of sandy soil interspersed with fragments of shale. Joints are present in the rock bed.

The area was once a sandstone quarry; quarrying destabilised the slope, and rockslides occurred in 1957 and 1968. Quarrying was then discontinued. Further rockslides occurred on 5 May 2002 and 25 November 2007 following indiscriminate excavation of the hill. [10], [11]

The next sign of landslide activity was in 2010 when cracks developed in a five-storied building. In September 2012, cracks appeared in the rock bed and on the walls of a large Public Works Department (PWD) building that was located on the crown of the hill. The base of the building was on the sandstone-shale interface. In the interest of safety, geologists from the Directorate of Geology and Mineral Resources, Government of Mizoram, strongly recommended the demolition of the building, but timely action was not taken. On account of improper drainage, rainwater penetrated the foundation of the PWD building and further weakened it. At 2:30–3:00 am, 11 May 2013, after a week of heavy rainfall, the building and its foundation slid downhill burying ten houses and a church. The top sandstone layer was almost completely eroded – only a little remains along the left flank. [10], [11]
Anthropogenic factors – quarrying, indiscriminate excavation of the hill, the construction of the large PWD building on the sandstone-shale interface – played a major and obvious role in the Laipuitlang landslides. Other causative factors include the presence of vertical joints, heavy rainfall, improper drainage, and water seepage through rock joints and bedding intersections. Shale can be a problematic material; water caused the weathering of the shale foundation, and this weakening and the subsequent sliding of the foundation played a pivotal role in the 2013 landslide occurrence.

8. Anthoniar Colony Landslide, Munnar Town, Western Ghats, Southwest India
Anthoniar Colony (48°08' N, 11°31' E, elevation 1520 m, figure 7) is located in the tourist town of Munnar in Kerala State.

Precambrian crystallines consisting of hornblende-biotite gneiss, biotite gneiss, granite gneiss, charnockite and pink granites form the main rock types at Munnar [12]. The bedrock at Anthoniar Colony consists of granite gneiss, underlying thick overburden of lateritic soil. Predominant minerals include kaolinite and illite; quartz sericite bands are also seen. Fissures are observed on the hill [4].

Two slides have occurred at Anthoniar Colony. The first one in 1926 was most likely caused by the combined action of rainfall and weak geology, since the place was uninhabited then. More recently, a torrential downpour of 451 mm on 25 July 2005 triggered landslides here and at two other sites in Munnar. This slide was exacerbated by human activity such as the excavation of the hill [4].

9. Results and Discussion
1. We have presented the results of our field investigations – the geology of the landslide sites, and the causes of the slides – in the preceding sections. India consistently has one of the highest incidences of landslides, but there is insufficient information on the geology of the sites and the slides themselves. A record and subsequent study of such data will facilitate better understanding of landslide causes and consequently, a more accurate prediction of landslide events.

Our findings on the Bhatwari slide (section 3) can be extrapolated to other landslide events in the vicinity. We visited the nearby slides and noted that the hills all lie on the banks of the Bhagirathi, have similar geology and slope angle as Bhatwari Hill, and like the latter, they too experienced landslides on 16 June 2013. We are led to believe that as in the case of Bhatwari Hill, these landslides were also caused by the combined action of toe erosion by the Bhagirathi, and saturation of loosely-consolidated overburden induced by excessive rainfall.

Caution should be exercised in extrapolating results. Both Ramhlun (section 6) and Laipuitlang (section 7) in Aizawl have similar geology, but the slides at Laipuitlang were caused primarily due
to anthropogenic factors, while geological factors played a predominant role in the Ramhlun slides.

2. Our results illustrate that landslides occur under diverse geoenvironmental conditions (sections 3 – 8). Landslides are seldom caused by a single factor; rather, they usually occur due to the combined effect of several causes. These causes may increase shear stress, or decrease material strength, or simultaneously increase shear stress and decrease material strength [2]. For example, erosion at Bhatwari, Mangan and Ramhlun Sports Complex leads to a removal of lateral support, which causes an increase in shear stresses acting on the hill. Another example is the presence of joints, foliations, bedding surfaces, faults, fissures or discontinuities which are seen at the sites described in this paper and which contribute to the low strength of the slope-forming material. Yet another example is rainwater infiltration which increases soil weight (and thus, shear stress) and simultaneously decreases the strength of the slope-forming material.

3. Landslides occur either due to natural causes alone as in the case of the 1926 Anthoniar Colony slide, or due to a combination of natural and anthropogenic causes as seen in the Laipuitlang slides.

10. Conclusion
We have presented an account of the geology and landslide causes for six landslide sites in different regions of India. The causative factors have been examined in detail.

References
[1] Petley D N, Dunning S A and Rosser N J 2005 The analysis of global landslide risk through the creation of a database of worldwide landslide fatalities Landslide Risk Management (Amsterdam: Balkema) pp 367–74
[2] Cruden D M and Varnes D J 1996 Landslide types and processes Landslides: Investigation and Mitigation (Transportation Research Board Special Report 247) ed A K Turner and R L Schuster (Washington DC: National Academy Press) chapter 3 pp 67–71
[3] Vasudevan N and Ramanathan K 2015 Geotechnical characterization of a few landslide-prone sites in India Proc. 6th Int. Geotechnical Symp. on Disaster Mitigation in Special Geoenviron. Cond. (Chennai: Indian Geotechnical Society, Chennai Chapter) pp 509–12
[4] Ramesh M and Vasudevan N 2012 The deployment of deep-earth sensor probes for landslide detection Landslides 9(4) pp 457–474
[5] Dangwal D P, Chauhan N, Ghosh M and Ghosh T 2014 Preliminary Slope Stability Assessment of the Recent Disaster Affected Areas of Uttarkashi District, Uttarakhand, (Kolkata: Geological Survey of India)
[6] Paul D K, McNaughton N J, Chattopadhyay S and Ray K K 1996 Geochronology and Geochemistry of the Lingtse Gneiss, Darjeeling - Sikkim Himalaya: Revisited J. Geol. Soc. India 48(5) pp 497–506
[7] Rawat R K 2005 Geotechnical investigations of Chandmari landslide located on Gangtok-Nathula road, Sikkim Himalaya, India. Him. Geol., Dehra Dun 26(2) pp 309–22
[8] Basu S R and De S K 2003 Causes and consequences of landslides in the Darjeeling-Sikkim Himalayas, India. Geographia Polonica 76(2) pp 37–52
[9] Larsen J O, Grimstad E, Bhasin R, Dhawan A K, Singh R and Verma S K 2000 Landslides and their mitigation in Gangtok, Sikkim J. Nepal Geo. Soc. pp. 585-590
[10] Verma R 2014 Landslide Hazard in Mizoram: Case Study of Laipuitlang Landslide, Aizawl. Int. J. of Sci. and Res. 3(6) pp 2262-6
[11] Laldinpuia, Kumar S and Singh T N 2014 11th May, 2013 Laipuitlang Rockslide, Aizawl, Mizoram, North-East India. Landslide Science for a Safer Geoenvironment (Springer International Publishing) pp 401–5
[12] Abraham P B and Shaji E 2013 Landslide hazard zonation in and around Thodupuzha-Idukki-Munnar road, Idukki district, Kerala: A geospatial approach J. Geol. Soc. India 82(6) p 649