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Landslide Studies Between Devprayag and Pali along National Highway-7, Tehri District, Garhwal Lesser Himalaya

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Abstract: **Landslides are very common geological hazards which occur in Himalayan region mostly during monsoon season. It may be caused either due to natural factors such as rainfall, lithology, geomorphology, seismicity, geological structures and slopes, and anthropogenic factors such as road widening, blasting, deforestation, construction of houses etc. The present studies of landslides have been carried out along the National Highway-7 from Devprayag (N 30^0 08'34.80" E 78^{0}35'45.60") to Pali (N 30^0 10'04.80" E 78^{0}37'22.80"). The detail geological and structural mapping has been done on 1:10000 scale. Rocks along the road are phyllite and quartzite and at some places river bed materials are also present. Maximum landslides are present in phyllite rocks. During the field work five landslides (L_1 to L_5) have been observed along the road with locations N 30^0 08' 44.77" & E 78^0 35' 47.60"; N 30^0 09'01.37" & E 78^0 35'51.85"; N 30^0 08'47.95" & E 78^0 35' 56.60"; N 30^0 08' 43.92" & E 78^0 36' 9.36" and N 30^0 09' 51.45" & E 78^0 37' 1.62", respectively. These landslides are debris slide, soil creep and debris fall type. It affects road and at places houses. In the present work detailed analysis of landslides and their causes have been observed. Active landslide, potential landslide and safe zone have been identified. These landslides occurred at moderate to steep slopes in which gravitational action is playing an important role. The main causes of the L_1 landslide are the presence of highly fractured and weathered rocks and toe cutting by the river. The causes of L_2 to L_5 landslides are base cutting of the mountain for widening of the road, and another important factor is the water infiltration into the overburden during rains and consequent increase in pore water pressure within the overburden. For safety measure at L_1 cemented wall &wirecated wall are present, and netting, cementing and anchor hold mitigation methods are also used. In the present studies remedial measures have been suggested for each landslide.**

Index Terms: **Active Landslides, Damage zone, Mitigation, NH-7, Potential Landslides.**

I. INTRODUCTION

Himalaya is tectonically very active where Landslides have occurred from the Lesser Himalaya to Higher Himalaya (Singh, 2010, 2012 & 2013; Umrao,et al., 2011; Kumar et al. 2014; Sarkar, et al., 2016). Uttarakhand is a part of Himalayan region. Devprayag is a holy place where Alaknanda and Bhagirathi Rivers meet after that the river named as "Ganga River".

Alaknanda River originated from Satopanath Glacier and travels 195 km, while the Bhagirathi River formed at Gaumukh, at the foot of the Gangotri Glacier &Khatling Glacier, and traveling 205 km to Devprayag. The main tributaries of Alaknanda River are the Saraswati, Dhauliganga, Birahiganga, Balkhila, Nandakini, Pindar, Mandakini etc. The Bhagirathi River has cut a deep gorge across the granitic rocks of the higher Himalayas of Garhwal. Its main tributaries are the Janhavi and the Bhilangna Rivers.

Himalaya mountain chain is the most active and sensitive due to ongoing tectonic activity process. Its geological structures and climatic conditions increase triggering of landslides time to time. Landslides are very common geological hazards which occurred in the area mostly during monsoon season. Technically landslide is downslope movements of rock, debris and earth materials with or without presence of water under the action of gravity. Slope morphology also plays a vital role for slope stability and instability. Recent developmental activities such as cutting of mountain slopes for road widening, blasting, construction of dam, civilization in moderate to steep slopes causes serious

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problems. Rocks in the area are highly jointed, fractured, crushed and weathered which makes vulnerable to the landslide.

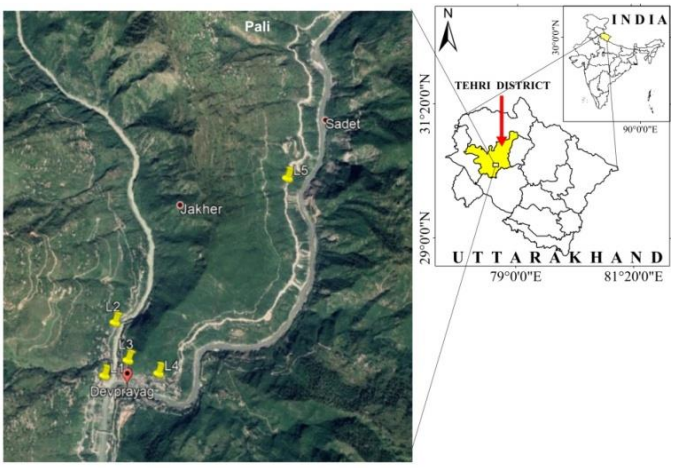

Fig. 1. Location map of the area from between Devprayag to Pali in Tehri Garhwal District of Uttarakhand, India.

II. Study Area

The present study area (Fig.1) lies in the Tehri District of Garhwal Lesser Himalaya. Devprayag is a small town of Tehri district which is 74 Km far from Rishikesh city. The present detailed investigation of landslides has been carried out along the National Highway-7 from Devprayag (N 30^0 08'34.80" E $78^0$35'45.60") to Pali (N 30^0 10'04.80" E $78^0$37'22.80"). The study area lies about 1 km along the Bhagirathi River and about 7 km along the right bank of Alaknanda River. This area falls under Indian toposheet no 53 J/12. The present study of landslides is important for the point of view of local people of Uttarakhand as well as tourists of Char Dham Yatra (Badrinath, Kedarnath, Gangotri and Yamunotri).

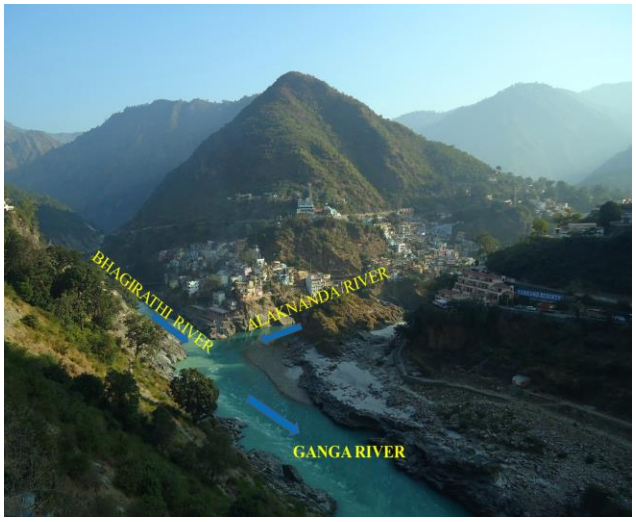

Fig. 2. Panoramic view of Devprayag where Alaknanda and Bhagirathi Rivers meet and after that the River is named "Ganga River".

III. Climate

The climate of the area varies from place to place and month to month. The maximum temperature ranges up to 36^0 C and the minimum temperature varies between 0^0 C and 6^0 C. In Devprayag summer season are pleasant with moderately cool in climate and the best time to visit area is May-June and September-October. The temperature ranges from 18^0 C to 31^0 C in these months. In Devprayag winter season is extremely cool which starts from October to February and temperature varies between 0^0 C and 18^0 C. During the monsoon season, Devprayag experiences heavy rainfall in the month of 15th June to 15th September.

IV. Methodology

Survey of India toposheet no 53 J/12 has been used to prepare the base map on the scale of 1:10,000. During the field work with the help of the global positioning system (GPS) location of landslides were confirmed and the same were marked on the respective enlarged base map. Lithology, structural data, hydrological conditions, collection of samples and morphological data of landslide were collected and assessment was made to categorize the landslides. Detailed investigation of landslides have been done morphologically and geologically, and according to this, three locations have been identified which come under the damaged zone between this road corridor (Fig. 3). These locations are sensitive for further landslides. Finally geological map has been prepared on a scale of 1:10,000. Some mitigation measures of these landslides are also suggested.

V. Geology and Structural Setup

Tectonically the Alakananda valley comprises of three separable major litho-stratigraphical units known as Dudatoli Group, Garhwal Group and Central Crystallines. Dudatoli Group in the area represented by the Pauri Phyllite and is also included in theKumaun Supergroup (Kumar et al., 1974) But according to Shekhar et al. (2006), this area belongs to Chandpur Group of the Srinagar Phyllite Formation. The Dudatoli Group is of Precambrian age (Kumar and Agarwal 1975).

In this area, low to medium grade of metamorphic rocks are present viz. Phyllite and Quartzite (Fig. 3) and at some places river boulder is also present overlying on these rocks. At places unmappable slate is interbedded with phyllite rocks. Phylliteexhibits gray, whitish green, dirty green & dark green in colour and silky appearance on the schistosity surface. In thin section, phyllite is showing parallel arrangements of flaky minerals. The minerals observed in thin section are chlorite, sericite, phengite, quartz, biotite, muscovite, zircon, iron oxides and apatite. Slateis characterized by brown, brownish black, gray and dirty green in colour. In thin section of slate chlorite, phengite, quartz, biotite, muscovite, zircon, iron oxides, apatite, tourmaline and kaolinite minerals are observed. Quartzite is

characterized by white, purple, brownish, and creamish in colour.

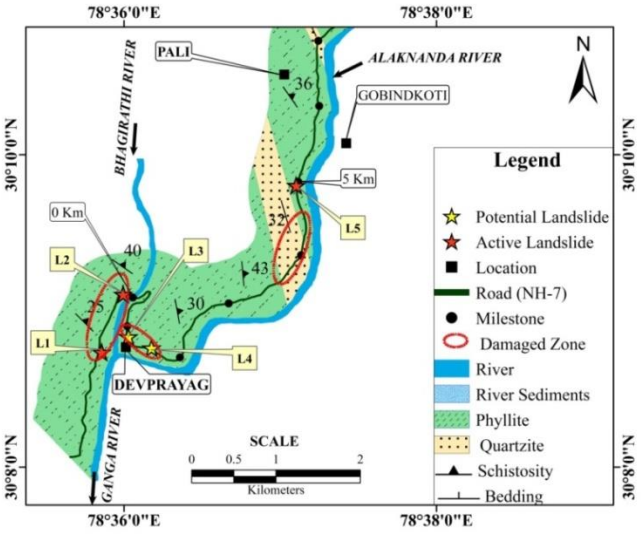

Fig. 3. Geological map of the study area.

In thin section, quartzite is showing interlocking crystalloblastic texture and maximum quartz grains are angular to subangular. Quartz is the major constituent of the rock, whereas sericite, iron oxide, biotite, ilmenite and zircon constitute accessory minerals.

The phyllite is characterized by folding such as open fold, isoclinal fold, chevron fold, crenulations, antiform&synform, kink folds, etc. Three sets of jointsin phyllite and four sets of joints in quartzite have been observed in the investigated area. En-echelon quartz vein, shear plane, pinch & swell and S-C structures are also observed. Five landslides are also observed in phyllite rock. The types of these landslides are rock fall, debris slide, soil creep and subsidence type.

VI. Causative Factors of Landslide

A. *Rainfall*

Rainfall is the most important factor of activation and reactivation of landslides. Landslides frequently occur when the ground is saturated by rainwater and penetrates through pores, joints and fractures, etc. and produces hydrostatic stress in the rocks. The increased pore water pressure get decreased the shear resistance of the material. Thus the rock, debris and soil material moves along the slope with the influence of gravity. The study area receives heavy rainfall during the monsoon period from 15th June to 15th September. During the monsoon period rainfall is 670 mm and the average annual rainfall of this area is 1045.1 mm (Kaur and Purohit, 2014). Last few decades the cloud burst incidents have become the most important factors in the Himalayan region which causes devastating landslides such as in August, 2018 cloud burst incident in Tehri district. In this cloud burst induced landslides 15 people were killed, and two bridge, water supply line, agriculture land, houses and many pathways were affected (Negi et al, 2018).

B. *Slope and Aspect*

Hill slope of the Himalaya is known for instability due to their endogenic and exogenic activity. The average slope of the area is steep. During 2010 and 2018 widening of the NH-7 makes the large scale of slope destabilization particularly along the road section in the Garhwal Himalayan region.

Aspect is one of the other factors which contribute to the slope and influence instability of the area. The Himalayan northern faces receive most rainfall with the comparison of southern faces. The southern side of the mountains received maximum solar insolation. The insolation is also related to the weathering process because the soil and rock materials got expansion and contraction due to diurnal temperature variations. The southern face is very sensitive for weathering and slope failure. The slope and aspect are both one of the major controlling factors of landslides formation. The highest degree of slope, expansion and contraction of all particles influence the rate of landslides.

C. *Lithology*

Lithology one of the major important internal controlling factors of slope stability or instability. The main lithology exposed in the area is phyllite and quartzite. Phyllite is the product of low grade regional metamorphism of pelitic rock. At places unmapppable slate is associated with phyllite. These rocks are highly fractured and weathered, and they make vulnerable to landslides. In the study area all five landslides present in phyllite rock. Phyllite and slate rocks have a very low friction angle. These rocks have a small porosity and low permeabilitydue to which loose weathered overburden material present above the rock moves downward with the presence of waterand the influence of gravity.

D. *Structure*

Structures of rocks such as bedding plane, schistosity, crenulation cleavage, joint, fracture, crenulation lineation, fold, etc. plays a vital role in the formation of landslides. In the present area, crenulation cleavages (Fig.4) and crenulation lineations (Fig.5) are well developed in phyllite which is also responsible factor for landslides. Four sets of joints pattern viz., N75^{0}E-S75^{0}W, N55^{0}W-S55^{0}E, N55^{0}E-S55^{0}W andN10^{0}W-S10^{0}E with variation in 5^0 to 10^0 are observed by rose diagrams, which also act as one of the triggering factor of landslides (Fig.6 & Fig.7).

Fig. 4. Crenulation cleavages in phyllite.

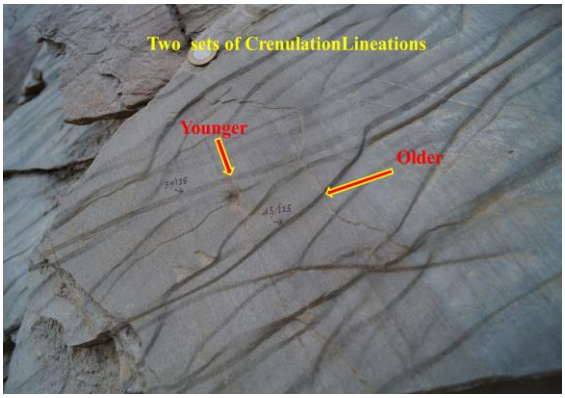

Fig.5. Crenulation lineations in phyllite.

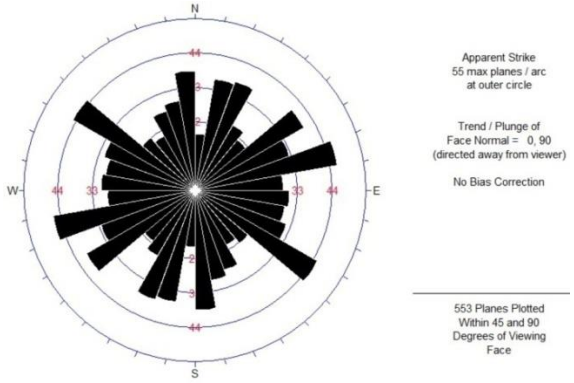

Fig.6. Rose diagram of joints in the area.

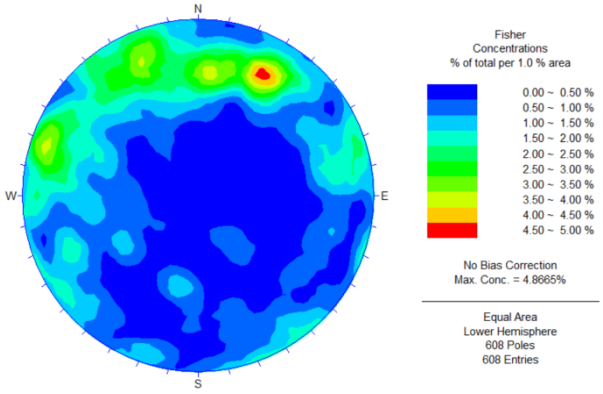

Fig.7.Contour diagram of joints in the area.

E. Land cover and land use

The slope stability also depends on vegetation cover on land surface because plant roots penetrate into the soil and reduce the slope instability. In the area moderately cover scrubs and other vegetation are present. During the recent years, mountain slope cutting for road widening and other new infrastructural developments make vulnerable for slope instability. Devprayag is a small town which is present over moderately to steep slope. The loose overburden debris materials move along the slope time to time with influence by water and gravity.

F. Weathering

Phyllite is a low-grade metamorphic rock which mainly composed of mica, chlorite, sericite and other minerals of clay group. These minerals belong to clay group of minerals and phyllosilicate structures. The clay minerals are primary product of chemical weathering. Chemical weathering as well as mechanical weathering act together in the area and due to this talus and scree deposits present near the roadside. The soil is result of weathering of rocks which supports vegetation and plantation.

VII. DESCRIPTION OF LANDSLIDES

In many regions of the world a temporary instability of superficial mass of soil and rock, consolidated or unconsolidated, has always been an acute problem. Landslide is one of the major problems in the hilly terrain of the Himalayan region. They affect human lives, livestock, infrastructures, disruption in traffic and as well as environmental degradation. The road networks are a common way of communication in mountain regions. Five landslides are present in the studied areabetween Devprayag to Pali along NH-7. All these landslides present in phyllite rock in which three landslides are active and two landslides are potential (Fig.3). These landslides have been classified by Varnes (1978) based on the type of material and their movement.

A. Landslide (L_1)

This landslide is present at N30^0 08’ 44.77” & E78^0 35’ 47.60” and an altitude of 517m, just above the confluence of Alaknanda and Bhagirathi Rivers (Fig. 8 & 9). The length and width of this landslide is 85 m and 54 m, respectively. This landslide reactivated during June 2013. This landslide is present on steep slope and the nature of this landslide is at places concave and at places planer. This is the complex type of landslide and contains boulders of about 4 m × 2 m in size. Causes of this landslide are rainfall, joints, slope, toe cutting and weathered materials.

Fig.8. House present in danger condition in middle right part of the photograph and foundation of another house damaged in middle left of the photograph due to L_1 landslide.

Fig. 9. Photograph shows L_1 landslide after treatment in 2018. A house marked by ellipse is still subsiding.

For safety measure gravity retaining wall and gabion retaining wall are present. Netting, cementing and anchor hold mitigation methods are used for this landslide. Rest house of Badrinath and Kedarnath Mandir Samiti is in danger condition because it is subsiding and cracks are also developed in the floor. Base rock around this landslide is Phyllite.

B. Landslide (L_2)

This landslide is present at N30^0 09'01.37" & E78^0 35'51.85" and an altitude of 498 m, just before the bridge of Devprayag (Fig.10). The length and width of this landslide is 26 m and 106 m, respectively. This is the old landslide which faces in eastern direction. The slope of this landslide is steep and the nature of the failure is concave. This is a rock fall and debris types of landslide containing boulders of up to 5 m × 3.5 m in size. The rock present around this landslide is Phyllite. Causes of this landslide are heavy rainfall, base cutting of slope for road widening, rock slope, joint and weathered materials. A house present is in danger condition by the impact of this landslide. Supporting wirecated wall is also present in the bulged condition.

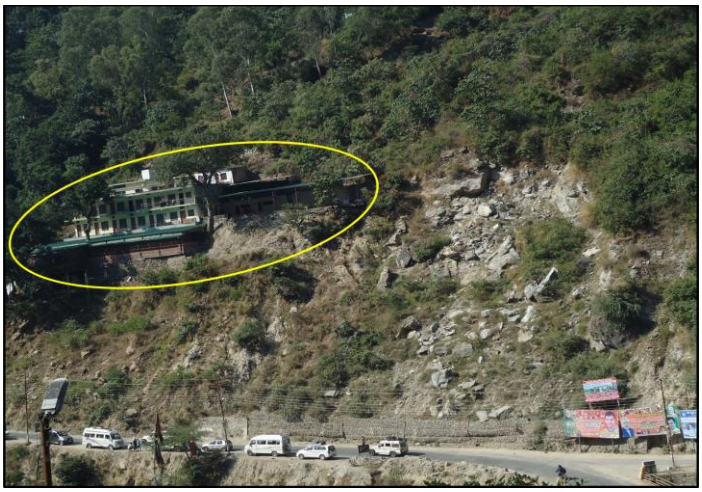

Fig. 10. House present is in danger condition due to L_2 landslide.

C. Landslide (L_3)

This landslide is located at N30^0 08'47.95" & E78^0 35' 56.60" and an altitude of 539 m just after 1 km from Devprayag along NH-7 (Fig. 11 a & 11 b). The Length and width of this landslide is 20 m and 60 m, respectively. This is an old landslide which facing in western direction. The Slope of a landslide is steep and the nature of the failure is concave. This is debris and soil creep types of landslide containing river boulders up to 32 cm × 20 cm in size. Phyllite and river boulders are present around the landslide. Causes of this landslide are rainfall, road cutting and loose materials. Due to this landslide, the materials below the foundation of toilet, Government Girls Inter College (GGIC)Devprayag is eroding and the toilet may fall in the future if proper treatment will not be done. Cactus has been planted on the landslide for stability and stairs are also made from road to GGIC in 2018. This is a potential landslide and may activate in the future.

Fig.11 a. Photograph shows that the materials below the foundation of toilet, GGIC, Devprayag has eroded due to L_3 landslide.

Fig.11 b. At places plantation of Rambans (cactus) has been done for landslide treatment.

D. Landslide (L_4)

This landslide is present at N30^0 08' 43.92" & E78^0 36' 9.36" and an altitude of 552 m along NH-7 (Fig. 12). The length and width of this landslide is 42 m and 40 m, respectively. This is an old landslide and present on the steep slope. This is debris and soil creep types of landslide containing boulders up to 20 cm × 30 cm in size. Phyllite rock and river bed materials present around this landslide. Causes of this landslide are rainfall, loose materials (soil & river bed material) and base cutting of slope for road widening. Due to this landslide foundation of the building is removed under the action of gravity and house owner kept wood and sand fill bags for safety measure. This is also under potential landslide. This landslide may activate in the future and damaged the house.

Fig. 12. In this photograph material below the house has moved down due to L_4 landslide and house is in danger condition. House is marked by ellipse.

E. Landslide (L_5)

This landslide is present at N30^0 09' 51.45" & E78^0 37' 1.62" and an altitude of 578 m along NH-7 (Fig.13). The length and width of this landslide is 30 m and 70 m, respectively. This landslide is reactivated after road widening and heavy rainfall during 2018. The slope of failure is steep. This is debris slide type of landslide containing boulders up to 2 m × 3 m in size. Phyllite is present around the landslide. Causes of this landslide are rainfall, rock slope, base cutting of slope for road widening and gravity.

Fig. 13. Photograph shows debris slide of L_5 landslide.

Discussion and Conclusion

During the monsoon period (15th June - 15th September) this area received heavy rainfall due to which these landslides activated/reactivated and at places damaged NH-7 also. Due to this tourists and pilgrims face many problems during Char Dham Yatra. Devprayag town is situated near the confluence of Alaknanda and Bhagirathi Rivers. These rivers do toe cutting time to time. All these landslides (L_1 to L_5) present in phyllite and have steep slope. Rocks of the area are highly jointed, sheared and fractured due to tectonic activity, and at most places four sets of joints are observed. Phyllite has a low friction angle and friction angle further reduces due to presence of water by which rock, debris and earth material moves downward due to gravity. Deforestation is also the main contributing factor for the slope instability. Geological and geomorphological factors such as lithology, structures, slope, aspect, landuse, landcover, plantations are controlling factors for the landslides. Unscientific and indiscriminate way of construction is most important anthropogenic activities in the area which accelerated landslides incidences. These landslides occurred at steep slopes into which gravitational action is playing an important role. The main causes of the L_1 landslide are the presence of highly fractured, jointed and weathered rock as well as toe cutting by the river. The causes of L_2 to L_5 landslides are base cutting of the mountain for widening the road. Another important factor is the water infiltration into the overburden during rains which

increases pore water pressure within the overburden and induces landslides. After detail studies of landslides, it is suggested that landslides (L_1 to L_5) have been largely trigger due to heavy rainfall, loose weathered material and slope cutting. Construction of road or houses should maintain a safe distance from river and streams and will be done in proper and scientific way.

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