Geological investigation of heavy rainfall induced landslide incidences at Bastari and Naulra village of Pithoragarh District of Uttarakhand

A report

Disaster Mitigation and Management Centre

Department of Disaster Management

Uttarakhand Secretariat

Dehradun- 248 001

July, 2016

Introduction

As communicated by District Emergency operation Centre (DEOC) Pithoragarh slope failure incidences took place at many places in the district on 1st July 2016 amid heavy rainfall (160 mm within 4 - 5 hours in Didihat area). Bastari (29° 43' 48.83" N and 80° 17' 41.22" E), Naulra (29° 52' 20.70" N and 80° 09' 54.12" E) and Didihat (29° 48' 8.84" N and 80° 15' 9.44" E) were amongst the worst affected areas. Geological investigation was carried out in the area between 3rd and 12th July 2016.

According to eyewitness accounts cloudburst like incidence took place around Bastari village on 1st July 2016 in two phases. Debris flow occurred after heavy rainfall in the morning hours (around 0430 hrs) in which one house was damaged. The inhabitants of the same were rescued by the villagers. Thereafter most people of the village (around 24) took shelter in a well constructed house in the village that was perceived to be safe by the people. While they were still waiting for rain to stop another debris flow took place around 0600 hrs. This engulfed the very house in which people had taken shelter.

All the persons were thus burried in the debris that flowed down along a 1st order drainage passing through Urma village, which is situated below Bastri village. 19 persons were killed in this incidence. Of these bodies of 08 could not be recovered. Total 16 buildings were destroyed or damaged and 174 cattle were lost.

Heavy rainfall also accelerated gulley erosion on river born material (RBM) and debris flow took place at Kumalgaon (near Naulra village) as well. 03 persons were killed in this incidence while houses of 05 families were burried under the debris. Around 70 animals were lost in the incidence. 2.5 - 3.0 m thick pile of debris was observed at the site.

Details of the other villages affected by landslides and debris flow are given in Table 1.

Table 1: Description of affected villages and affected families

Sl. No.	Affected village	Affected families
1.	Bastari	29
2.	Patherkot Malla	16
3.	Urma	47
4.	Patherkot Talla	11
5.	Ojha Malla	08
6.	Siroli	02
7.	Majhera	07
8.	Tal	01
9.	Sunakot	02
10.	Amthal	10
11.	Athkhet Dafilla	10
12.	Kalasilla	01
13.	Naulra	05
14.	Pipli (Pantsera)	03
15.	Didihat town area	08

Total families	160

The area

The areas devastated by disasters are located in Thal and Didihat tehsils of Pithoragarh district and fall in the catchments of East Ramganga and Charma rivers respectively (Fig. 1). Urma village is located on the downhill side of Bastari and both these villages are situated on the left flank of south flowing Charma river and can be approached by Didihat – Ogla – Singhali motor road. Kumalgaon (Naulra) is located on the right flank of southerly flowing local stream and can be approached by Thal - Munsiyari motor road (NH 309A).

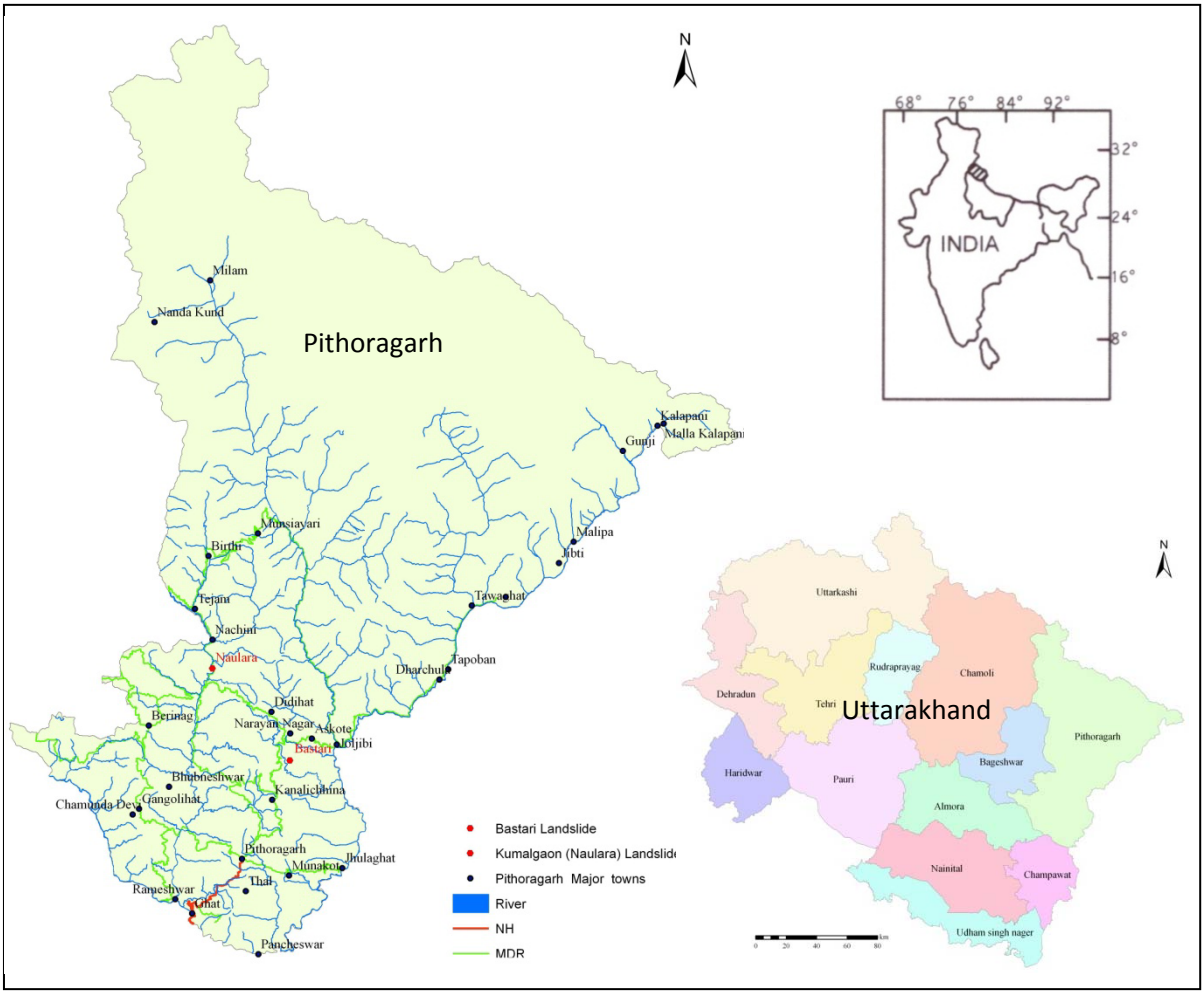

Fig. 1. Location map of the study area

Geological setup

Geologically the area falls in Lesser Himalaya and earlier works of Auden (1937) and Heim and Gansser (1939) suggest that the rocks of Pithoragarh area belong two tectonic units; one belonging to the Almora Crystalline Zone and the other belonging to the sedimentary zone of

Garhwal Group. In the area the rocks of Almora nappe are observed to be thrust over quartzites and limestones of Garhwal Group along North Almora Thrust. Granites and augen gneisses of Almora Crystallines are observed around Didihat and Bastari area. Quaternary deposits (RBM) and limestones of Garhwal Group are observed around Naulra landslide zone.

The rocks exposed around the area are traversed by numerous joints that comprise important structural discontinuities affecting the strength of the rock mass and stability of slopes. The phylites exposed in the slide zone of Bastari are generally observed to strike NW – SE and dip towards northeast at angle of around 35°. Prominent joints observed in the area are also observed to strike NW – SE parallel to the foliation and dip at moderate to high angles (55°) towards SSW.

At Kumalgaon landslide area exposed limestone rocks are observed to strike E - W and dip towards south at an angle of around 50°. These rocks are observed to be well jointed.

Reconnaissance geological-geotechnical assessment

Rocks exposed in the Bastari area are dominated by fractured and jointed granitic gneisses of Almora Crystallines and phyllites of Garhwal Group. Slope in the uphill side of village have steep gradient. This area is observed to have predominance of boulders that are embeded in thick cover of debris. In the middle portion of the debris flow zone prominent rock exposures are observed together with the contact zone of granitic gneisses with phyllites.

The slope in the area is generally observed dip towards southwest at steep angles (55° - 60°). This has facilitated fast downslope movement of debris. A number of agricultural fields along with houses were thus damaged due to debris flows in the Bastari area (Fig. 3 and 4). The thickness of the debris accumulated in the area is observed to be around 3.5 to 4.0 meters. This material is observed to comprise of hill wash and debris consisting of brown, fine grained silty-sandy matrix with rare boulders and fragments of granitic gneisses.

Heavy rainfall is deduced to be the main triggering factor for the downslope movement of the debris. Steep slope together with the presence of thick cover of colluviums dominated with boulders on uphill side of Bastari only added to the damaging potential of the debris flow that moved past swiftly and had high erosion potential to create deep gullies in the area.

The habitation is situated along seasonal drains and on steep slope. During spells of prolonged heavy rainfall slope mass got completely saturated with water and pore water pressure exceeded due to coarse grained soil. This facilitated debris flow along the seasonal nala. Steep slope accompanied with heavy discharge of water is deduced to have aggravated

the pace of erosion along the nala. Rapidly running water and gravity driven movement induced by lubricating action of ground water thus drived the debris down slope at fast pace. The west flowing seasonal stream is observed to have overrun the cultivated lands and a partially damaged house (at right flank of landside) in the Urma village (Fig. 4).

In case of Naulra landslide, presence of river born material (RBM) is observed behind the habitation. Slope at this location is observed to dip towards east at an angle of around 40°. Indications of heavy rainfall induced gulley erosion and debris flow are observed during field investigation.

RBM is always vulnerable for the slope failure due to the roundness of its constituents and poor cohesion. The debris slide is observed to have occurred on the eastern slope of N-S trending ridge. The width of the failure slope is about 50 meters along the cultivated fields and height of the crown from cultivated fields is about 30 meters.

The landslide debris that descended down from the area upslope of the village is observed to have overrun both agricultural fields and houses (Fig. 7 and 8). The thickness of the debris accumulated in the area is observed to be around 3.0 meters. This overburden material is observed to comprise of river borne material consisting of dark brown to reddish, fine grained silty-sandy matrix with rounded boulders and pebbles.

Rehabilitation site for the Bastri village

During the fieldwork attempt was made to identify suitable and safe site for the rehabilitation of Bastari and Kumalgaon (Naulra) villages. No suitable land could however be identified for Naulra village.

Locals suggested a site at Thulkhali area (29°43'.809 N and 80°18'.393 E) for the rehabilitation of Bastari village (Fig. 2 and 10). This area has a gently sloping land covered with grasses and shrubs. Slope dips towards northeast at an angle of 10° to 15°. To the southern of the area phyllites of Garhwal Group are observed. These dip towards NNW at an average angle of 50°. Two southeasterly flowing local streams are present at northern and southern extremity of this site.

Churmal temple is situated western direction of the site and uphill side to road is surrounded by thick vegetation. Mostly oak trees and bushes are observed in this area. Apart from a playground for the locals this is the site for hosting local fairs (melas). Approach road is present at the site and it is coming from Singhli and Bastari motor road. This site seems to be free of hazards and can be considered for rehabilitation.

Remedial measures

Based on preliminary field investigation, it is perceived that necessary precautions are required to be taken, especially in view of the fact that the slide is in close proximity of densely populated area of Urma village and remaining part of Bastari village.

Besides major landslide several landslide scars are also observed on the uphill side to Bastari village (Fig. 5). Activation of these have the potential of posing danger to the village. Geologically, the area is deduced to be in a critical state of equilibrium and the following mitigation measures are suggested:

1. The hill slope around Bastari village is deduced to be highly susceptible to failure, particularly in the event of heavy or prolonged rainfall. The residents are therefore advised to keep safe distance from the vulnerable slope and vacate the area, especially during heavy or prolonged rainfall.
2. For the treatment of landslide scars developed on uphill side of Bastari village it is recommended that suitably designed wire mesh gabion walls be put in place in steps. The remaining portion of village is required to be treated appropriately, particulary on the left flank of Bastari landslide.
3. It is recommended that the debris and rock mass accumulated in the agricultural lands of Urma village be cleared so as to enable masses to continue with their routine agricultural chores.
4. It is highly important to ensure all future constructions only on firm ground. At the same time excavation on steep slope should not be allowed. The excavated slope if left untreated is sure to pose threat during heavy rainfall.
5. During field investigation it was observed that the devastation mostly occurred along areas where Quaternary deposits were present. Construction on RBM and old landslide debris should therefore be avoided.

Concluding remarks

The villages affected by disaster incidences are traditional habitations where people had been living happily for ages. Even though mass movement is a function of a number of factors of which presence of water plays a decisive role, none can really claim that the area has never in the past received this kind of heavy rainfall. So it can be deduced that despite spells of heavy and prolonged rainfall these habitations were not affected by mass movement in the past.

One therefore needs to investigate if the area has witnessed some physical changes in the recent past (5 to 7 years) and if there has been increase in the frequency of such incidences

after these changes. These changes could be related to landuse, construction, drainage, road, forest, agriculture and the like.

Newly constructed road around Bastari in which there would have been use of explosives and ground excavation for the construction around Kumalgaon are such changes observed during the field investigation. Around Didihat town rapid unplanned urbanisation is deduced to be the causative factor for the slope failure. This is reflected absence of proper drainage network, overloading of debris slope, excavation and left untreated, construction on old landslide debris and road construction.

At Sunakot (Devel) area dip slope (valley side dipping strata) is observed to be responsible for the mass movement. 5 – 7 cm wide cracks on cultivated land are observed around the area. At many places non-maintenance of agricultural fields due to migration has been observed to be responsible for such incidences.

At locations where ground fissures have developed and subsidence has taken place appropriate measures are required for checking infiltration of rainwater. This should preceed implemention of permanent treatment measures. People living around these slopes should remain vigilent, particularly during the monsoon period and any physical change in the slope should immediately brought into the notice of authorities.

References:

Auden, J.B., 1937, The Structure of the Himalaya in Garhwal, Records of Geological Survey of India, Vol. 71 (4), 407-433.

Heim and Gansser, A., 1939, Central Himalayas: Geological observations of the Swiss expedition in 1936, Mem. soc. helv. Sci. net., 73, 1-245.

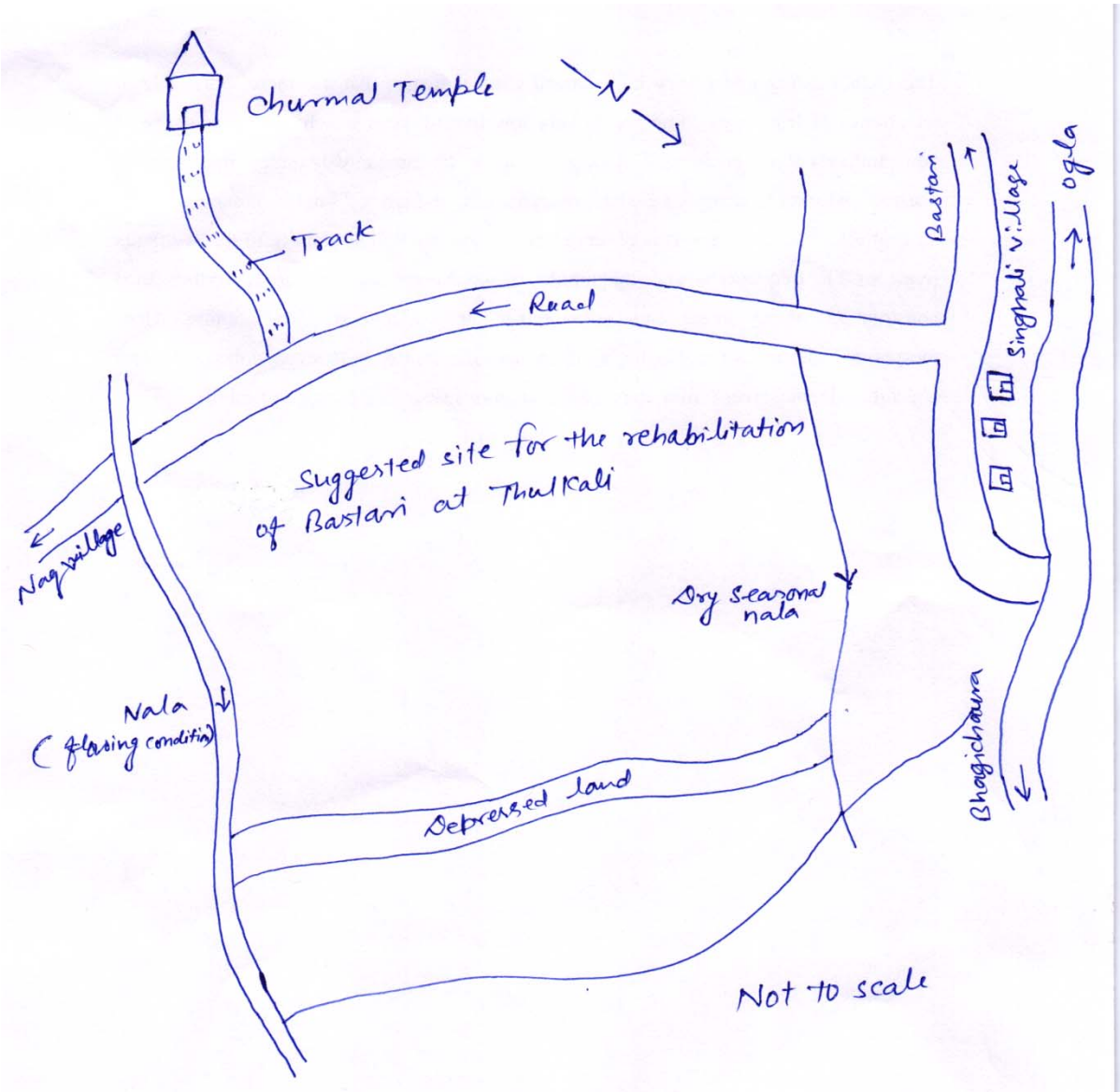

Fig. 2: Suggested site for the rehabilitation of Bastri village at Thulkhali.

Fig. 3: View of Bastari debris flow (camera looking east).

Fig. 4: Close up view of Bastari landslide.

Fig.5: Landslide scars developed after heavy rainfall around Bastari village.

Fig. 6: View of relief / medical camps at Singhali on the uphill side to Bastari village.

Fig. 7: Debris flow on slope made up of RBM at Kumalgaon near Naulra village (camera looking west).

Fig. 8: Devastation around Kumalgaon village.

Fig. 9: Photograph depicts excavation and treatment (retaining wall) of the slope for construction on right flank of Naulra slide.

Fig. 10: Suggested rehabilitation site for Bastari village at Thulkahli.

Investigations around Didihat region in Pithoragarh district aftermath of landslide disaster of 1st July, 2016

A report

Disaster Mitigation and Management Centre
Department of Disaster Management
Uttarakhand Secretariat
Dehradun- 248 001

August, 2016

Introduction

Slope failure incidences took place at many places in the Pithoragarh district, Uttarakhand on 1st July 2016 amid heavy rainfall. As communicated by District Emergency Operation Centre (DEOC), Pithoragarh and local persons 160 mm rainfall was recorded within 4 - 5 hours in Didihat area. Geological investigation was carried out in the area between 3rd and 12th July 2016. Didihat town (29° 48' 8.84" N and 80° 15' 9.44" E) and surrounding region was observed to be the worst affected due to heavy rainfall. The areas devastated by disasters are located in Thal, Munsiyari and Didihat tehsils of Pithoragarh district.

Debris flow occurred at Bastari village where 19 persons were killed in this incidence. Of these bodies of 08 could not be recovered. Total 16 buildings were destroyed or damaged and 174 cattle were lost. Heavy rainfall also accelerated gulley erosion on river borne material (RBM) and debris flow took place at Kumalgaon (near Naulra village) as well. 03 persons were killed in this incidence while houses of 05 families were burried under the debris. A preliminary report of both villages has already been submitted.

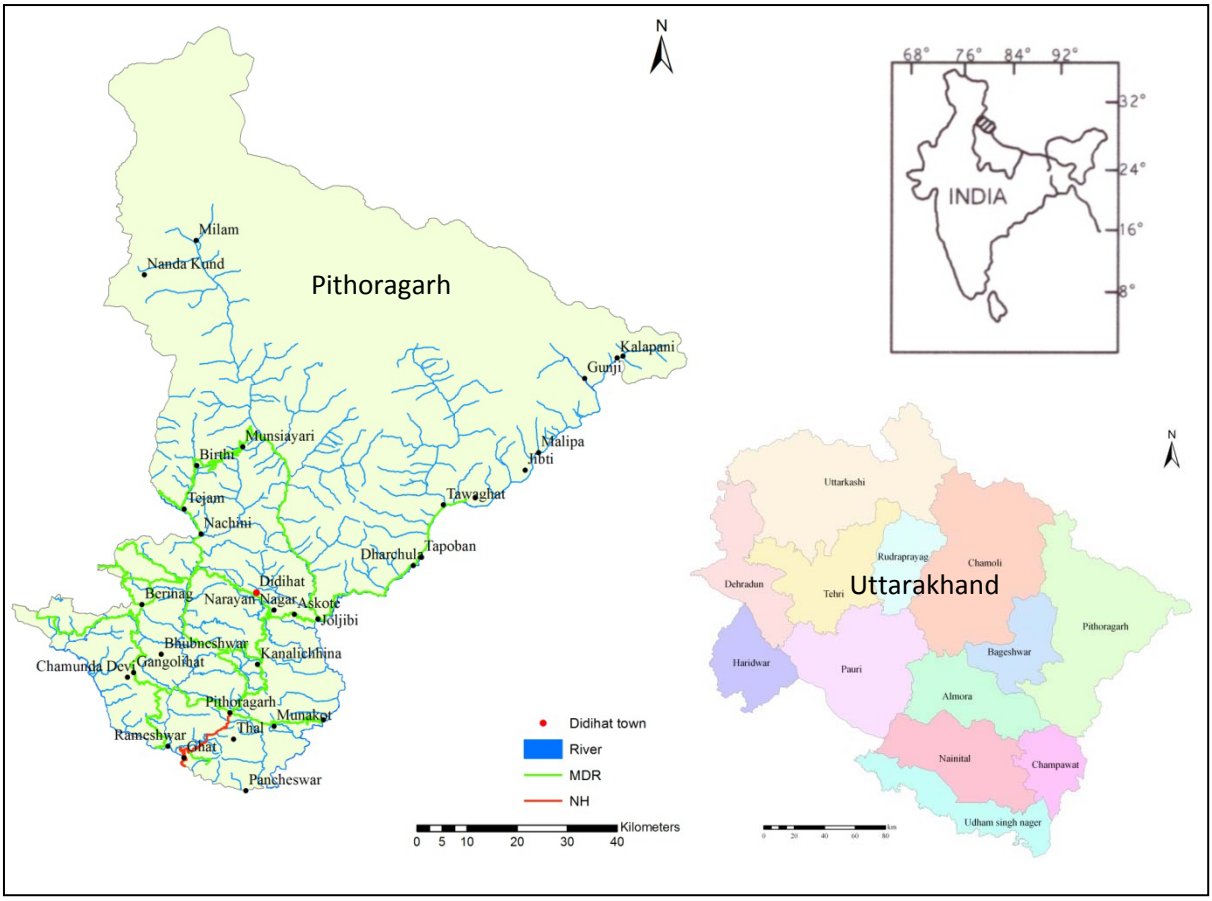

Fig. 1. Location map of the study area.

During field investigation a number of landslides were observed in Didihat town. Due to heavy rainfall slope failure incidences took place in all Wards and around Didihat town. An

attempt is made here to give brief description of landslide location, damaged infrastructure and agriculture land together with the details of major landslide zones, causes and mitigation measures.

The study area

The areas devastated by disasters are located in Thal and Didihat tehsils of Pithoragarh district and fall in the catchments of East Ramganga and Charma rivers respectively (Fig. 1). Patet, Ghatigad, Daphla villages are located in Thal Tehsil whereas remaining villages and locations are situated in Didihat Tehsil.

Geological setup

Geologically the area falls in Lesser Himalaya and earlier works of Auden (1937) and Heim and Gansser (1939) suggest that the rocks of Pithoragarh area belong two tectonic units; one belonging to the Almora Crystalline Zone and the other belonging to the sedimentary zone of Garhwal Group. In the area the rocks of Almora nappe are observed to be thrust over quartzites and limestones of Garhwal Group along North Almora Thrust. Granitic gneisses of Almora Crystallines are observed around Didihat area. Quaternary deposits (RBM) and limestones of Garhwal Group are observed around Patet, Ghatigad, Daphla villages along Thal – Munsiyari road section. Granitic gneisses of Almora Crystallines are observed around Didihat area. The rocks exposed around the area are traversed by numerous joints that comprise important structural discontinuities affecting the strength of the rock mass and stability of slopes.

Landslides in Didihat town

1. Deendayal Park landslide

The landslide is located just below the Didihat - Adichaura motor road that is occupied by outcrops as well as thick overburden. Due to heavy rainfall a major landslide took place in Ambedkar ward and Deendayal Park was severally damaged (Fig. 2). This slide has partially damaged two houses on its left and right flanks and these are under severe threat.

Geological Setting: The landslide zone is observed to have moderate to steep slope. Rock exposures of granitic gneisses (Almora Crystallines) belonging to Garhwal Group of Lesser Himalaya are observed along the road section (Fig. 3). The foliation plane is generally observed to be well developed and dips at angles of about 40° towards northeast (valley side).

Fig. 2. Slope failure at Deendayal Park.

Fig. 3. Broad view of Deendayal Park landslide.

Reconnaissance geological-geotechnical assessment: The debris slide is observed to have occurred on the northeastern slope below Deendayal Park. The inclination of failure slope is observed to be 40°. The width of the failure slope is about 50 meters along Didihat-Pamsiyari road section and height of the crown is about 110 meters. The landslide debris that descended down from the Deendayal Park is observed to have accumulated on a newly constructed Pamsiyari road and along the drain. This overburden material is observed to comprise of hill wash and debris consisting of brown to reddish brown, coarse-grained sandy matrix with fragments of granitic gneisses. 10 - 15 cm wide NW-SE trending cracks are observed in front of house on the right flank of the slide. Together with this retaining wall below the house is observed to have bulged.

Heavy rainfall is deduced to be the main triggering factor for the debris slide. Steep slope together with the presence of thick cover of debris with valley side dipping strata are some other contributing factors for the slope failure.

Suggested measures: The hill slope around Deendayal Park is deduced to be highly susceptible to failure, particularly in the event of heavy or prolonged rainfall. The residents are therefore advised to keep safe distance from the vulnerable slope and vacate the area, especially during heavy or prolonged rainfall.

It is recommended that appropriately designed retaining structures of suitable height with firm foundation are required to be erected from Pamsiyari road level for checking slope failure. Appropriate measures are required for checking infiltration of rainwater. For the treatment of house situated at the right flank pre-constructed bulged retaining wall should be demolished and it needs to be reconstructed properly. At left flank of the slide, suitably designed masonry wall should be provided below the house together with proposed retaining

wall coming from Pamsiyari road. For the protection against landslide scar developed downhill side to same house (northeastern direction), buttress wall needs to be given.

2. Lotpatta landslide

The area under present investigation is located just below Didihat – Adichaura motor road that is occupied by thick overburden. The landslide is observed to have affected the middle portion of Lotpatta village, Ambedkar ward. 4 houses, footpath, cultivated fields and a temple have been damaged and affected by the landslide debris. Houses situated around the landslide are in a critical condition due to slope instability.

Fig. 4. Slope failure at Lotpatta village.

Fig. 5. Landslide scar at Lotpatta village.

The landslide zone is observed to have steep slope and rock exposures are not observed near the landslide zone.

Reconnaissance geological-geotechnical assessment*:* The debris slide is observed to have occurred on the northeastern slope of Lotpatta village. The inclination of failure slope is observed to be 50° - 55°. The width of the failure slope is about 50 meters along the footpath and height of the crown is about 100 meters. Four more landslide scars are also observed around the major landslide. Descending down through the cultivated land the landslide debris is observed to have accumulated upslope of the footpath (Fig. 4 and 5). This overburden material is observed to comprise of hill wash and debris consisting of brown to reddish brown, coarse-grained sandy matrix with fragments of granitic gneisses.

Heavy rainfall is deduced to be the main triggering factor for the landslide. Steep slope, excavation and overloading on debris slope, poor drainage network, construction on cultivated land and gulley erosion are some other contributing factors for the slope failure.

Suggested measures: The hill slope around Lotpatta village is deduced to be highly susceptible to failure, particularly in the event of heavy or prolonged rainfall. The residents

are therefore advised to keep safe distance from the vulnerable slope and vacate the area, especially during heavy or prolonged rainfall.

It is recommended that suitably designed wire mesh gabion walls be put in place in three steps from upslope to footpath and uphill side check dams needs to be given in certain interval. For the slope treatment below the houses situated at the crown part, suitably designed masonry walls should be provided below the houses.

Appropriate measures are required for checking infiltration of rainwater. It is also strongly recommended that construction of any sort should not be allowed around Lotpatta slide zone. For the protection against landslide scars buttress walls needs to be given.

3. Pamsiyari road landslide

Landslide is located along newly constructed Didihat - Pamsiyari road to the south of Lotpatta. The landslide has severely damaged the motor road. One house on the downhill side of the road is also damaged by the slide.

Geological Setting: The area is observed to be located along the road that is occupied by thick overburden material with boulders of granitic gneisses. The landslide zone is observed to have moderate to steep slope. Rock exposures of granitic gneisses (Almora Crystallines) belonging to Garhwal Group of Lesser Himalaya are observed along the road section.

Fig. 6. Broad view of Pamsiyari road landslide.

Fig. 7. Close-up view of landslide.

Reconnaissance geological-geotechnical assessment: The bouldery debris slide is observed to have occurred on the northeastern slope. The inclination of failure slope is observed to be 40°. The width of the failure slope is about 200 meters along the Pamsiyari road section and height of the crown is about 350 meters. The bouldery debris landslide took place from uphill side of the newly constructed road and is observed to have accumulated on the road as also on the down hill side (Fig. 6 and 7). This overburden material is observed to comprise of hill

wash and debris consisting of brown to grayish brown, coarse-grained silty-sandy matrix with boulders of granitic gneiss. The prominent joint sets are generally observed to be well developed and dip at angle of 70° towards southwest and second set of joint is observed to be dip at angle 65° towards east.

Heavy rainfall is deduced to be the main triggering factor for the debris slide. Moderate to steep slope together with the presence of thick cover of debris dominated with boulders and road cutting are some other contributing factors for the slope failure.

Suggested measures: It is recommended that suitably designed wire mesh gabion walls be put in place together with road side drain.

4. Dhmiyakhan landslide

The area is observed to be located southern extremity of Ambedkar ward that is occupied by thick overburden. A debris slide is observed to have occurred at Dhamiyakhan, Ambedkar ward. A footpath was also damaged and the water-saturated debris entered the house situated in the toe portion of the slide. Two houses located around the crown and one on the left flank of the landslide face the threat of slope instability. The landslide zone is observed to have moderate slope and rock exposure is not observed near the landslide zone.

Reconnaissance geological-geotechnical assessment*:* The debris slide is observed to have occurred on the northeastern slope of Dhamiyakhan. The inclination of failure slope is observed to be 30° - 35°. The width of the failure slope is about 30 meters along the footpath and height of the crown is about 60 meters. The landslide debris is observed to have accumulated along the seasonal drain going across the footpath and entered a house (Fig. 8 and 9). This overburden material is observed to be comprised of hill wash and debris consisting of brown, coarse-grained silty-sandy matrix with fragments of granitic gneisses.

Fig. 8. Slope failure at Dhamiyakhan.

Fig. 9. Severely damaged house due to landslide.

Heavy rainfall is deduced to be the main triggering factor for the landslide. Overloading on thick cover of soil, encroachment along seasonal drain and gulley erosion are some other contributing factors for the slope failure.

Suggested measures: The landslide is deduced to be highly susceptible to failure, particularly in the event of heavy or prolonged rainfall. The residents are therefore advised to keep safe distance from the vulnerable slope and should remain vigilant especially during rainfall. It is recommended that suitably designed wire mesh gabion walls be put in place in two steps at the toe portion or along footpath. Besides, check dams made up of in-situ material at a certain interval needs to be given. Plantation of broad leafed plants and shrubs is recommended for ensuring protection against gully erosion. Drainage network should be improved and appropriate measures are required for checking infiltration of rainwater. It is also strongly recommended that any type of construction should not be allowed around the slide zone.

5. Mobile tower landslide

Landslide is located in GIC ward a few meters below the motor road leading to Subhas Chock. A seasonal drain flowing towards northeast is located on the northern side of slide. Rock exposures of basics and phyllites belonging to Lesser Himalaya are observed along the road section on the downhill side to landslide. The foliation planes are generally observed to be well developed and dip at 50° towards northwest.

Reconnaissance geological-geotechnical assessment: Debris slide took place due to have rainfall from the northeasterly slope of the area (Figs. 10 and 11). The inclination of failure slope is observed to be 45° - 50°. The width of the failure slope is about 30 meters below the mobile tower and height of the crown about 50 meters.

Fig. 10. View of damaged part of an electricity pole and a mobile tower due to landslide.

Fig. 11. Bird eye view of mobile tower landslide.

The shallow hill wash together with debris that descended down along a gully from the area upslope is observed to have overrun ultimately into the northeasterly flowing drain going across the Didihat – Dunakot road. This overburden material is observed to comprise of hill wash and debris consisting of brown to grayish brown, fine-grained silty-sandy matrix with fragments of rock. Foundation portion of an electricity pole and a mobile tower are also damaged by this incidence (Fig. 10).

Suggested measures: It is recommended that appropriately designed retaining structures with suitable height with firm foundation are required to be given for checking slope failure. It is also required that investigation of foundation part of mobile tower is also carried out by the geotechnical engineer. Drainage network should be improved and appropriate measures are required for checking infiltration of rainwater.

6. Milan Restaurant Landslide

This debris slide is located near Milan restaurant, on the downhill side of Didihat – Pithoragarh motor road. The landslide is located between two NW and SE flowing seasonal drains and thick vegetation is observed around the slide zone.

Reconnaissance geological-geotechnical assessment: The area under present investigation is observed to be occupied by thick overburden material with dense vegetation cover. Rock exposures of granitic gneiss (Almora Crystallines) belonging to Garhwal Group of Lesser Himalaya are observed along the Didihat – Pithoragarh road section. The foliation plane is generally observed to be well developed and dips at 40° towards NNE. The prominent joint set is generally observed to be well developed and dips at angle 60° towards southeast.

The debris slide is observed to have occurred on the western slope due to heavy rainfall. The inclination of failure slope is observed to be 50°. The width of the failure slope is about 60 meters and height of the crown is about 50 meters. The debris slide took place from the downhill side of Didihat – Pithoragarh road and is observed to have accumulated along the nala below the slide (Fig. 12). This overburden material is observed to comprise of hill wash and debris consisting of brown to grayish brown, coarse grained silty - sandy matrix with fragments of granitic gneiss.

Heavy rainfall is deduced to be the main triggering factor for the debris slide. Steep slope together with the presence of thick cover of debris and toe erosion by seasonal stream are some other considerable causative factors for the landslide.

Fig. 12. Landslide near Milan Restaurant, GIC Ward.

Suggested measures: It is recommended that appropriately designed toe protection wall of suitable height be erected in two steps from seasonal stream and after these benches be provided with modification of slope. Suitably designed masonry walls should be provided to support the failure below the buildings.

7. DIET landslide

This debris slide is located near District Institute of Education and Training (DIET), Didihat. Presently, Govt. polytechnic is conducted in a building of DIET, situated just above the landside (Fig. 13).

Reconnaissance geological-geotechnical assessment: The area under present investigation is observed to be occupied by thick overburden material with dense vegetation cover. The landslide zone is observed to have moderate to steep slope. Rock exposures are not observed near the landslide zone. The debris slide is observed to have occurred on the northern slope due to heavy rainfall. The inclination of failure slope is observed to be 40°. The width of the failure slope is about 80 meters and height of the crown is about 60 meters. This overburden material is observed to comprise of hill wash and debris consisting of brown to reddish brown, medium grained silty - sandy matrix with fragments of granitic gneiss.

Heavy rainfall is deduced to be the main triggering factor for the debris slide. Steep slope together with the presence of thick cover of debris and gulley erosion are some other causative factors for the landslide.

Fig. 13. Landslide near DIET, Didihat.

Suggested measures: It is recommended that appropriately designed retaining structures of suitable height be erected in two steps to protect the toe of the slide. In between crown and proposed retaining structures, check dams be constructed using in-situ material at a certain intervals. Plantation of broad leafed plants and shrubs is recommended for ensuring protection against gully erosion.

Fig. 14 A, B, C, D, E, F, G, H, I and J are from different locations of Didihat town but scenario is almost same in all the region, though the area was devastated by heavy rainfall of 31st June 2016, but most of the region common things responsible for the slope failure are construction on moderate to steep slope made up off overburden material or old landslide debris, excavation of slope, absence of proper drainage network. Besides, encroachment along the drain is observed at several locations and most of the places buildings have been constructed close vicinity to hill slope even 2 meter minimal gap is avoided between hill slope and buildings. Due to this reason most of the places debris laden water either entered into the rooms or flowing through the roof.

Landslides around Didihat area:

8. Landslides at Sunakot

Triggered by torrential rainfall on 31st June 2016 landslides are observed to have affected the area around Sunakot (Devel) village. One house is observed to be severely damaged at

Majhera (Devel). About 1 meter wide and 2 meter deep cracks are observed in front of the house while about 15 cm wide cracks are observed on cultivated land around Sunakot.

The area under present investigation can be approached by Didihat – Ogla – Bhagichaura motor road. The area is occupied by thick overburden with dip slope (valley side dipping strata).

Reconnaissance geological-geotechnical assessment: One building is observed to be severely damaged at Majhera. Front portion of the house and stairs are damaged and cracks are observed on the walls of the house. The slope failure in front of the house is observed to have occurred on the northwestern slope due to heavy rainfall. The width of the failure slope is about 20 meters and height of the slope is about 15 meters (Fig. 15).

One more landslide is also observed just before the house along the village footpath (Fig. 16). The width of the failure slope is about 35 meters and height of the slope is about 30 meters. The landslide debris is observed to have accumulated along the footpath. This overburden material is observed to comprise of hill wash and debris consisting of brown, fine-grained silty - sandy matrix with fragments of basics and phyllite of Garhwal Group. The prominent joint sets in basics are generally observed to be well developed and dip at angle of 40° towards northwest and second set of joint is observed to be dip at angle 60° towards southeast. The foliation plane in phyllite is generally observed to be well developed and dips at 30° towards northwest.

Heavy rainfall is deduced to be the main triggering factor for the slope failure. Dip slope, loose soil, avoidance of Guls (water drains) in between cultivated land due to migration of local people to city / town areas are some other contributing factors for the slope failure around Sunakot (Devel) area.

Fig. 15. Slope failure in front of house at Sunakot.

Fig. 16. Landslide along the footpath of village.

Suggested measures: Severely damaged portion of the house should be demolished and rebuild with proper foundation. For the protection against landslide along footpath suitably designed wire mesh gabion wall be put in place in steps along the footpath. If guls (water drains) could be maintained by the locals, development of cracks on cultivated land could be reduced.

9. Nonpapon Landslide

A major landslide took place after heavy rainfall of 31st June 2016 in Nonpapon village of Didihat Tahsil. The area under present investigation can approached by newly constructed Didihat – Sandev motor road.

A newly constructed MLA funded road, old PMGSY road and Primary School are observed to be situated around the crown portion of the landslide.

Reconnaissance geological-geotechnical assessment*:* The rock cum debris slide is observed to have occurred on the eastern slope of Nonpapon village. The inclination of failure slope is observed to be 60°. The width of the failure slope is about 40 meters at the toe portion and height of the crown is about 100 meters (Figs. 17 and 18). Thick pile of landslide debris that descended down from the area upslope of the village is observed to have overrun both cultivated fields and a house. The thickness of the debris accumulated in the house is observed to be 1.0 to 1.5 meters. This overburden material is observed to comprise of hill wash and debris consisting of brown to grayish brown, fine grained silty - sandy matrix with fragments of granitic gneiss.

The prominent joint sets in granitic gneiss are generally observed to be well developed and dip at angle of 45° towards southwest, second set of joint is observed to be dip at angle 50° towards northeast and third sets of joint is observed to be dip 60° towards southeast.

Fig. 17. Slope failure at Nonpapon village.

Fig. 18. Damaged house at Nonpapon village.

Heavy rainfall is deduced to be the main triggering factor for the landslide. Steep slope together with thick cover of debris and road cutting on crown portion are some other contributing factors for the slope failure.

Suggested measures: It is recommended that suitably designed breast and retaining walls of appropriate height be provided both above and below the road and a retaining wall be erected just above the damaged house. Road side drains must be provided for checking infiltration of rainwater. It is also strongly recommended that construction of any sort should not be allowed around the slide zone.

The households located between the landslide zone are required to be shifted to alternate safer locations.

10. Bagjivilla Landslide

Slope failure occurred after heavy rainfall of 31st June 2016 at Bagjivilla village of Didihat Tahsil. The area under present investigation can be approached by Ghorpatta – Ghinwali motor road and one to negotiate last 5 kilometers on foot. Village is located on the uphill side of cultivated lands on the right flank of Chandrabhaga river.

Fig. 19. Slope failure at Bagjivilla village.

Fig. 20. Debris flow uphill side of a house.

Reconnaissance geological-geotechnical assessment*:* The area is affected by the debris flow at several locations and on the uphill side of the village one major landslide is observed. Debris flow is observed to have occurred on the southwestern slope of Bagjivilla village (Figs. 19 and 20). The inclination of failure slope is observed to be 60° - 65°. Width of the failure slope is about 30 meters and height of the crown is about 50 meters. Shallow landslide debris that descended down from the area upslope of the villages is observed to have overrun both cultivated fields and a house. A cemented gul (water drain) located at crown portion of the landslide is observed to be damaged due to landslide. On the downhill side of the house in

middle portion of the village debris flow is observed at three locations. This overburden material is observed to comprise of hill wash and debris consisting of brown to reddish brown, medium grained silty - sandy matrix with fragments of granitic gneiss. Rock exposure of Phyllite of Garhwal Group is observed towards southeastern extremity of the village. The foliation plane in phyllite is generally observed to be well developed and dips at 70° towards west.

Heavy rainfall is deduced to be the main triggering factor for the debris flow. Steep slope, absence of proper drainage network and gulley erosion are some other contributing factors for the slope failure.

Suggested measures: The hill slope around Bagjivilla village is deduced to be highly susceptible to failure, particularly in the event of heavy or prolonged rainfall. The residents are therefore advised to keep safe distance from the vulnerable slope, especially during heavy or prolonged rainfall.

It is recommended that suitably designed wire mesh gabion wall be provided in steps from the houses situated at the toe part of the landslides.

11. Patherkot Malla

Patherkot Malla village is located on around 4 km south of both Bastari and Urma villages and can be approached by Didihat-Ogla-Singhali motor road. The affected site at Patherkot Malla is located below road amid agricultural fields. Both Government Primary school and Junior School are located to the west of severally damaged houses in close proximity. Fortunately, these were spared by the slide.

Reconnaissance geological-geotechnical assessment: Rock exposures of metabasics and phyllites belonging to Lesser Himalaya are observed along the road section as also to the upslope of the village. The foliation planes are generally observed to be well-developed and dip at angles of around 35° towards northeast. The joint sets are observed to have steep and almost vertical disposition. These are observed to be SSW dipping and NE-SW striking respectively (55°/ 240° and 90°/ 60°). The debris slide is observed to have occurred on the southern slope of E-W trending ridge. The inclination of failure slope is observed to be more than 50°. The width of the failure slope is about 40 meters along the cultivated fields and height of the crown from cultivated fields is about 35 meters.

Fig. 21. Photograph showing slope failure at Patherkot Malla.

Fig. 22. View of the house and a number of agricultural land damaged by water saturated debris in Patherkot Malla.

The shallow landslide debris that descended down from the area upslope of the village is observed to have overrun both agricultural fields and a house (Figs. 21 and 22). The thickness of the debris accumulated in the house is observed to be 0.5 to 1.0 meters. This overburden material is observed to comprise of hill wash and debris consisting of gray to grayish brown, fine grained silty matrix with fragments of metabasics and phyllites.

Heavy rainfall is deduced to be the main triggering factor for the landslide. Steep slope, road construction and thick overburden are some other contributing factors for the slope failure.

Mitigation measures: It is recommended that the debris and rock mass accumulated by the slide in the agricultural lands of Patherkot Malla village be cleared. After removing debris this area can safely be utilized for agricultural purposes.

Appropriately designed breast wall and retaining wall with suitable height required to be given above and below the road together with road side drain. It is highly recommended that the severally damaged house be demolished.

12. Patet

Patet village is located along the Thal – Munsiyari motor road (NH- 309A). The village is situated on the right flank of northwesterly flowing Liparti nala in close proximity of the road.

Reconnaissance geological-geotechnical assessment: General slope in the area is observed to be gentle. The area is observed to be largely occupied by overburden material. No rock outcrop is observed in the vicinity of the village. The overburden material consists of brown

to blackish brown, fine to medium grained sandy matrix with large boulders and river borne material.

Fig. 23. Photograph depicts high sediment leaden discharge by Liparti nala.

Patet village is observed to be affected by stream erosion that is deduced to contribute to the instability of the area. On 30th June, 2016, the Liparti nala reportedly diverted towards the village on its right flank. Due to this, total 09 houses and a number of agricultural fields were covered with water saturated debris. The thickness of the debris accumulated in the houses is observed to be around 0.5 to 1.0 meters (Fig. 23).

Mitigation measures: It is recommended that the debris mass accumulated by the local stream in the agricultural lands and houses of Patait village be cleared.

In order to regulate the flow of water of the Liparti nala in Patait village, the channel bed is required to be turned into a series of cascades. Both the sides of the nala are also required to be protected by around 1.5 to 2.0 meters high concrete walls with suitable dimension. This would protect the banks and the village would be rendered safe.

13. Ghatigad village

Ghatigad village is located along the Thal – Munsiyari motor road (NH- 309A). Ghatigad tok of Patet Gramsabha is siyuated above the road. The area is drained by westerly flowing Ghati gad.

Reconnaissance geological-geotechnical assessment: Rock exposures of slates belonging to Lesser Himalaya were observed along the road section as also upslope of the village. The foliation planes are generally observed to be well developed and dip at 45° towards

southwest. The joint sets were observed to have steep dips towards NNE and SSW respectively (45°/ 20° and 75°/ 150°).

Fig. 24. Photograph depicting debris flow.

Fig. 25. View of an electricity line was damaged and disconnected by debris flow.

Hill wash materials together with bouldery debris flow are observed to have occurred on the northwestern slope of NE-SW trending ridge. The inclination of failure slope is observed to be 50°. The width of the failure slope is about 40 m along the cultivated fields and height of the crown from cultivated fields is about 30 meters.

The landslide debris (shallow hill wash together with river borne materials) that descended down along a gully from the area upslope of the eastern side to villages is observed to have overrun both agricultural fields and national highway, NH – 309A (Fig. 24). Thickness of the debris accumulated both in the road and agricultural fields is observed to be 0.5 to 1.0 meters. This overburden material is observed to comprise of hill wash and debris consisting of gray to brown, fine grained silty-sandy matrix with rounded boulders. An electricity line is also damaged by this incidence (Fig. 25). No major damaged however occurred in the village.

Suggested measures: It is recommended that the debris mass accumulated by the slope failure in the agricultural lands of Ghatigad tok be cleared. After removing the materials local community can utilize the same for agricultural operations.

14. Daphla

Daphla village is located at downhill side of the Thal – Munsiyari motor road (NH- 309A). The landslide debris that descended down from the area upslope of the village is observed to have overrun both agricultural fields and houses (Fig. 26). A double storied house is severally

damaged due to slope failure. Back side wall of this house is totally damaged and debris accumulated into the house (Fig. 27).

Reconnaissance geological-geotechnical assessment: The area is observed to be largely occupied by overburden material. No rock outcrop is observed in the vicinity of the Village. General slope in the area is observed to be moderately steep. The overburden material is observed to comprise of river born materials consisting of brown, fine grained silty – sandy matrix with rounded boulders and pebbles.

The slope above the village is observed to be steep and failure slope trending WNW. Increase in slope height by gulley erosion due to excessive rainfall together with low cohesion of river born material is deduced to have contributed to the instability of the slopes in this area.

Fig. 26. Photograph depicts slope failure in river borne materials.

Fig. 27. View of damaged walls of a double storied house.

Mitigation measures: The slope is required to be modified at different levels in the area affected by bouldery debris slide at the upslope of the village by benching and erection of appropriately designed masonry buttress / retaining walls. It is recommended that the debris mass accumulated by the slope failure in the agricultural lands and houses of Daphla village be cleared. After removing of accumulated debris mass from house, reconstruct the damaged component.

Discussion and conclusion

According to list provided by Nagar Panchayat Didihat, a total of 232 families are affected by the slope failure in Didihat town out of 101 families live in GIC Ward alone. This is followed by 92 in Tehsil Ward, 32 in Ambedkar Ward and 07 in Shiv Mandir Ward. Besides, several other villages are affected by slope failure around Didihat area.

At Sunakot (Devel) area dip slope (valley side dipping strata) is observed to be responsible for the mass movement. 5 – 7 cm wide cracks on cultivated land are observed around the area. At many places non-maintenance of agricultural fields due to migration has been observed to be responsible for such incidences. Change in angle of repose due to road construction is responsible for the slope failure particularly at Patherkot Malla, Nonpapon and Kandai villages.

Didihat town, like any other urban area in the hills of Uttarakhand, is faced with the dilemma of striking a balance between fast growing population and limited availability of land for fulfilling their housing and other related needs. Earlier (before 10 to 15 years ago) people living there were not vulnerable to landslide hazard and had the option of choosing a better site for settling down. The scenario has changed dramatically in the present times largely due to fast landuse / landcover changes. Rampant excavation of toe portion of slope for building and road construction is observed to be common place around Didihat. Indiscriminate construction, overloading of debris slope, encroachment along drain / streams and absence of drainage network for safe disposal of rainwater are some other factors responsible for slope failure.

Excavation of slope often introduces changes in slope characteristics and in the hills it mostly transforms moderately sloping land into steep sloping land. Tendency of leaving the excavated slopes untreated is dangerous, especially during spells of heavy rainfall.

Indiscriminate and unscientific construction should be banned especially in landslide affected areas. Besides this safe disposal of rainwater needs to be given due importance. Both surface and subsurface drainage measures should therefore be planned and executed. For this drain pipes could be provided on debris slope. The planned drainage network should be stepped and wide enough to accommodate heavy downpour events.

At some places including Nain Basti in Tehsil Ward, Shiva Colony in Ambedkar Ward and Kandai village on the uphill side to Shiva colony subsidence, cracks on buildings and slope failures are attributed to construction on recent material / loose soil / overburden material and poor drainage network. Increasing anthropogenic activities, venturing in unsafe areas due to limited land availability and heavy localized precipitation. These are continuously increasing the vulnerability of Didihat to landslides. In case indiscriminate construction could not be regulated all mitigation measures would remain a mere formality and would be of little use.

References

Auden, J.B., 1937, The Structure of the Himalaya in Garhwal, Records of Geological Survey of India, Vol. 71 (4), 407-433.

Heim and Gansser, A., 1939, Central Himalayas: Geological observations of the Swiss expedition in 1936, Mem. Soc. Helv. Sci. Net., 73, 1-245.