Influence of Geological Factors on Landslides: A Review of Several Landslides in Various Regions Of India

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Abstract:Massive downslope movements of rock, detritus, or earth that constitute landslides are global occurrences that annually result in estimated 5,000 fatalities and extensive property damage. These phenomena arise from the complex interaction of human-induced and natural influences, and they manifest in a wide range of geoenvironmental conditions. Landslides predominantly transpire in the Himalayas of northern India and the Western Ghats of southern India within the country of India. Six landslip sites in the northern, northeastern, and southern regions of India were investigated in the field for the purposes of this article. At each of the locations, we offer explanations for the occurrence of multiple landslides. The objective of our research is to acquire a more comprehensive understanding of the precursors and causes of landslides. This knowledge will empower us to identify landslide-prone areas with greater precision and facilitate the timely detection of landslide incidents.

I.INTRODUCTION

Massive movements of rock, detritus, or earth down a slope, known as landslides, are natural phenomena that have significantly influenced the topography of the planet. Nevertheless, as human habitation expands into precarious terrain, landslides present an unprecedented peril to humanity, resulting in an approximate annual toll of 5000 lives [1].

Landslides transpire when the cohesive forces that maintain the landmass together are surpassed by the downward forces, which include the gravitational force. As a consequence, the slope-forming material fails. A multitude of factors contribute to the occurrence of landslides. These include morphological elements such as tectonic uplift, glacial rebound, and erosion of the hill slope or toe; physical factors including heavy rainfall, rapid snow melt, and earthquakes; and anthropogenic elements including mining, deforestation, and excavation. Each of these contributes to the likelihood of a landslide occurring.

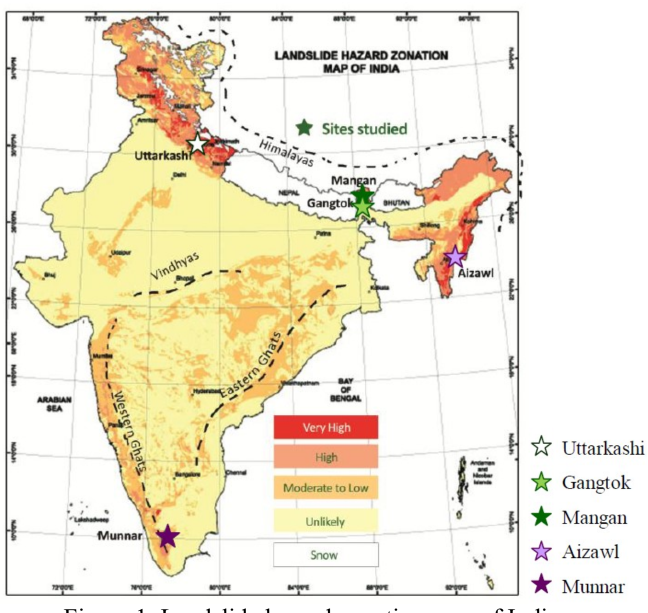

Figure 1. Landslide hazard zonation map of India.
(The towns/cities –Uttarkashi, Gangtok, Mangan, Aizawl and Munnar – are also indicated)

We visited and conducted field investigations at multiple landslide sites in the Sikkim Himalayas, the Patkai highlands of the Northeast Himalayas, and the Western Ghats of South India as part of a larger study [3]. Despite the diverse geologies, topographies, drainage patterns, and geotechnical characteristics of the sites, a significant number of landslides have occurred at each. The following sites' reconnaissance results are presented in this article (refer to Figure 1):

- Himalayas, Bhatwari, Uttarakhand State, Uttarkashi Town, North India
- Gangtok City, Chandmari, Sikkim State, Northeast India, Himalayas
- Eastern Mangan Bazaar, Mangan Town, Sikkim State, Northeast India, Himalayas
- Aizawl City, Mizoram State, Ramhlun Sports Complex, Patkai Hills, Himalayas, Northeast India
- Northeast India, Laipuitlang, Aizawl City, Mizoram State, Patkai Hills, Himalayas
- Anthoniar Colony, Munnar Town, Western Ghats Region of Kerala State, Southern India

1. Methods

We traversed each of the locations and adjacent slides in the company of regional geologists. Identification of prevailing materials, minerals, and geological formations. It was observed that rivers, streams, and subterranean water sources were present. Particular emphasis was placed on indicators of landslides, including skewed trees, blocked doorways and windows, and fissures in both the ground and structures. Archives of precipitation, land utilization, and landslide incidence were consulted. Local government and residents supplied supplementary information. The findings of these investigations are detailed in this article. Additionally, laboratory and in-situ soil tests were performed [3], [4], and piezometers and inclinometers were installed at select sites [4]. The outcomes of these investigations are not covered in the present manuscript.

3. Bhatwari Landslide, Uttarkashi Town, Inner Himalayas, North India

Similar to several neighboring hills, the Bhatwari hill/village (30°49’ N, 78°37’ E, elevation 1610 m, figure 2) is situated along the banks of the River Bhagirathi, one of the two headstreams of the Ganges, in Uttarkashi Town. National Highway 108 traverses the aforementioned peaks. Numerous landslides have occurred in Bhatwari and the surrounding highlands of Uttarakashi, specifically apprehensively during the monsoon season [5].

Uttarakashi is situated in a seismically active zone and is bounded by two main thrust faults: the Main Central Thrust (MCT) and the Srinagar Thrust. The metamorphosed Central Crystallines (schists, gneisses, amphibolites, migmatites) that protrude southward over the less metamorphosed Garhwal Group (quartzites, epidiorites, slates) constitute the MCT. Fluvioglacial material is present as a loose, unconsolidated overburden on Bhatwari Hill, which is composed of foliated mica schist sandwiched between massive jointed gneissic rocks.

Since 2009, subsidence has been documented [5]. A landslip induced by precipitation transpired from the evening of August 12th to the 13th, 2010, and an additional slide transpired on June 16th, 2013 amidst the Uttarakhand floods of 2013 [5]. Erosion of the hill's toe by the Bhagirathi, saturation of the loosely-consolidated overburden, the steep slope of the hill, the presence of thin mica schist foliations between the jointed gneissic rocks, and water leading to the removal of fines at the overburden-rock interface were all contributory factors to these landslides.

Figure 2. Bhatwari Landslide

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

Figure 3 illustrates the location of Chandmari Hill (27°20' N, 88°33' E, 1459 m elevation) within the Eastern Himalayan mountain ranges of Gangtok, the capital of Sikkim State. The Daling Group, which consists of dolomites, phyllites, and quartzites, is frequently encountered, in addition to streaky foliated augen gneisses like the Lingtse Gneiss [6]. Additionally, bands composed of weathered biotite-muscovite schist are often observed. A substantial accumulation of soil overburden coexists with weathered mica gneiss and boulders. Prevalent minerals in the area consist of quartz, feldspar, and mica.

In 1966, subsidence was initially documented [7]. Following its relatively active phase from 1975 to 1976, the landslide exhibited a period of relative stability until its reactivation as a landslide and subsidence zone in June 1984 [8]. On the night of June 8-9, 1997, a precipitation of 211 millimeters in four hours caused at least nine landslides in the vicinity of Gangtok, one of which occurred in Chandmari. Landslides instigated by precipitation transpired in July 2007 and June 2011, whereas minor debris slides were instigated by an earthquake that struck the Sikkim-Nepal border on September 18, 2011. At the moment, a downward trend is being detected in this location.
Landslide occurrences can be attributed to various factors, including but not limited to heavy precipitation, the existence of weathered rocks, the contrast in permeability between adjacent soil strata, seismic activity, and anthropogenic influences like improper construction practices.

Figure 3. Chandmari Landslide

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

District headquarters for North Sikkim are located in Mangan. The local marketplace, Old Mangan Bazaar (27°30' N, 88°32' E, 1137 m elevation, figure 4), has previously been affected by landslides [9]. Three rock varieties predominate in Mangan: biotite schist, quartz-biotite schist, and garnetiferous mica schist. Due to their characteristic foliation, schists are susceptible to erosion. Approximately one kilometer from this location, the Teesta River erodes the hill's base, causing additional instability. The most recent deluge transpired on September 20, 2012, subsequent to a precipitation of 196.6 mm. Extreme precipitation from September 19–23, 2012, precipitated numerous additional landslides in the area. RaffongKhola, a tributary of the River Teesta, exacerbated erosion, which reactivated previous landslides.

Figure 4. Mangan Landslide

6. Ramhlun Sports Complex Slide, Aizawl City, Patkai hills, Inner Himalayas, Northeast India

Aizawl, the administrative center of the state of Mizoram, is situated at an average elevation of 1132 meters on a narrow, elongated, north-south trending anticlinal ridge. Ramhlun Sports Complex, situated at an elevation of 963 m (23°45’ N, 92°43’ E) and bounded to the east by an escarpment and the north by Bangla Lui, a tributary stream of the Chite Lui River, is a densely populated area in Aizawl City (figure 5).

In Mizoram, only sedimentary minerals are present. A narrow bed of fine-grained silty shale underlies a relatively thick bed of silty sandstone/siltstone, which is followed by well-bedded sandstone, constitutes the rock formation at Ramhlun Sports Complex. A number of joint pairs and fractures are discernible within the granite substrate. The overburden is comprised of fragments of porous shale embedded in powdery soil.

Since 1994, creep movement has been documented. Debris collapses and rock falls triggered by precipitation transpired on the 19th of July, 2004; the 14th of September, 2007; and the 10th and 20th of August, 2012. More recently, in August 2013, land subsidence caused the collapse of several homes. Joints, fractures, and fissures within the granite substrate are pivotal contributors to the slope's instability. Additional elements that contribute to slope instability comprise the sharp eastward escarpment, conspicuous bedding planes within the bedded sandstone, substantial precipitation, erosion caused by Bangla Lui Stream, and an inadequate drainage system that permits water infiltration through joints and fissures, resulting in overburden material saturation.

Figure 5. Landslide at Ramhlun Sports Complex

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

Figure 6 illustrates Laipuitlang Hill (23°44' N, 92°43' E, 1134 m elevation) as an additional densely populated area within Aizawl City. Substratum bedded sandstone is composed of shale, whereas the overburden is comprised of granular soil that is fragmented with shale. Joints can be observed within the granite substrate.

The region was formerly a sandstone quarry; the slope was destabilized by the quarrying, which caused rockslides in 1957 and 1968. Quarrying ceased at that time. The hill experienced additional rockslides on 5 May 2002 and 25 November 2007 as a result of careless excavation. [10], [11]
The next indication of landslide activity was the development of fissures in a five-story structure in 2010. Cracks began to manifest in September 2012 along the walls and limestone base of a sizable Public Works Department (PWD) structure perched atop the hill. Placing the building at the interface of shale and sandstone was essential.

Geologists from the Directorate of Geology and Mineral Resources, Government of Mizoram, firmly advised the building's demolition for reasons of safety; however, no prompt action was taken. Due to inadequate drainage, precipitation infiltrated the substructure of the PWD structure, exacerbating its structural vulnerability. After a week of intense rainfall, the structure and its foundation fell downhill between 2:30 and 3:00 am on 11 May 2013, submerging ten dwellings and a church. On the left flank, the uppermost sandstone stratum was virtually entirely eroded, with only a few remnants remaining. [10], [11].

The Laipuitlang landslides were significantly and visibly influenced by anthropogenic factors, including quarrying, indiscriminate excavation of the hill, and the construction of the enormous PWD building on the sandstone-shale interface. Additional contributing factors comprise the existence of vertical joints, substantial precipitation, inadequate drainage, and water infiltration through bedded intersections and rock joints. Shale is a potentially problematic material; the occurrence of the 2013 landslide was significantly influenced by the deterioration and subsequent shifting of the shale foundation, which was precipitated by water.

Figure 6. Laipuitlang Landslide

8. Anthoniar Colony Landslide, Munnar Town, Western Ghats, Southwest India

Figure 7 illustrates the location of Anthoniar Colony (48°08' N, 11°31' E, 1520 m elevation) in the Kerala State tourist town of Munnar. The primary rock types at Munnar are Precambrian crystallines, which include hornblende-biotite gneiss, biotite gneiss, granite gneiss, charnockite, and pink granites [12]. Granite gneiss forms the bedrock at Anthoniar Colony, which is covered by a substantial overburden of lateritic soil. Kaolinite and illite are the predominant minerals, with quartz sericite patterns also being observed. There are fissures visible on the hill [4].

Two slide events have taken place in Anthoniar Colony. The initial one that occurred in 1926 was plausibly the result of precipitation and poor geological conditions, as the area was devoid of inhabitants at the time. More recently, on July 25, 2005, a torrential deluge of 451 mm caused landslides in this location as well as two other locations in Munnar. The slope was further intensified as a result of anthropogenic activities, including the excavation of the hill [4].

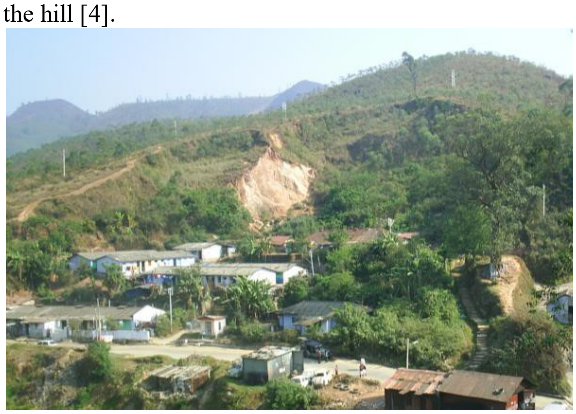

Figure 7. Anthoniar Colony Landslide

II. RESULTS AND DISCUSSION

In the antecedent sections, we detailed the findings of our field investigations, including the geology of the landslide sites and the causes of the collapses. India consistently experiences a high frequency of landslides; however, the available information regarding the geology of these sites and the slides themselves is inadequate. Such data, when documented and analyzed subsequently, will aid in the comprehension of landslide causes and, as a result, in the development of more precise forecasts for landslide occurrences.

The implications of our results regarding the Bhatwari collapse (section 3) extend to other landslide incidents in the surrounding area. Upon observing the adjacent slides, we observed that all of the hills are situated along the Bhagirathi River, possess comparable geological characteristics and slope angle to Bhatwari Hill, and landslides occurred on June 16, 2013, just as they did on that date. There is an assumption that, similar to the landslides on Bhatwari Hill, these also resulted from the combined effects of excessive rainfall and toe erosion induced by the Bhagirathi River over loosely compacted detritus.

It is advisable to exercise caution when extrapolating findings. Laipuitlang (section 7) and Ramhlun (section 6) both have comparable geological characteristics in Aizawl; however, anthropogenic factors were the primary cause of the slides at Laipuitlang, whereas geological factors were the predominant contributors to the Ramhlun slides.

The findings of our study demonstrate that landslides transpire in various geoenvironmental circumstances (sections 3 through 8). Rarely do landslides result from the action of a single factor; instead, they are frequently triggered by the interaction of multiple causes. The aforementioned factors have the potential to either elevate shear stress or diminish material strength, or even both [2]. As an illustration, erosion at the Bhatwari, Mangan, and Ramhlun Sports Complex results in the deprivation of lateral support, thereby augmenting the shear stresses exerted on the hill. An additional illustration pertains to the joints, foliations, bedding surfaces, faults, fissures, or discontinuities that are observed at the locations detailed in this manuscript. These features significantly contribute to the slope-forming material's diminished strength. Additionally, precipitation infiltration can lead to an increase in soil weight and, consequently, shear tension, while concurrently reducing the strength of the material used to form the slope.

Landslides may be triggered exclusively by natural factors, as exemplified by the Anthoniar Colony slide of 1926, or by a confluence of natural and anthropogenic influences, as demonstrated by the Laipuitlang slides.

III.CONCLUSION

Geographical characteristics and landslip triggers for six distinct landslip locations across India have been described. A comprehensive analysis of the causal factors has been conducted.

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