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Study of Slope Failures in and around Yuksom, the First Capital of Sikkim, India- A case study

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Abstract

Harmful landslides like other hilly regions of India have affected Sikkim Himalayas; these disasters are triggered naturally as well as due to intervention of anthropogenic activities. The rapid urbanization in the hilly terrains and consequently exploited for the benefits of the dwellers of the state. At present the increasing in number of landslides are due to the extension of anthropogenic activities in the different areas. Loss of lives and property along with economic losses in the state is a big challenge. Hampering of road traffics in Sikkim is very much affected due to landslides and the tourism which is the major source of revenue in the state is heavily affected. Yuksom is a well known tourist destination in the state. The present study carried out on Yuksom- Tashiding road section of West Sikkim district in the state of Sikkim. The roads are being affected by slope failures especially during the monsoon season. The geology plays an important role in triggering of landslide along with other factors. The area comprises of rocks belongs to Daling Group, which consists of phyllites and quartzites rocks. As per the nature of phyllite, when wet it loses 25% shear strength as compared to dry rocks, hence this becomes highly vulnerable for landslides during monsoon period. The geological mapping of the landslides using Survey of India topographic maps, satellite imagery, Google earth, landslide inventory from published literature and field survey. By integrating all the data in the ArcGis 10.6 and Erdas Imagine 2016 proper delineation of the slope failures done. A total of 15 landslides studied to understand their types and causative factors.

Introduction

Indian Himalayan region has always been the victim of the adverse effects of the slope failures. Sikkim Himalayas has no exception in this context as every year the state is affected by the series of slope failures at different locations. Himalayan terrain is unstable due to its inherent intense tectonic activity and the complex geology. Landslides cause various problems and losses which directly affect the economy of the area. These disasters are produced both by the natural phenomenon and the anthropogenic activity (Guzzetti, 1999). If we talk of history of Sikkim in this context, the state was worst hit by hundreds of landslides in the year 1968 killing more than 33,000 people (Bhasin et. al, 2002). This was one of the biggest disasters in the region. Himalayas of which Sikkim is a part is one of the youngest mountains in the world and has got the most complex topography. Indian Himalayan Region comprises 18% area of the country, where 6% of the population is living (Rawat et.al, 2012). Sikkim is affected by landslides mostly in the rainy season which are triggered by continuous heavy rainfall. These landslides are mostly affected by the super saturation of the slope forming materials. In the present scenario landslide has attracted the attention due to the increasing awareness of the social economic impact of landslides and increasing urbanization on the mountain environment (Aleotti and Choudhury, 1999). The different condition under which landslides can be triggered are intense rainfall, earthquake, variation of water level, snowmelt, typhoon etc. (Jiang et.al, 2016;Yang et.al,2016; Xie et.al, 2015; Wu et.al, 2014; Dai et.al, 2002; Keefer, 1999). The different influencing factors for the landslides are structural, lithological, geomorphologic, climatic, environmental, hydrological, seismological conditions and the anthropogenic activities of the area.

The present study area lies in the West District of Sikkim (N27^{0} 21.062' E88^{0} 16.334' to N27^{0} 21.717' E88^{0} 13.125') in the Yuksom-Tashiding road section area. Sikkim is prone to landslides due to the factors like heavy rainfall, weak geology and frequent occurrences of earthquakes (Tashi, 1993). With the rapid urbanization the infrastructures are rapidly developing in the vulnerable terrains as well. This is one of the factors which are accelerating these disasters. The study has also got significance in this area because these places are of tourist attraction because of the presence of Kanchenjunga National Park and ancient Monasteries. Yuksom was also the first capital of Sikkim and Tashiding is a home to ancient monasteries, therefore the place has got significance.

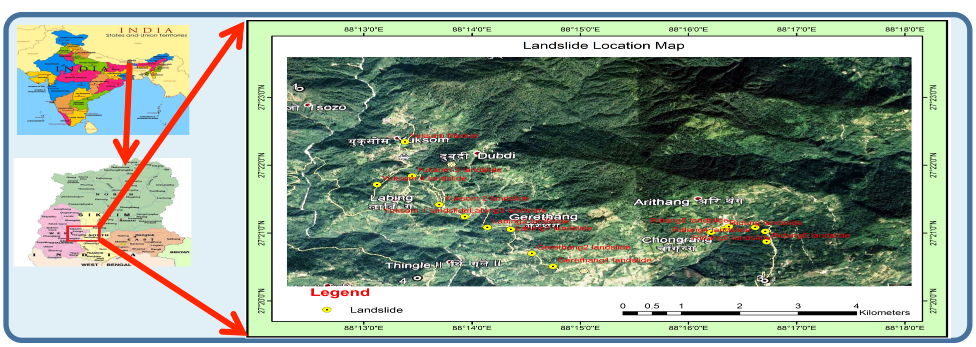

Figure1: Landslide location map of the study area (Google Earth,2018)

The average rainfall in states varies from 2000mm to 5000mm. Rainfall data of west Sikkim district of the last five years from 2013 to 2017 is also confirming the rainfall trend (Figure 2) The lithology of the area are mostly foliated metamorphic rocks comprising phyllite, quartzite and schist. All these rocks belong to the Precambrian age. The fragile foliated rocks coupled with heavy rainfall are the main triggering factors for the slope failures.

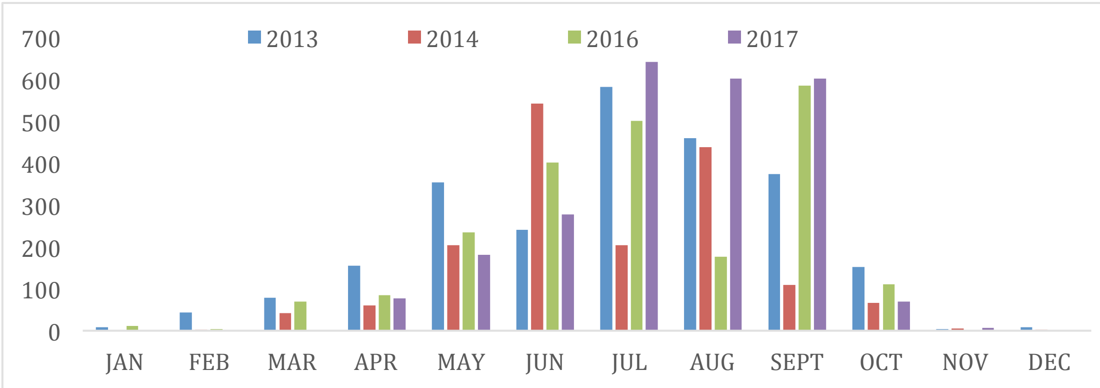

Figure 2: Rainfall data of West Sikkim from 2013-2017 (IMD, 2018)

The main purpose of this study is mapping and delineation of the landslides with direct field study, studying different deformations, discontinuities and lithologies. Uses of kinematic analysis for identification of different failure types are made. Remote sensing and GIS techniques are used for the generation of maps. The formations of the study area are given in the Table 1.

Table.1: Generalized stratigraphic succession of Sikkim Himalaya (As per unified legend scheme of GSI, 2012)

Lithology	Formation		Group/age
Ortho-quartzite, pyritiferous black slate, variegated cherty phyllite, meta- greywacke	Reyang Formation	Daling Group	Proterozoic Undifferenciated
Interanded chlorite-sericite schist/ phyllite and quartzite, meta-greywacke(quartzo-feldspathic greywacke), pyritiferous black slate, biotitephyllite/mica schist,biotite quartzite, mica schist with garnet, with/ without staurolite, chlorite quartzite	GorubathanForamtion		

Materials and Methods

The methodology is divided into three stages like Pre-field investigation, Field investigation and the Post-Field investigation. The pre-field investigation included preparation of base map using different Geo-tools and Geodata. This included the map preparation using different Remote Sensing imagery such as digital elevation model (DEM) and other Geo-tools like ArcGis (ArcMap 10.6) to generate various vector layers such as drainage, river, study sites etc. The details used to generate vector layers have been shown in the table (Table.2). Field investigation is the most important part, where direct field visit has been done and the lithology and other discontinuities have been marked taking point location of the landslide affected area with the GPS device. Also taking the various dimensions of the landslide like height, width etc. In the post field study all the data collected from the field has been incorporated in the map to give the final output. Kinematic analysis of the discontinuities done to find out the different failure types.

Table 2: Vector layers created from generation of geo-data base for the study area.

Map	Form	Source	File type	Software used
Drainage	Polyline	SOI Toposheet	Shapefile	ArcMap10.6
Observation sites	Point	GPS	Shapefile	ArcMap10.6
Landslide zones	Point	GPS, Google earth	Shapefile	ArcMap10.6

Results and Discussions

A total of 15 landslides wre delineated in the road section of the study area connecting Yuksom_Tashiding road section in the West Sikkim district of Sikkim. Out of the total 15 landslide, 4 of them are more vulnerable viz. Ridang landslide, Ridang2 landslide, Gerethang2 landslide and Yuksom 3 landslide. Ridang landslide is the most disastrous, damaging almost 5 acre crop field and two houses of the local residents. Phyllites, schists and quartzites are the major lithologies which are found in the study area. The major causative factors are weak lithology highly fractured and weathered with lot of discontinuities. Road cutting is another serious concern which is taking place in the rainy season. All these factors coupled with the heavy continuous rainfall are the main causative and the triggering factors of these failures. Roads are the major affected part due to these slope failures. Apart from the road damage and blockade, the retaining walls are highly affected and have been damaged due to these activities. The settlements (houses) of the villagers are at great risk. A maximum of three set of joints in the rocks were measured. All these discontinuity are analyzed using Kinematic Analysis in Dips 6.0 to delineate the different types of failures and in all the locations the failure type is planar. In the Kinematic analysis the failure is not very severe but due to the other supporting factors like fragile geology and heavy precipitation, these failures are extremely hazardous. People are risking their life by living in landslide prone zone. Even the properties of the villagers are damaged by these failures. Different field photographs of the affected area are shown in the images below (Figure 3). The detailed landslide inventory of the 15 locations in this study is given in the Table 3.

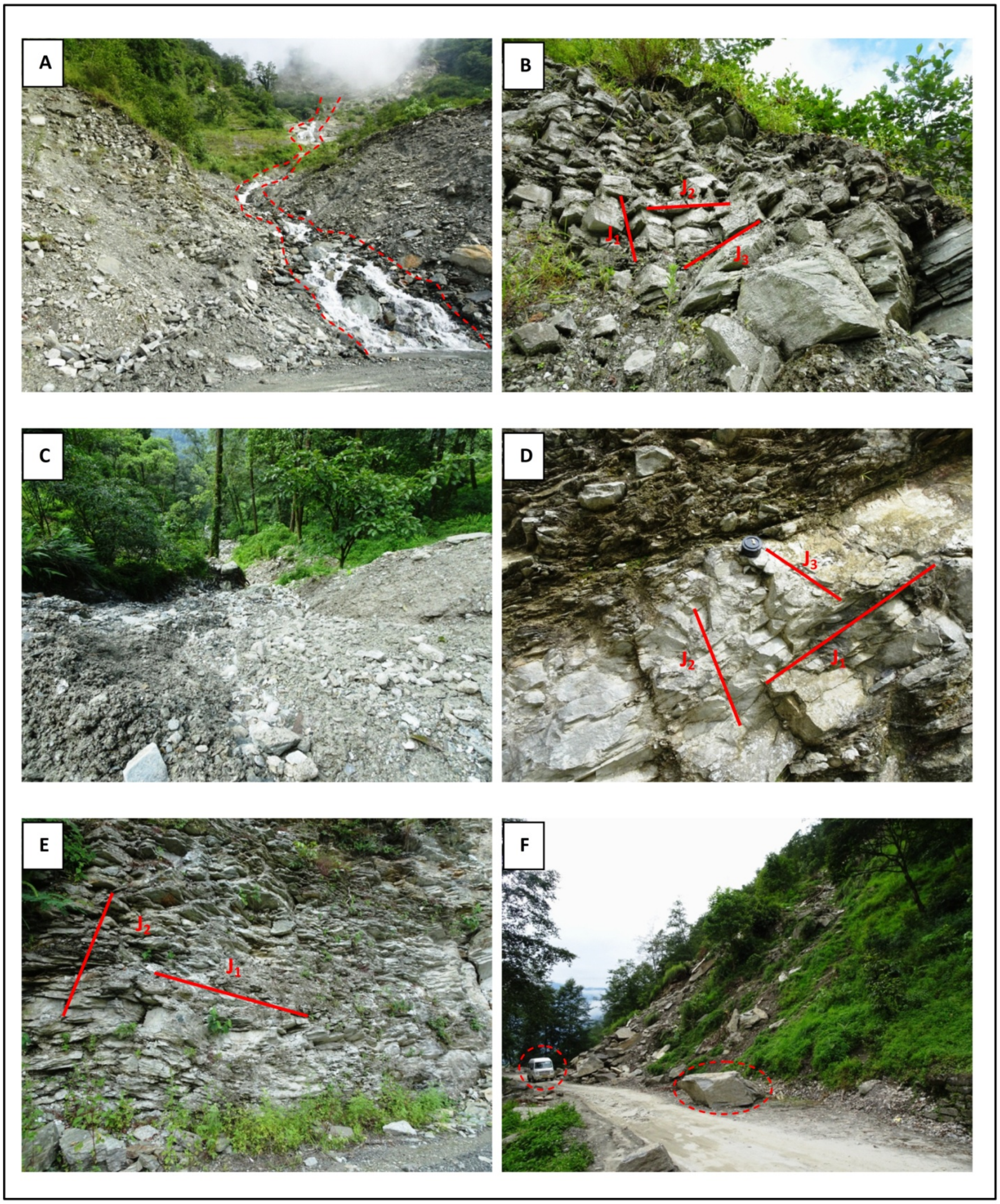

Figure 3: A) Water channel in Ridang1 slide B) Three set of joints in Ridang1 slide C) Ridang2 slide D) Ridang3 slide with three set of joints E) Gerethang1 slide with two set of joints F) Gerethang2 slide with rockfall in the road making the traffic at risk.

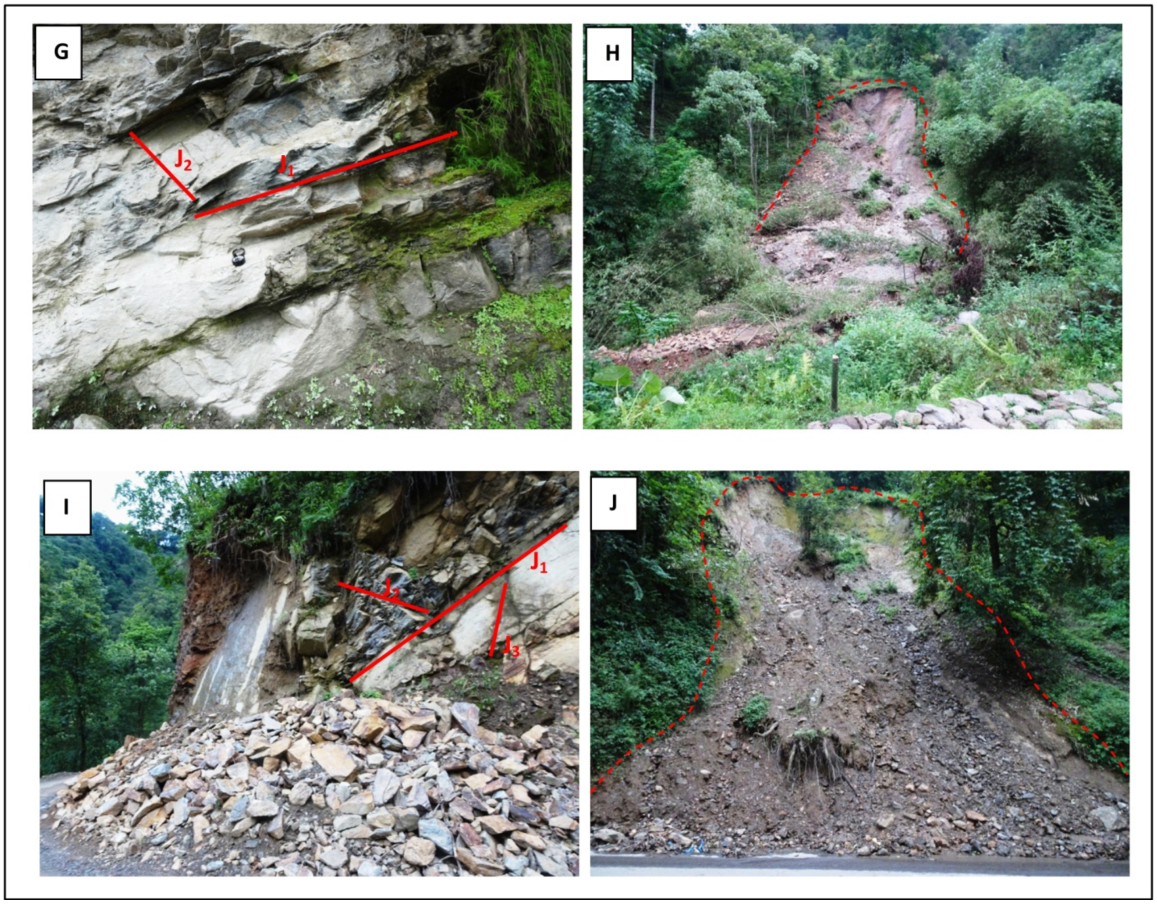

Figure 3: G) Two joint sets in Gerethang2 slide H) Yuksom1 slide I) Yuksom3 slide induced by road cut with three set of joints J) Yuksom4 slide induced by rainfall

The detailed kinematic analysis of some selected location is given. In the figure it is very clearly mentioned the different sets of joints, types of failures etc. The shaded portions in the figures are the direction of probability of failure. We can clearly have the idea in which direction there is the high chance of failure.

In the current study the detailed geological map of the study area that is the road section between Yuksom and Tashiding is done. A total of 15 landslides have been delineated out of which 4 of them are quite severe viz. Ridang landslide, Ridang2 landslide, Gerethang2 landslide and Yuksom 3 landslide. Much damage is caused by these landslides affecting the roads and the properties of the dwellers. The lithology identified in the field study are the metamorphic rocks of the Precambrian age. The rocks are mostly foliated such as phyllites, schists and quartzite. These rocks are fractured and highly weathered with lots of discontinuities. A maximum of three joints sets are marked in the field and kinematic analysis of joint data is performed. All the failures from Kinematic analysis are of Planar failure type

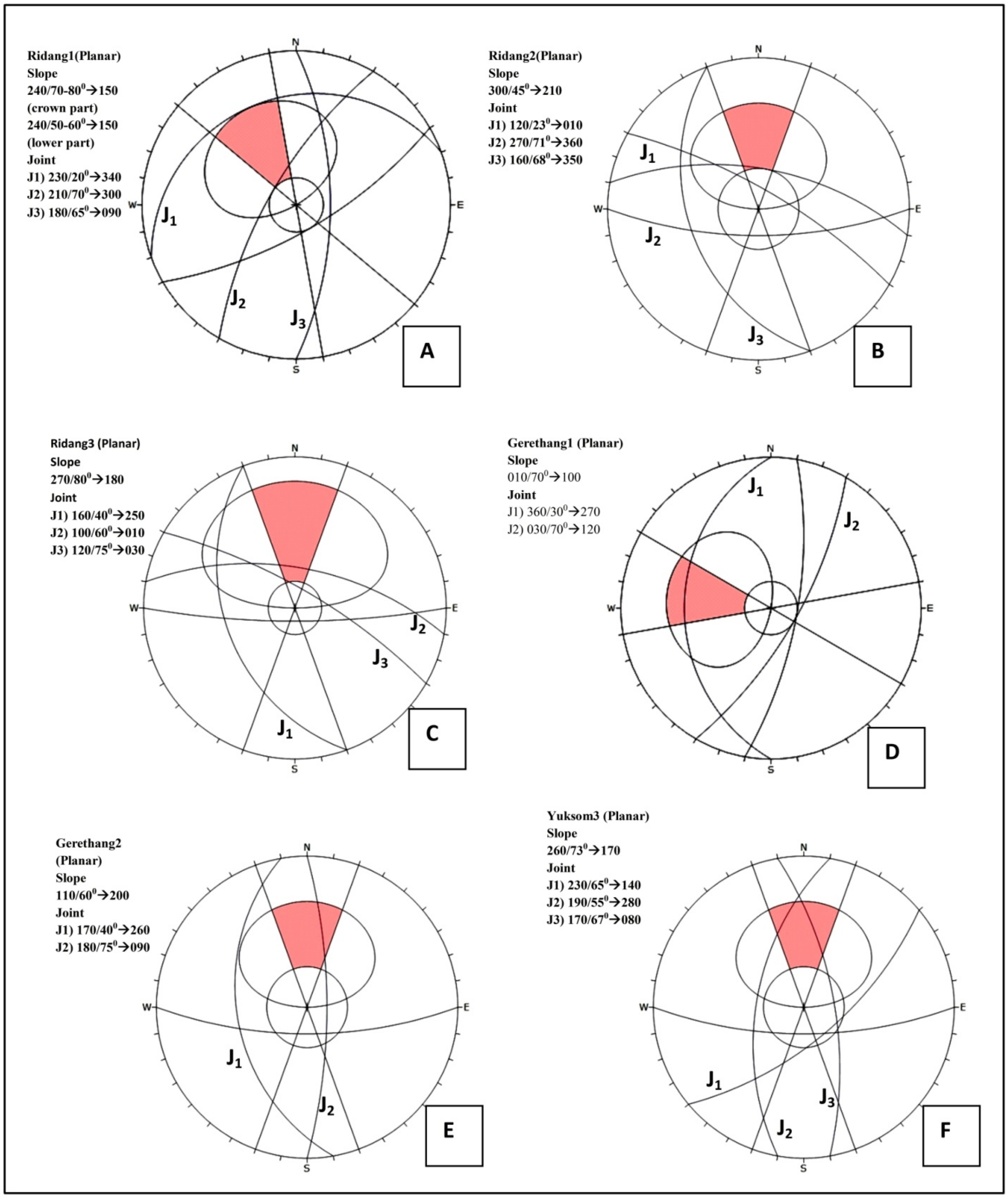

Figure 4: Kinematic analysis of the major landslides showing the joint sets and the types of failures. All the failures are planar type. A) Ridang1 slide B) Ridang2 slide C) Ridang3 slide D) Gerethang1 slide E) Gerethang2 slide F) Yuksom3 slide

Table 3: Detailed landslide inventory of the study area

S.N.	Name of landslide	Coordinates	Lithology	Types of materials	Major Causative factors	Dimension (height/ length) in meter	Types of failures	Affected area
1	Ridang landslide	N27 21.062 E88 16.334	Phyllite/ Quartzites/ Mica schist	Loose debris/Highly weathered/fractured	Geological structure triggered by Rainfall	300/200	Debris slide/ Rockslide	Road/Village
2	Ridang2 landslide	N27 21.097 E88 16.374	Phyllitic rocks	Loose debris	Weak channel triggered by Rainfall	12/15	Debris slide/ Rockslide	Road
3	Ridang3 landslide	N27 21.012 E88 16.216	Phyllitic rocks	Fractured and weathered	Fractured lithology triggered by Rainfall	15/25	Rock slide	Road
4	Ridang4 landslide	N27 21.086 E88 16.617	Quartzite and phyllite	fractured	Fractured lithology triggered by Rainfall	6/20	Debris	Road
5	Ridang5 landslide	N27 21.029 E88 16.715	Phyllitic rocks	Weathered material	Perpendicular joints trigeered by tectonic activity and rainfall	8/25	Debris slide	Road
6	Ridang6 landslide	N27 20.879 E88 16.725	Phyllitic rocks	Fractured and weathered	Fractured lithology triggered by Rainfall	10/20	Debris slide	Road
7	Gerethang 1 slide	N27 20.608 E88 14.730	Phyllite/Quartzite	Fractured and weathered	Loose fractured/weathered triggered by rainfall and road cutting	35/50	Rock slide	Road
8	Gerethang 2 slide	N27 20.508 E88 14.750	Quartzite &phyllitic rocks	Jointed/Fractured beds	Fractured lithology triggered by rainfall	100/300	Rock slide/Rock fall/Debris slide	Road
9	Labing 1 slide	N27 21.057 E88 14.363	Phyllites and micaceous schist	debris	Fractured lithology triggered by rainfall	15/20	Debris slide	Road
10	Labing2 slide	N27 21.089 E88 14.146	Phyllites	Loose debris	Triggered by Rainfall	15/20	Debris slide	Road
11	Labing3 slide	N27 21.241 E88 13.933	Phyllite	Weatghered and fractured Phyllite	Road widening activity	40/60	Debris slide	Road
12	Yuksom1 slide	N27 21.242 E88 13.934	Phyllite	Fractured/Loose materials	Heavy rainfall	30/40	Debris slide/Mud slide	Road
13	Yuksom2 slide	N27 21.422 E88 13.699	Phyllite	Weathered	Road cut triggered by Rainfall	15/60	Debris slide	Road
14	Yuksom3 slide	N27 21.845 E88 13.450	Phyllite	Fractured	Road cutting	15/50	Debris slide/Rock slide	Road
15	Yuksom4 slide	N27 21.717 E88 13.125	Phyllite	Fractured/Loose phyllitic material	Rainfall	15/60	Debris slide/rock slide	Road

The actual triggering factor of these landslides is the heavy rainfall along with some tectonic activity. The rocks Phyllites and schist are more vulnerable to failure as compared to quartzite. Phyllites and schist are also highly weathered and fractured. Very steep slope in the affected area has made the exposure more vulnerable. The fragile geology and steep slope coupled heavy uninterrupted rainfall for several days is the main triggering factor of the slope failures. During the rainfall the overburden and phyllitic rocks get saturated with water and get swelled up thus increasing the weight causing fracture and consequently slope failure taking place. The characteristics of phyllite also show that it loses 25% of its shear strength when it is wet. Proper scientific measures should be taken for road construction in vulnerable areas to minimize the loss caused by slope failures. Awareness of slope failures among the local dwellers is very much essential to reduce the loss.

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