Geological note on landslide affected villages in Kapkot tehsil of Bageshwar district in Uttarakhand

A report

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Foreword

Landslide is simply down slope movement of rock mass and debris under the impact of gravity. It is a natural landform building process in the mountainous areas. Enhanced pore water pressure and down slope acting forces together with reduced frictional forces during rainfall season is responsible for enhanced frequency of landslides during the rainfall season. Anthropogenic intervention, particularly those related to slope modification is often responsible for triggering landslides.

A number of villages of Kapkot tehsil located to the north of Bageshwar town face serious slope stability related problems that are mainly attributed to active and diverse tectonic setting, high rates of weathering and excessive rainfall. The problem is observed to be aggravated by human interference in the form of various infrastructure development initiatives that adversely affect the stability of the hill slopes. Most landslides in the area are observed to be triggered by intense and specifically high atmospheric precipitation. Some are however also triggered by undercutting of slopes, bank erosion, destabilization of the slope material and quarrying.

Based upon the investigations carried out in the area site specific mitigation measures have been incorporated in the report. In order to be effective, these have to be planned and designed carefully under the supervision of an experienced geotechnical engineer / civil engineer. It however needs to be taken note of that even though the mitigation measures are designed, planned and executed well these do not rule out the possibility of the old slides being reactivated, particularly during extreme precipitation events and high intensity seismic tremors. It is therefore important to adopt fine blend of relocation, mitigation, capacity building and awareness.

Present study was undertaken by the DMMC team comprising of Shri Sushil Khanduri and Shri Mohan Singh Rathore in compliance of the office order No. 149/DMMC/IXV-287/2010-11 dated 18th May 2012. The site inspections and other investigations were carried out Patwari circle wise in the presence of the concerned Patwari, Gram Pradhan and others. Assistance provided by the officials of Bageshwar district administration and other departments during the field work is duly acknowledged.

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Abstract

A number of villages of Kapkot tehsil of Bageshwar district located to the north of Bageshwar town face serious slope stability related problems that are mainly attributed to active and diverse tectonic setting, high rates of weathering and excessive rainfall. The problem is observed to be aggravated by anthropogenic interference in the form of various unplanned infrastructure development initiatives that adversely affect the stability of the hill slopes. Most landslides in the area are observed to be triggered by intense and specifically high atmospheric precipitation. Some have however also been triggered by undercutting of slopes, bank erosion, destabilization of the slope material and quarrying.

Based upon the fieldwork carried out in the field suggestions have been incorporated in this report for undertaking site specific mitigation works. In order to be effective these have to be planned, and designed carefully under the supervision of experienced geotechnical engineer / civil engineer. Though intended at reducing the vulnerability of the affected villages and providing stability to the slopes these do not guarantee that the area would be free of risk of all kinds in future. The possibility of the failure slopes being reactivated by extreme precipitation events and high intensity seismic tremors, particularly on the aftermath of slope modification attempts, cannot be ruled out. It is therefore highly important that vulnerability of the area be taken note of while planning all developmental initiatives in the area. Particular care needs to be taken in all initiatives involving slope modification. Together with this it is highly important that provision be made for safe disposal of the excavated material as also for safe disposal of rainwater. At the same time care needs to be taken to ensure that encroachments do not take place in the proximity of streams.

Introduction

Bageshwar district lies between 29°40’ N and 30°20’ N latitudes and 79°25’ E and 80°10’ E longitudes (SoI Toposheet Nos. 53 N/15, 53 N/16, 53 O/9, 53 O/13, 53 O/14, 62 B/3, 62 B/4 and 62 C/1) and is bound by Almora district in the south, Chamoli district in the north and northwest and Pithoragarh district in the east. Location of areas covered under the present study is given in Fig. 1.

Bageshwar district enjoys good road connectivity and can be approached from Dehradun, the capital of Uttarakhand, via Haridwar – Kashipur – Haldwani - Almora (NH 72, NH 74 and NH 87) or Rudraprayag – Gwaldam - Garur (NH 58). The nearest airport is at Pantnagar (206 kilometers from Bageshwar) and the nearest railway station is at Kathgodam (180 kilometers from Bageshwar).

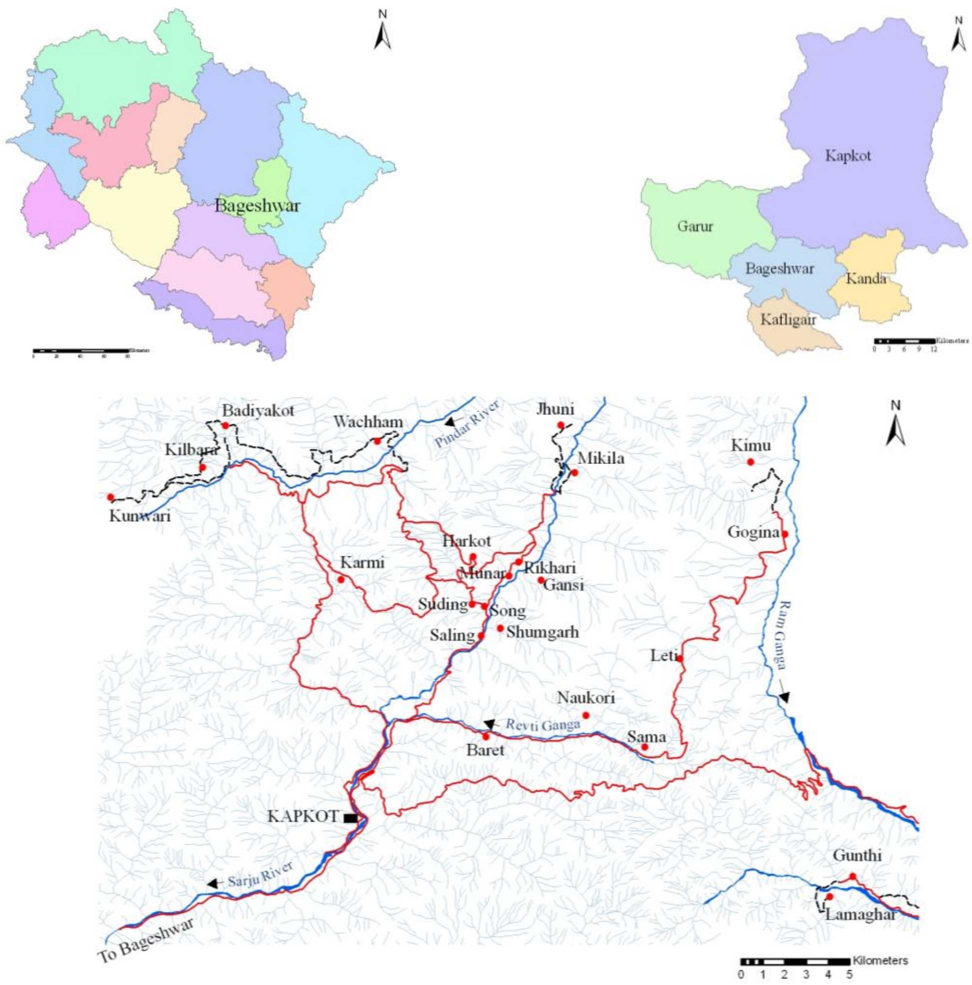

Fig. 1: Location map of the study areas in Kapkot tehsil of Bageshwar district.

General geology

The rocks exposed in the state of Uttarakhand range in age from Archaean to Holocene and are grouped into 15 super – sequences while important tectonic planes generally trend NW - SE. From south to north these tectonic planes are Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), South Almora Thrust (SAT), North Almora Thrust (NAT), Main Central Thrust (MCT) and Tethyan Fault.

In Bageshwar district rocks of Central Crystalline and Garhwal Group (Lesser Himalaya) are observed to be exposed and these are separated by a major tectonic plane, Main Central Thrust (MCT). In the Sarju valley MCT is observed to the north of Loharkhet.

Repeated tectonic disturbances have resulted in very complex geological setup of the area. The rock units generally comprise of quartzite with associated volcanics, phyllite, talc - mica schist, limestone, conglomerate, slate, gneiss and granite gneiss.

In the northern part of the district Centre Crystalline rocks comprising of migmatites, gneiss, calc gneiss, quartzite, mica schist and amphibolite are observed to be exposed. These occur as thrust sheet over the sedimentary and meta - sedimentary rocks of Lesser Himalaya. Major portion of the district falls under the Lesser Himalayan Zone and includes sedimentaries, meta - sedimentaries and plutonic igneous rocks. The rock units have suffered multiple phases of deformation and metamorphism. Litho - stratigraphy of Bageshwar – Kapkot - Loharkhet area to the south of Main Centre Thrust (MCT) is summarized in Table 1.

Table 1: Litho - stratigraphy of Bageshwar – Kapkot - Loharkhet area to the south of Main Centre Thrust (MCT).

Formation	Lithology
Berinag Formation	Fine to coarse grained massive quartzite, often sericitic and schistose with pebble beds (impersistent), chlorite schist and interbedded metabasics.
Saling Formation	Argillaceous sequence of grey, green and black slate/phyllite with calcareous interbeds. Stramatolite bearing dolomite/limestone with magnesite, talc.
Kapkot Formation	Chert, pebble beds (impersistent) and subordinate slate/calcareous slate.

Kapkot Formation

The Kapkot Formation is dominantly represented by rocks of the calcareous facies together with rocks of the argillaceous facies. It conformably overlies the Hatsila Formation but at a number of places the contact is tectonic; either marked by a fault or local shears. Marked dolomistisation and recystallisation is a common feature of the limestone. Magnesite occurs usually in the upper portion of this Formation. These deposits are associated with or controlled by some fault planes. Black phosphatic chert is also associated with this Formation particularly in the Pungar valley.

Saling Formation

The Kapkot Formation is conformably overlain by a predominantly meta-argillaceous rock unit called Saling Formation. Phyllite and slate are the dominating rock types of this Formation, though locally developed limestone / dolomite, quartzite and meta-siltstone are also observed. Lithological dissimilarities, attributable to local facies variations, appear to be typical features of this Formation. This Formation is well developed and represented by two prominent members. The lower, has grey phyllite showing yellow to reddish stains of limonite and intercalations of siliceous and calcareous beds. The upper one consists of pyritiferous black carbonaceous slate / phyllite. To the west of Kapkot, it occupies the core of the Kapkot syncline. Here, the rocks of the calcareous and areanaceous facies are also well developed along with slate and phyllite.

Berinag Formation

Lithological succession as observed in the Berinag Formation is given in Table 2.

Table 2: Lithological succession of Berinag Formation in Bageshwar – Kapkot - Loharkhet area.

Sericite quartzite, schistose quartzite, sericite schist, biotite schist, chlorite schist and amphibolites.
Coarse grained schistose quartzite with porphyroblasts of quartz, often gritty quartzite, sericite quartzite, chlorite schist.
White to pinkish white quartzite with pebble beds (impersistent), hard and compact fine grained quartzite (rare).

Geomorphology and physiography

Rocks of both Central Crystalline and Garhwal Group are observed in Pinder, Sarju and Ramganga valleys of Bageshwar district. These mostly consist of gneisses, schist, quartzite, limestone / calc tuffa, slate and marble. These valleys exhibit very rugged topography and the ground elevations generally vary between 795 and 3,000 meters above meal sea level (msl). High relative relief together with presence of overburden and high precipitation makes this area prone to landslides.

Drainage

Sarju, Gomti and Pindar are the main rivers of the area. The central and north central parts of the district are drained by Sarju while Gomti drains the western and southeastern parts and Pinder drains the northern part. Important tributaries of these rivers include Pungar nadi, Khir Ganga, Bhadrapati nadi, Kanal gad, Lahor nadi, Jagtana gad, Kulur gad, Sukunda gad, Revti Ganga, Sambhu nadi, Khamiya gad and Koti gad. The drainage pattern in the area is largely sub - trellis, sub - rectangular and sub - dendritic.

Rainfall and Climate

The climate in Bageshwar district is temperate to sub - humid. The northern portion of the district experiences sub - zero temperatures almost round the year whereas the central and southern parts are relatively warm and humid. Severe winter is the main climatic feature of the district.

In general, the district experiences a tropical to sub - tropical and sub - humid climate except for the northern part where cold temperate climate prevails. Most rainfall (about 75 percent) occurs during the monsoon months of June to September. Winter precipitation is associated with the passage of the western disturbances and is in the form of snowfall over higher elevations.

Factors contributing to slope instability in the area

There are many factors that contribute to landslides and instability of specific affected sites. These include:

- Presence of very weak natural materials in the area and steep slope cuttings.
- Low rock mass strength due to the proximity to Main Central Thrust (MCT) and other associated faults and shear zones.
- Extremely high relief, very steep slope and heavy precipitation.
- Disturbances in the rock strata by uncontrolled blasting during road construction.
- Construction in the proximity of natural water courses (river / gad / nadi / nala / roli).
- Large portion of the area falls under cataclinal slope.
- Severe climatic conditions leading to rapid weathering.
- Seismically active nature of the region.

Landslide affected villages of the area

Naukori (Ukhrani *tok*)

Ukhrani *tok* is located at a distance of 14 kilometers from Kapkot town and is located on the left bank of southwest flowing Khamiya gad, a tributary of Revati Ganga. The area can be approached by Kapkot - Harsingyabagar link road. The *tok* is located about 7 kilometers from the road head. The area is observed to be drained by two streams.

The investigations around the village were carried out in the area on 23rd May, 2012 and traverses were taken around the village, nala bed, footpath section and upslope to examine the geological setup as also to investigate the causes of slope instability.

Geological set up of the area**:** The area was observed to be located amid agricultural fields over thick cover of overburden. The slope direction in the area was observed to be northwest that is parallel to the dip direction of the foliation planes. The failure slope was observed to be located little far from *tok* towards valley side and was occupied by both outcrops and overburden.

The rock exposures of Lesser Himalayan slates were observed along the footpath section and on the right bank of Khamiya gad as also upslope of the area. The strike of the rocks was observed to be NE – SW. These were observed to dip towards NW at dips varying between 30º and 35º. The rocks were observed to be traversed by numerous joints that constitute the most important structural discontinuities affecting the strength of rock mass and stability of slopes. The crucial joint sets were observed to dip at steep angles towards SW and SE (70° / 200° and 60º / 120º).

Reconnaissance geological-geotechnical assessment**:** The overburden thickness including weathered rock around the village was generally observed to vary between 2 to 3 meters but at places the thickness was observed to be up to 6 meters. The overburden material was observed to comprise of debris consisting of grayish brown to brown, fine grained silty with minor clayey matrix with fragments of slate.

The slide was observed to have occurred on the northwestern slope of NE - SW trending ridge. The inclination of failure slope was 30° to 35° whereas in the crown portion it was observed to be 50°. The width of the failure slope was about 50 meters along the Khamiya gad and height of the slide from gad to the crown was about 85 meters (Fig. 2).

Right flank of the slide was observed to be active and extending towards the houses around the crown. Cracks and ground fissures observed in loose overburden on agricultural fields were indicative of this.

Toe cutting / bank erosion by gad and water charged debris material during intense rain seemed to have facilitated the slide. Existing five houses at southeastern side of the slide above the crown were observed to be located at a distance of around 25 to 30 meters from the slide. This was observed to pose grave threat to these houses.

Fig. 2: View of huge detached slide mass just below the Ukhrani *tok*.

Baret (Bhaliyabagar *tok*)

Bhaliyabagar *tok* is located at a distance of 12 kilometers from Kapkot and can be approached by the Kapkot - Harsingyabagar link road. This village is located on the left bank of southwest flowing Revti Ganga, a tributary of Sarju river. This area is situated on a small terrace of Revti Ganga and is drained by a perennial stream.

The affected site was investigated on 24th May 2012 and traverses were taken around affected site to examine the geological setup and to investigate the causes of instability.

***Geological set up of the area*:** The area was observed to be largely occupied by overburden material. No rock outcrop was observed in the vicinity of the *tok*. The exposures along the road section as also on the stream bed were however observed to be that of Lesser Himalayan limestones and slates. The general trend of the rocks was observed to be E -W with moderately steep to steep dips towards south. This is attributed to local folding.

Fig. 3: Photograph depicting bank erosion/ toe cutting by Revati Ganga at Bhaliyabagar *tok* in Baret.

Reconnaissance geological-geotechnical assessment**:** The area around the *tok* was observed to have thick overburden and its thickness was up to 6 meters. This overburden material was observed to comprise of river borne material that consisted of grey, medium grained sandy matrix with rounded boulders.

Bank erosion caused by spate in Revti Ganga during excessive rainfall events in this valley was observed to have contributed to the instability of the slopes in this area. The river terrace was observed to be cut vertically by this stream. An eroded terrace with vertical cut around of 5 meters was observed on the left bank of Revti Ganga (Fig. 3).

Mitigation measures**:** Appropriately designed retaining structures of suitable height with firm foundation are required to be erected for preventing toe cutting / bank erosion by Revti Ganga. This would help in protecting the affected site as well as bank of Revti Ganga from stream erosion.

Baret (Talla Bagar *tok*)

Talla Bagar *tok* is located at a distance of 6 kilometers from Kapkot and is located on the left bank of Revti Ganga, a tributary of Sarju river. The area can be approached by Kapkot - Harsingyabagar motor road. The area is situated on small river terrace comprising largely of overburden material. The area is drained by two streams at this location.

The area was investigated on 24th May 2012 and traverses were taken around the road section and affected site to examine the geological setup of the rocks and look into the causes of instability.

Geological set up of the area**:** The area was observed to be located on the terrace of Revti Ganga and was largely occupied by overburden material. Exposures of limestone belonging to the Lesser Himalaya were observed in the road section around the *tok*.

The bedding plane was generally observed to be well developed. The strike of the rocks was observed to be NW - SE with moderate to steep dips (30º and 55º) towards south to southeast.

The rocks in the area were observed to be traversed by numerous joints and the important joint sets were observed to dip at steep angles towards NW and SE (76º / 310º and 60º / 140º).

***Reconnaissance geological-geotechnical assessment*:** In the area around the *tok* general thickness of overburden including weathered rock zone was observed to be 4 meters. This overburden material comprised of river borne materials consisting of boulder, gravel and sand.

Terrace was observed to be eroded by Revti Ganga and vertical erosion of around 4 meters was observed. This was attributed to high flood and intense rainfall events in the catchment and the same was deduced to have contributed to slope instability in this area (Fig. 4).

Fig. 4: Photograph depicting bank erosion in agricultural land by Revti Ganga just below Tallabagar *tok* in Baret area.

Mitigation measures**:** Western end of the affected area has a seasonal stream that flows in northeast direction. It is recommended that the course of this stream be properly trained and appropriate measures be taken to dispose off all the water that often gets accumulated on the road by this stream.

Appropriately high concrete retaining structure with stepladder and deep foundation needs to be erected at the location of the affected site. This would protect the house as well as agricultural fields from stream erosion.

Sama

Sama is located on the right flank of Sama Dhura nala and is located at a distance of 25 kilometers from Kapkot tehsil. The area can be approached by Kapkot – Bharari - Sama link road. The village is located in close proximity of the road head on the down slope direction. This area is drained by two seasonal streams.

This area was investigated on 25th May 2012 and traverses were taken around the site and road section to examine the geological setup and to examine the causes of slope instability and mass wastage.

Geological set up of the area**:** The area around the village Sama was observed to be located on agricultural lands and occupied by outcrops as well as overburden (Fig. 5). In the road section above the village exposures of Lesser Himalayan quartzites were observed. These rocks were medium grained, white, thin to medium bedded and slightly weathered. The rocks dip at angles varying from 32º to 35º towards northeast. These were moderately to highly jointed. The prominent joint sets were observed to dip towards SSW and ESE (75º / 200º and 55° / 105°).

Fig. 5: View of agricultural fields damaged by bank erosion by nala located down slope of Sama.

Reconnaissance geological - geotechnical assessment: The area under study was observed to be located amid agricultural land and was occupied by outcrops as well as overburden. General thickness of the overburden including weathered rock zone around the village was observed to be more than 3 meters but at places the thickness was observed to be up to 6 meters.

The slope failure was observed to have occurred on the southern slope of the strike ridge around Sama Dhura *tok*. The width of the failure slope was about 30 – 40 meters along the west flowing seasonal nala while the height of the slide from nala bed to the crown was about 75 – 80 meters. The inclination of failure slope was observed to be around 30°.

The failure slope was observed to be beneath the habitation and grass was observed to be growing over it. Soil creep often builds up stress in the soil mantle and the same is sometimes relieved by tension cracks. Cracks up to 4 cm deep and 10 cm wide were observed and these ground fissures continued for 0.5 meters.

Two seasonal streams flowing south and west were observed around the village. These were observed to have contributed to the instability of the area.

Mitigation measures**:** Appropriately designed retaining structures with deep foundation are required to be erected to prevent the toe cutting / bank erosion by nala. These would protect the slopes below village Sama.

A series of wire crate retaining walls are required to be constructed across the failure slope in steps without disturbing the slope. Afforestation is required to be undertaken on the slopes below the village. This would arrest further extension of the slide.

The course of the south flowing minor seasonal stream is required to be trained; cascading would help in reducing the pace of the flow and thus arrest erosion. Provision has to be made for effectively draining off the water that often gets accumulated on the road to the north of Talla Zadbinda *tok*. For this lined hill side drain with suitable gradient is required to be provided so as to drain the water directly into the nearby stream.

Gogina (Maubheri *tok*)

Maubheri *tok* (Fig. 6) is situated on the right flank of Parthi roli, a tributary of river Ramganga. It is at a distance of 45 kilometers from Kapkot and can be approached by Kapkot – Sama - Gogina link road. The main village is located about 5 kilometers upslope of the road head. The area is bound by two perennial streams.

This area was investigated on 26th May 2012 and traverses were taken around the site and upslope to examine the geological setup and to investigate the causes of slope instability and mass wastage.

Geological set up of the area**:** The area was observed to be located amid agricultural fields and was occupied by outcrops as well as overburden.

Exposures of grey gneiss belonging to Centre Crystalline were observed along the footpath section on the southeasterly slope. Slightly to moderately weathered gneisses were observed to be exposed at the eastern end of the *tok*. The foliations were observed to dip at angles varying between 20º to 25º towards northwest. The outcrops were covered with thin overburden around the village on the footpath section. The rocks were observed to be moderately jointed and were traversed by numerous joints. The important joint sets were observed to dip towards ENE and SE (80º / 065º and 58° / 145°).

Reconnaissance geological-geotechnical assessments**:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. Around the *tok* the general thickness of the overburden material including weathered rock zone was observed to vary between 2 and 3 meters but at places the thickness was observed to be up to 5 meters.

The relative relief of the *tok* was observed to be fairly high with vertical rocky scarp towards the valley side. This was attributed to heterogeneity, jointing and fracturing of the rocks.

Two southeasterly flowing perennial streams were observed at northern and southern extremity of the *tok*. In the area around the *tok* a seasonal stream was observed to flow through agricultural fields and in close proximity of the habitation. During heavy rainfall spells this stream was deduced to have potential of eroding the ground surface and threatening the habitation.

Building material was observed to be excavated from the southern extremity of the natural slopes for construction of houses in the *tok* by the local community. This was deduced to have triggered slope failure.

Fig. 6: Panoramic view of Maubheri *tok*.

***Mitigation measures*:** A minor southeast flowing seasonal stream around the *tok* is required to be trained. It is required that the same be lined and channelized in a cascading form along a gully so as to ensure safe disposal of rainwater into the main stream. This measure would protect the slopes of the area.

On the hill slope around the southern extremity of the *tok* retaining walls with free draining backfill have to be constructed at different levels of the slope so as to support the slope material around the failure area.

At the same time quarrying is required to be completely banned. To add to it grass turfing has to be provided on the slopes where quarrying has been done and the same has resulted in a transverse slide. This would help in protecting the failure slope besides checking soil erosion.

In case of seepage continues to exist in the houses the back slopes have to be appropriately treated.

Kimu (Tallagara *tok*)

Tallagara *tok* is located at a distance of 45 kilometers from Kapkot and is situated on the right flank of Kimu roli, a tributary of Ramganga river. The area can be approached by Kapkot - Gogina link road. The *tok* is located at a distance of 9 kilometers from the road head. The area is bound by two seasonal streams at this location.

This *tok* was investigated on 26th May, 2012 and traverses were taken around the site and upslope to examine the geological setup as also to investigate the causes of slope instability.

Geological set up of the area: The area was observed to be located amid agricultural land and occupied by outcrops as well as overburden. Exposures of grey gneisses belonging to the Centre Crystalline were observed along the footpath section on eastward trending slope. On the left flank of Kimu roli moderately weathered gneisses were observed. The foliations were observed to dip at angles varying from 20º to 25º towards northwest. The most important joint sets were observed to dip towards SE and ENE (60º / 135º and 76° / 060°).

***Reconnaissance geological-geotechnical assessment*:** General slope in the area was observed to be gentle to moderate. The overburden thickness including weathered rock zone was observed to be about 7 meters. This overburden material comprised of debris consisting of brown, fine grained silt with minor clayey matrix and angular fragments of gneiss.

Flow direction of Kimu roli was observed to change suddenly towards north - south in the eastern extremity of the *tok*. This was observed to result in toe erosion on its right bank. Resultant ground fissures were observed on the agriculture land below the *tok* (Fig. 7).

A spring was observed on the southern side of the *tok*. Enhanced ground water was observed to result in weathering that was highly pronounced along the discontinuities. The rocks below the overburden mass were observed to be highly weathered.

Fig. 7: Ground fissure in agricultural lands caused by bank erosion by nala below Tallagara *tok*.

***Mitigation measures*:** Construction of appropriately designed concrete retaining structure with buttress support on the eastern side as well as below the *tok* on agricultural land is recommended.

Appropriately designed wire crate retaining structures with suitably deep foundation are required to be constructed to prevent the toe cutting / bank erosion by Kimu roli. This would protect both bank and *tok* from stream erosion.

Appropriately designed retaining structures have also to be provided at the southeastern extremity as well as below the *tok* on agricultural land where slope failure has taken place. This would be beholding the critical failure slope mass and protecting the slope.

Leti (Kimu Tok)

Kimu *tok* is located on the left flank of Liti Gadiya gad. It is located at a distance of 40 kilometers from Kapkot and can be approached by Kapkot - Leti link road. The main *tok* is about 6.5 kilometers below for the road head. The area is drained by two seasonal streams.

This *tok was* investigated on 27th June 2012 and traverses were taken around the site and upslope to examine the geological setup as also to investigate the causes of instability and mass wastage.

***Geological set up of the area*:** The area under study was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. Rock exposures of tuffaceous - slate and talcose rocks belonging to the Tejam Formation of the Lesser Himalaya were observed along the footpath section as also upslope of the area. The rocks were observed to be moderately weathered and slightly smooth. The general trend of the rocks was observed to be NW - SE with moderate dips towards NE. The rocks were observed to be moderately jointed. The prominent joint sets were observed to dip towards SSW and ESE (62º / 210º and 75° / 105°).

***Reconnaissance geological-geotechnical assessment*:** Slopes of the area were observed to have moderate gradients whereas the overburden thickness including weathered rock zone was around 3 meters. This overburden material comprised of debris consisting of brown, fine grained silty matrix with angular fragments of slate and talcose rocks.

Around 5 years ago a number of agricultural fields at the eastern end of the *tok* were reportedly damaged by the landslide that was observed to have been reactivated (Fig. 8). Crown portion of the failure slope had steep to very steep slope and jointed, folded, fractured and locally sheared rocks were observed to be exposed in that area. Primary school and a house located just above the crown of the slide were observed to be in highly vulnerable state.

Fig. 8: View of agricultural fields damaged by slope failure in the area around Kimu *tok*.

Ground fissures up to 1 meter wide were also observed in the agricultural fields at the southern side of the *tok*.

Another landslide was observed at the western extremity of the *tok* and the same was observed to have damaged a number of agricultural fields. The slide was however fairly far from the *tok*. The inclination of failure slope was observed to be around 25° with the slope direction being southeast. The width of the failure slope was about 40 meters and vertical height of the slide was about 75 meters.

***Mitigation measures*:** Two southwest flowing seasonal streams in the vicinity of the *tok* are required to be trained. It is recommended that cascading be introduced along their course. This would be help in minimizing bank erosion besides ensuring proper gradient along their course.

It is recommended that the Primary School and a house located in close proximity of the crown of the landslide be vacated and put to disuse.

The slope is required to be modified at different levels in the area affected by debris slide at the western extremity of the *tok* by benching and erection of appropriately designed masonry buttress / retaining walls.

Kalapair Kapri (Malla Bagar *tok*)

Malla Bagar *tok* is located at a distance of 55 kilometers from Kapkot and can be approached by Sama - Tejam – Nachani motor road. The main *tok* is located at a distance of 2 kilometers for the road head. The area is drained by two northeast flowing streams; Guptiya roli and Ghatta roli that are tributaries of southeast flowing Ramganga river.

This area was investigated on 29th May 2012 and traverses were taken around the area, nala bed and footpath section to examine the geological setup as also to investigate the causes of instability and mass wastage.

***Geological set up of the area*:** The area was observed to be located on amid agricultural fields and occupied by outcrops as well as overburden. The exposures of Lesser Himalayan phyllites were observed on the nala bed. The rocks were observed to be moderately weathered but at places highly weathered. These were highly to moderately jointed and thinly foliated. The general trend of the rocks was observed to be E – W with moderate dips towards south.

Fig. 9: Panoramic view of Tallabagar *tok*.

***Reconnaissance geological-geotechnical assessment*:** In general gentle slope gradient was observed around the village but the gradient was observed to be steep in the upslope direction. Slope direction was observed to be towards northeast. Around the *tok* overburden thickness including weathered rock zone was observed to be around 5 meters. This overburden material comprised of hill wash and debris consisting of brown, fine grained silty - sandy matrix with angular fragments of phyllite.

Guptiya roli was observed to flow in close proximity of the *tok*. Enhanced discharge during monsoon has the potential of threatening the *tok.* A number of agricultural fields on the northern side as well as on right flank of Guptiya roli were observed to be threatened by bank erosion.

Another failure was observed along the northeast flowing Ghatta roli but the same is fairly far from the *tok* (Fig. 9).

***Mitigation measures*:** Construction of oblique anchored RCC wall with deep foundation is recommended at the right flank of Guptiya roli for protecting the houses in the down slope direction.

Construction of retaining structure at the right flank of the roli is recommended for preventing bank erosion of the agricultural fields as also for protecting the houses.

Gunthi

Gunthi is located about at a distance of 65 kilometers from Kapkot and can be approached by the Kapkot – Sama – Tejam – Nachani - Lweta motor road. The main village is located at a distance of about 1 kilometer from the road head. The area is drained by southeast flowing Mahar gad and south flowing Gunthi gad, both tributaries of Ramganga river. The area is thus bound by three streams.

This site was investigated on 29th May 2012 and traverses were taken around the questioned area, nala bed and footpath section to examine the geological setup as also to investigate causes of instability.

***Geological set up of the area*:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. Exposures of limestone belonging to the Lesser Himalaya were observed in the area, particularly along the Gunthi gad bed and footpath section. General trend of the rocks was observed to be NW – SE with very steep dips (65º to 70º) towards NE. The rocks were observed to be traversed by numerous joints that constitute important structural discontinuities affecting the strength of rock mass and stability of the slopes. Important joint sets were observed to dip towards SSW and ESE (68º / 195º and 55° / 155°).

***Reconnaissance geological-geotechnical assessment*:** Slope around the village was observed to be gentle but the gradient was observed to increase sharply in the upslope direction. Slope was observed to be southeasterly inclined.

Fig. 10: View of nala and failure slope on the uphill side of Gunthi village.

Around the village overburden thickness, including weathered rock zone, was observed to be around 2 meters. The overburden material was observed to comprise of top soil, hill wash and debris consisting of grey to brown, fine grained silty matrix with fragments of limestone.

The area was bound by southwest and southeast flowing streams; Gunthi gad and Mahar gad. These were observed to erode the base of the village.

Presence of two large tuffaceous boulders was observed in the area to the northwest of the village. Dislodging of these boulders was perceived to pose grave threat to the houses situated in the down slope direction.

High monsoonal discharge along the seasonal stream with steep gradient at the western end of the village has the potential of overwhelming the village with debris besides damaging the houses (Fig. 10).

Mitigation measures**:** To the north as well as uphill side of the village wire crate retaining structures are required to be constructed, particularly along the left flank and / or towards the valley side of the seasonal stream so as to minimize erosion at this location. This would help in diverting the transported material besides protecting the houses below. It however needs to be noted that quarrying need not be resorted to around this location for the construction of the retaining structures.

Tuffaceous boulders are required to be removed from the northwest as well as upslope of the village. This would reduce the vulnerability of the houses located on the down slope direction.

Construction of wire crate retaining structures is recommended at the southern end of the area to prevent the bank of the gad on its left flank. It would protect the bank and the toe of the slope material from stream erosion.

Lamaghar (Talla Lamaghar *tok*)

Talla Lamaghar *tok* is located at a distance of 75 kilometers from Kapkot and can be approached by Sama – Tejam – Nachani – Lweta motor road. The main *tok* is located at a distance of about 1.5 kilometers from the road head. The area is drained by a northwest flowing Bhatigariya gad, a tributary of southeast flowing Mahar gad.

This *tok* was investigated on 29th May 2012 and traverses were taken around the area and footpath section to examine the geological setup as also to investigate the causes of slope instability and mass wastage.

***Geological set up of the area*:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. Lesser Himalayan limestone and slate were observed to be exposed around the *tok*. In the footpath section around the *tok* exposures of limestone were observed. General trend of the rocks was E – W and these were observed to dip towards south to southeast at moderately steep angles (43º to 45º). The rocks were observed to be traversed by numerous joints that constitute important structural discontinuities affecting the strength of rock mass and stability of slopes. The important joint set was observed to dip towards NNE (65º / 025º).

***Reconnaissance geological-geotechnical assessment*:** The slopes around the *tok* were observed to have gentle gradient. This is attributed to step farming. Upslope of the area the gradient was however observed to be steep. Overall slope direction was towards southwest.

The area upslope of the village was occupied by unconsolidated overburden mass comprising of debris and scattered mass of dolomites. Generally overburden thickness including weathered rock zone was around 2 meters but at places thickness was observed to be as much as 4 meters.

On the northeastern side as also upslope of the *tok* outcrops of dolomites were observed amid agricultural land. The rocks were observed to be characterized by deep joints widened into swallow holes by groundwater (Fig. 11).

Cracks were observed in two houses located on the slope. These were up to 3 cm wide and were attributed to active slope movement with local settlement of the loose overburden material (Fig. 12).

Fig. 11: Photograph depicting ground fissure in agricultural fields.

Fig. 12: Photograph showing cracks and bulges in the house.

Kunwari

Kunwari is located on the right bank of Sambhu nadi, a tributary of Pindar river. Situated at a distance of 65 kilometers from Kapkot the area can be approached by the Kapkot - Badiyakot link road. The main village is located about 18 kilometers from the road head. The area is drained by two streams at this location.

This village was investigated on 2^{nd} June 2012 and traverses were taken around the footpath section, local nala bed and upslope to examine the geological setup of the area and to investigate the causes of instability.

***Geological set up of the area*:** The area was observed to be located amid agricultural fields that were occupied by both outcrops and overburden. Exposures of Lesser Himalayan phyllites were observed around the area along the footpath section and on nala bed below the village. The general trend of the rocks was NW– SE and these exhibited moderately steep dips towards NE. The rocks were observed to be traversed by numerous joints. The important joint sets were observed to dip towards NE and SE (80º / 050º and 73° / 140°).

Reconnaissance geological-geotechnical assessment**:** A number of retaining structures were observed to have been erected to stabilize the old landslide uphill of the village. The landslide was however observed to be reactivated. Crown of the slide was situated in the forest area and a number of trees were observed to have been uprooted by the slide. Around the crown the failure slope gradient was around 45°. Landslides were observed to occur uncontrollably over almost the entire stretch of the hill side which follows the trend of the bed rocks. The slide was observed to slide pose risk to the houses located on the down slope direction (Fig. 13).

Below the village and on the northeastern side of the village as well as on the nala bed shattered, sheared, folded and heavily jointed phyllites were observed. These enhance the risk. A major spring was also noticed at the base of village.

Primary School, Junior High school and Milan Kendra located in the northwestern extremity of the village on the left flank of the local nala were observed to show local settlements (numbers of cracks in walls and floors) and active creeping due to toe erosion by the stream (Fig. 14).

Fig. 13: View of reactivated old landslide upslope of Kuwari village.

Fig. 14: Photograph showing cracks in Junior High School building.

Around the Kuwari village, particularly towards the valley side, the slope was observed to be parallel to the foliations planes causing instability. This active landslide was observed to extend up to Sambhu nadi. This was deduced to adversely affect the stability of Kuwari village.

The thinly foliated and fragile nature of the phyllites had resulted in the formation of landslide that was observed to facilitate movement of huge slope mass below the village. The angle of failure slope was observed to be around 45° and even more. The direction of the slope was observed to be towards northeast. The ground fissures in the failure slope area were observed to be 2 to 5 meters long (Fig. 15).

Fig. 15: Panoramic view of Kunwari village.

Kilbara

Kilbara is located on the right bank of Pindar river at a distance of 65 kilometers from Kapkot and can be approached by Kapkot - Badiyakot motor road. The main village is located at a distance of 5 kilometers from the road head. The area is drained by one stream at this location.

This village was investigated on 2nd June 2012 and traverses were taken around the affected site and footpath section to examine the geological setup as also to investigate the causes of instability.

***Geology of the study area*:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. The exposures of Lesser Himalayan phyllites were observed around the area as also along the footpath section. The general trend of the rocks was NW– SE and these were observed to dip at moderately steep angles towards SW. The rocks were observed to be traversed by numerous joints that constitute important structural discontinuities affecting the strength of rock mass and stability of the slopes. The important joint sets were observed to dip towards ENE and SE (75º / 070º and 68° / 320°).

***Reconnaissance geological-geotechnical assessment*:** Zones of water accumulation were observed at several locations in the agricultural fields. East flowing local drainage, Buyigara rola, was observed to flow through the agricultural fields near the village. Bank erosion by this drainage on its both flanks was deduced to contribute to increased instability of the agricultural lands as well as the village.

Creep in the debris material and the underlying thinly foliated and moderately jointed phyllites due to enhanced pore water pressure was held responsible for decreased frictional resistance and together these contributed to the instability of the area. Soil creep builds up stresses in the soil mantle that are sometimes relieved by tension cracks. The ground fissures on the agricultural land were observed to continue for as long as 3 meters.

In the past slope failure around the village had reportedly damaged a number of agricultural fields and houses. The direction of failure slope was observed to be southwest. Failure plane exhibited concave morphology with steep slope around the crown portion. The slope around the toe was however observed to be around 45° (Fig. 16).

Most of the affected people have already shifted from the landslide affected area and have constructed the houses in the safer areas.

Fig. 16: Photograph depicting slope failure around Kilbara village.

Badiyakot (Patak *tok*)

The *tok* is located on the left flank of Ghat gad, a tributary of Pindar river. It is at a distance of 65 kilometers from Kapkot and can be approached by the Kapkot - Badiyakot motor road. The main *tok* is located about 7 kilometers upslope of the road head. The area is drained by a stream at this location.

This *tok* was investigated on 2nd June 2012 and traverses were taken around the footpath section and affected site to examine the geological setup and to investigate causes of instability and mass wastage.

***Geology of the study area*:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. The exposures of quartzites belonging to the Lesser Himalaya were observed along the footpath section and below the village. General trend of the rocks was observed to be NW - SE with moderately steep dips towards NE (38º to 43º / NE). The rocks in the area were observed to be traversed by numerous joints that constitute important structural discontinuities affecting the strength of rock mass and stability of slopes. The important joint sets were observed to dip towards SSE and WNW (57º / 195º and 80° / 300°).

***Reconnaissance geological-geotechnical assessment*:** The general slope angle of the area was observed to be moderate and the overburden thickness including weathered rock zone was 2 meters. The overburden material was observed to comprise of hill wash and debris consisting of brown, fine grained silty - sandy matrix with fragments of quartzite.

The failure was observed to have occurred around the village on the southern slope of E-W trending ridge. This was observed to have damaged a number of agricultural fields. General inclination of the failure slope was 25° but it gained gradient of 35° in the crown portion. The width of the failure slope was about

40 meters and vertical height of the slide was about 95 meters. Bouldery debris was mostly observed along the failure slope (Fig. 17).

Fig. 17: View of the landslide around Patak *tok* where it has damaged a number of agricultural fields.

***Mitigation measures*:** Construction of masonry retaining structure at specific interval without disturbing the natural slope would protect the critical slope mass.

Wachham (Talla Wachham *tok*)

Talla Wachham *tok* is located on the right of Pindar river. It is at a distance of 55 kilometers from Kapkot and can be approached by Kapkot - Kharkiya (Pindari) motor road. The main *tok* is located about 8 kilometers upslope of the road head. This area is drained by a southeast flowing seasonal stream that finally joins southwest flowing Pindar river.

This *tok* was investigated on 3rd June 2012 and traverses were taken around the *tok* and footpath section to examine the geological setup as also to investigate the causes of instability.

***Geology of the study area*:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. The exposures of gneisses belonging to the Central Crystallines were observed along the footpath section as also in the area below the village. The foliations were observed to dip at angles varying from 30º to 35º towards northeast. The rocks in the area were observed to be traversed by numerous joints. The important joint sets were observed to dip towards SSW and ESE (75º / 200º and 67° / 125°).

***Reconnaissance geological-geotechnical assessment*:** The general slope around the *tok* was observed to be gentle because of step farming but the slope was steep both on the uphill and downhill side. Around the *tok* overburden thickness including weathered rock zone was observed to be around 5 meters. This overburden material comprised of hill wash and debris consisting of grey to brown, fine grained silty matrix with angular fragments and large boulders of gneiss.

In the eastern side of *tok* southeast flowing Buyigara rola was observed to contribute to the instability of the area.

The slide was observed to have occurred on the southwestern slope of NE - SW trending ridge. Two houses were damaged in the southern side below the *tok* due to bank erosion by the local seasonal drainage on its right flank (Figs. 17 and 18).

Fig. 17: Photograph showing slope failure below Talla Wachham caused by bank erosion.

Fig. 18: Panoramic view of Talla Wachham.

Mitigation measures**:** Appropriately designed masonry retaining walls are required to be constructed at specific intervasl without disturbing the natural slope so as to protect the critical slope mass.

Karmi (Lora *tok*)

Lora *tok* is located on the right flank of Toli roli. It is a distance of 15 kilometers from Kapkot and can be approached by the Kapkot - Karmi motor road. The main *tok* is located about 3 kilometers upslope of the road head. The area is drained by a southwesterly flowing seasonal stream that finally joins the Sarju river.

This area was investigated on 5th June 2012 and traverses were taken along the footpath section and the nala bed to examine the geological setup as also to investigate the causes of instability.

Geology of the study area**:** Lesser Himalayan quartzites of Berinag Formation were observed to be exposed around the *tok*. The rocks were slightly weathered and highly to moderately jointed. These were observed to dip steeply towards northeast. The critical joint set was observed to dip at angles varying from 45°

to 70° towards southwest and the same was parallel to the natural slope. At places the rock mass was observed to be disturbed due to fractures and joints.

***Reconnaissance geological-geotechnical assessment*:** Quartzite was observed to exhibit well developed foliation planes that dip at 40° towards 015°. These thus dip hill wards at moderately steep angles. In the northeastern portion of the *tok* failure surface was observed to have slopes steeper than 45° (Fig. 19).

The saturation by rainwater was held responsible for increased pore water pressure in the overlying overburden mass. This at the same time provided lubrication amid the underlying jointed and fractured weathered rock layers. This was deduced to have reduced shear resistance of the slope forming materials and triggered the landslide.

Fig. 19: Photograph showing huge critical landslide mass over Lora *tok*.

The bouldery debris mass of Karmi landslide was observed to be dangerous, particularly during the monsoon season when it could be transported through the local nala during intense rainfall events and cause damage to the houses located on both sides of the nala.

Mitigation measures: It is recommended the huge critical mass around the crown and in the detached or subsided area of landslide be removed mechanically. As a precautionary measure the houses located on the down slope direction should be totally vacated while undertaking this exercise.

Rikhari (Malla Rikhari *tok*)

Malla Rikhari is located on the right bank of Sarju river and is at a distance of 17 kilometers from Kapkot. The area can be approached by Kapkot – Munar - Patiyasar motor road. The main village is located about 1.5 kilometers upslope of the road head. The area is drained by a stream that flows towards southwest at this location.

This area was investigated on 8th June 2012 and traverses were taken around the village and footpath section to examine the geological setup as also to investigate the causes of slope instability.

Geology of the study area: The area was observed to be located on the hill slope and occupied by outcrops as well as overburden. Exposures of Higher Himalayan gneisses were observed upslope of the *tok* as also along the footpath section. The foliations were observed to dip at angles varying from 18º to 22º towards northeast. The rocks were observed to be traversed by numerous joints. One joint set was observed to dip towards NE while the other had vertical attitude with the strike trending NE –SW (76º / 45º and 90° / 35° - 215°).

Reconnaissance geological-geotechnical assessment: In general the slope around the area was observed to be gentle. The southerly slope was however very steep. Upslope of the *tok* steep rocky slope was observed. The rocks were moderately weathered and were observed to dip gently towards hillside.

Detached rock mass was observed upslope of the *tok* and the same was deduced to pose threat of falling down. It could adversely affect the interests of the three families residing in the down slope area.

South of the Primary School, Rikhari jointed and fractured rocks mass was observed on the steep rocky slope. The loose blocks on the hill slope were observed to be hanging over the *tok*. These were deduced to have potential of falling down and damaging the houses (Figs. 20 and 21).

Fig. 20: View of rock fall zone over Malla Rikhari *tok*.

Fig. 21: Photograph depicting slope failure below Malla Rikhari *tok*.

Rikhari (Dhurkot *tok*)

Dhurkot *tok* (Fig. 22) is located on the right bank of Sarju river and is at a distance of 17 kilometers from Kapkot. The area can be approached by Kapkot – Munar - Patiyasar motor road. The main village is located about 3.5 kilometers upslope of the road head. The area is drained by a southwest flowing stream.

This area was investigated on 8th June 2012 and traverses were taken around the area and footpath section to examine the geological setup and to investigate the causes of instability.

Geology of the study area**:** The *tok* was observed to be located on the hill slope and occupied by outcrops as well as overburden. Exposures of Higher Himalayan gneisses were observed upslope of the *tok* as also on the footpath section. The foliations were observed to dip at angles varying between 10º and 20º towards northeast but at places northwesterly dips were also observed. The rocks were observed to be traversed by numerous joints. Important joint sets were observed to dip towards N, NNE and SSW (50º / 360º, 77º / 030º and 68° / 220°).

Reconnaissance geological-geotechnical assessment**:** The general slope of the area was observed to be gentle however both the northwestern slope and the slope above the *tok* were observed to be steep. Increase in slope height by erosion due to excessive rainfall was deduced to have contributed to the instability of the slopes in this area.

The shallow debris above the steep rocky slopes was deduced to have potential of initiating debris flow during heavy rainfall events. This could pose danger to the habitation below (Fig. 23).

Fig. 22: Panoramic view of Dhurkot *tok*.

Fig. 23: Photograph showing shallow debris slide over Dhurkot *tok*.

In the area upslope of the *tok* a completely damaged water canal / channel was observed together with a tin shed and the temple of *Bhumiyal Devta* that were both partially damaged due to slope failure. The area on the back side of the partially damaged tin shed and temple of the *Bhumiyal Devta* was observed to be filled with debris.

***Mitigation measures*:** Debris accumulated on the back side of the partially damaged tin shed and the temple of the *Bhumiyal Devta* is required to be removed mechanically. After removing the debris concrete breast wall / toe support wall would have to be constructed for the stability of the affected slope and the protection of the structures.

Retaining structure with suitable provision of weep holes would have to be provided to support the failure slope at its toe. The foundation of this wall has to be put on compact materials. The damaged water canal / channel should also be repaired.

In order to minimize the percolation of water into the slide zone, lined drains are recommended in the upslope portion of the failure towards the depression in the northeast side.

Harkot (Pass *tok*)

Pass *tok* is located on the left flank of Koti gad, a tributary of Sarju river and is at a distance of 25 kilometers from Kapkot. The *tok* is located just above the Kapkot - Pindari motor road. The affected site was investigated on 8th June 2012 and traverses were taken around the road section and *tok* to examine the geological setup and to investigate the causes of instability.

***Geology of the study area*:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. Exposures of white to reddish quartzites of the Lesser Himalaya were observed in the area along the road section and near the failure area. The foliations were observed to dip at angles varying between 34º and 37º towards north to northwest. The rocks were traversed by numerous joints of which the important ones were observed to dip towards SSE and ESE (65º / 175º and 85° / 120°).

***Reconnaissance geological-geotechnical assessment*:** The slope around the area was observed to be moderate. The overburden thickness including the weathered rock zone was observed to be around 2 meters. The overburden material comprised of hill wash and debris consisting of brown, fine grained silty - sandy matrix with fragments of quartzite.

The failure was observed to have occurred on agricultural fields below the houses. A number of agricultural fields below the *tok* were completely damaged due to the slope failure. The quartzitic rocks were observed to be shattered by blasting undertaken during the road construction and this was deduced to have adversely affected the rock mass strength (Fig. 24).

Fig. 24: Panoramic view of Pass *tok*

Fig. 25 : Photograph showing landslide below existing houses

The slide was observed to have occurred on the eastern slope of NE - SW trending ridge. General inclination of failure slope was 20° to 25° whereas in the crown portion inclination was above 45°. The width of the failure slope was observed to be about 50 meters along the agricultural fields while the height of the slide from the fields to the crown was about 90 meters (Fig. 25). Cracks up to 1 meter deep and 30 cm wide were observed in the agricultural fields together. The ground fissures were observed to extend for more than 2 meters. Four hoses were observed to exist in a close vicinity of the landslide area. Of these two were located just above the crown of the slide while one was at the right flank and another was at the toe. The landslide was deduced to pose serious threat to these houses, particularly during monsoons.

Suding

Suding village is located on the right bank of Sarju river and is at a distance of 15 kilometers from Kapkot. The area can be approached by Kapkot - Pindari motor road. The main village is located about 0.5 kilometers below the road head. The area is bound by two streams at this location.

This village was investigated on 9th June 2012 and traverses were taken around the road and footpath section to examine the geological setup and to investigate the causes of instability.

Geology of the study area: The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. Exposures of Lesser Himalayan quartzites were observed along the road section as also along the footpath section below the village. The rocks were observed to dip at angles varying from 55º to 60º towards northwest. The rocks were traversed by numerous joints of which important ones were observed to dip towards SW and E while the vertical one was observed to strike NW - SE (76º / 245º, 53° / 90° and 90° / 310° -130°).

Reconnaissance geological-geotechnical assessments**:** An old slide was observed to have damaged a number of cultivated fields in the eastern end of Gharwari *tok*. Crown portion of the failure was observed to have very steep slope. Seepage and ground fissure up to 5 meters long were observed on the failure slope. The width of slide along road was 200 meters while the height of the crown from the road was 300 meters. Large number of Utis trees (*Alnus nepalensis)* were observed to grow in the middle and toe portion of the slide.

The slope of the failure plane was observed to be more than 35°. Saturation by rainwater was deduced to have resulted in increased pore water pressure conditions in the overlying overburden mass that resulted in the reduced shear resistance of the slope forming materials. This ultimately triggered the landslide (Fig. 26).

Landslide debris deposited upslope of the village along the nala bed was observed to pose threat to Suding village, especially in monsoons when the debris could flow through Bhendera nala and damage the houses along its course (Fig. 27).

Fig. 26: View of landslide on the uphill side of Suding village.

Fig. 27: Photograph depicting encroachment along the course of Bhandera nala.

Mitigation measures**:** Construction of appropriately designed wire mesh check dams at specific intervals across the Bhandera nala and upslope of Suding village is recommended. This would reduce the pace of flowing down water and thus check its carrying capacity. This would at the same time check the transported material.

Upslope of village particularly in left flank of Bhandera nala construction of wire mess retaining structures is recommended. This would help in protecting the houses and agricultural land.

All encroachments on the nala bed are required to be removed immediately. The villagers should at the same time be advised to stay away from Bhandera nala, particularly during monsoons.

Suitably designed and anchored concrete RCC wall is required to be erected in the subsided portion of the failure slope in the crown area at the eastern end of Gharwari *tok*.

Gansi

Gansi is located on the left bank of Sarju river. It is situated at a distance of 14 kilometers from Kapkot and can be approached by the Kapkot - Munar motor road. The main village is located about 6 kilometers from the road head. The area is drained by northeast flowing seasonal stream, Laundhariya nala and northwest flowing perennial stream, Gansi gad which is the tributary of south flowing Sarju river.

The Gansi village was investigated on 9^{th} June 2012 and traverses were taken around the affected area, nala bed and footpath section to examine the geological setup and to investigate the causes of slope instability.

***Geology of the study area*:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. Exposures of Higher Himalayan gneisses were observed around the nala bed and footpath section around the *tok*. The foliations were observed to dip at angles varying from 30º to 35º towards northeast. The rocks were observed to be traversed by numerous joints. The important joint sets were observed to dip towards SE and W (73º / 140º and 75° / 270°).

***Reconnaissance geological-geotechnical assessment*:** The general slope of the area around the village was observed to be gentle. Southern slope of the area with slope direction towards northeast was however steep. The overburden thickness including weathered rock zone was observed to be around 3 meters. The overburden material comprised of hill wash and debris consisting of grey to brown, fine grained silty matrix with fragments of gneisses.

In the area around the village on the left flank of the Gansi gad natural slope was observed to be parallel to the foliation planes. This was deduced to cause instability in the area.

High flood in Laundhariya nala was observed to have damaged a number of agricultural fields at the eastern extremity of village (Fig. 28). The slide was observed to have occurred on the eastern slope of NW - SE trending ridge. General inclination of failure slope was observed to be 35° whereas the slope in the crown portion was more than 50°. The width of the failure slope was about 60 meters and its height was about 90 meters.

Fig. 28: View of the agricultural fields damaged at the eastern extremity of Gansi village.

Fig. 29: Panoramic view of Gansi village.

The Gansi village was observed to be situated over in situ rocks and the failure slope was fairly far away from the village (Fig. 29). At the eastern end of the village a house was observed to be located on critical slope and waste / household water was observed to flow in close proximity of the house. This may be dangerous to the house during monsoons.

Mitigation measures**:** Good surface drainage is required to be provided along the eastern end of village for safe passage of monsoon discharge and household waste water.

Construction of appropriately designed anchored RCC wall is recommended at the eastern slope of the village. This would protect the critical slope as well as the existing houses.

Gansi (Kuee *tok*)

Kuee *tok* is located on the left bank of Sarju river and is at a distance of 14 kilometers from Kapkot. The area can be approached by Kapkot - Munar motor road. The *tok* is located about 4 kilometers from the road head. The area is drained by northwest flowing local stream.

This *tok* was investigated on 9th June 2012 and traverses were taken around the affected area, upslope and footpath section to examine the geological setup and to investigate the causes of slope instability and mass wastage.

Geology of the study area**:** The Kuee *tok* was observed to be located amid agricultural fields that were occupied by outcrops as well as overburden. Upslope of the area along the footpath section phyllites were exposed. The foliations were observed to dip at angles varying from 33º to 35º towards north to northeast. The rocks were traversed by numerous joints of which the important ones were observed to dip towards SSW and SSE (55º / 210º and 85° / 160°).

Reconnaissance geological-geotechnical assessment**:** The overburden thickness including weathered rock zone was observed to be around 3 meters. The overburden material comprised of hill wash and debris consisting of grey to brown, fine grained silty matrix with fragments of phyllites and quartzites.

The slide was observed to have occurred on the northwestern slope of the area. The general inclination of failure slope was observed to be 25° but the inclination around the crown was more than 35°. The width of the failure slope along the agricultural fields was observed to be about 40 meters and its height from fields to the crown was about 100 meters. Soil creep was observed to have resulted in stress built up in the soil mantle and the same was being relieved by tension cracks. Ground fissures up to 10 cm deep, 10 cm wide and around 1 meter long were observed (Fig. 30).

Two seasonal water courses flowing towards west in the upslope portion of the *tok* were deduced to have contributed to the instability of the area. In the western side of the *tok* one house was observed to be damaged by landslide (Fig. 31).

Fig. 30: View of the damaged agricultural fields.

Fig. 31: Photograph depicting partially damaged house.

Suding (Song *tok*)

Song *tok* is located on the left flank of local drainage named Timul roli, a tributary of Sarju river. It is located at a distance of 12 kilometers from Kapkot on Kapkot – Bharari – Song - Pindari motor road. This *tok* was investigated on 9th June 2012 and traverses were taken around the road section and the affected site to examine the geological setup and to investigate the causes of slope instability.

Geology of the study area**:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. Exposures of Lesser Himalayan phyllites were observed on the right flank of Timul roli as also on the road section. The foliations were observed to dip at angles varying from 28º to 32º towards northwest. The rocks were traversed by numerous joints of which important ones were observed to be dip towards ESE and NNE (73º / 135º and 67° / 010°).

Reconnaissance geological-geotechnical assessment**:** The general slope in the area was observed to be moderate. The overburden thickness including weathered rock zone was observed to be around 3 meters. The overburden comprised of hill wash and debris consisting of grayish to grayish brown, fine grained silty - clayey matrix with fragments of phyllites.

Fig. 32: View of slope failure around the *tok*.

Fig. 33: Photograph depicting bank erosion by the seasonal nala.

In the southern side of the affected area just above the road, slope failure was observed to have occurred due to bank erosion and road cutting. The inclination of failure slope was observed to be 25° (Fig. 32). Excessive rainfall and monsoonal flooding in Timul roli was deduced to have caused the bank erosion (Fig. 33).

Mitigation measures**:** Appropriately designed breast wall is recommended to the **s**outh of the *tok* on the road side. This would help in stabilizing the critical failure slope mass.

Plants with high root – shoot ratio should be introduced in the failure slope area between *tok* and the road to arrest further extension of the slide.

Construction of deep founding wire crate retaining structure is also suggested to prevent the toe cutting / bank erosion by the stream.

Damaged retaining wall below the road on the right flank of Timul roli must be repaired for maintaining the road.

Munar

Munar village is located on the right bank of Sarju river and is at a distance of 14 kilometers from Kapkot. The area can be approached by the Kapkot - Munar motor road. The area is bound by two streams.

This village was investigated on 9th June 2012 and traverses were taken around the road section and upslope to examine the geological setup and to investigate the causes of slope instability and mass wastage.

Geology of the study area: The village was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. Exposures of Lesser Himalayan reddish quartzite were observed on the right bank of Sarju river and along the road section. The rocks were observed to dip at angles varying from 50º to 65º towards north to northeast. The rocks were observed to have multiple joints. These were observed to dip towards ESE and SE while the vertical joint had N – S strike (50º / 120º, 80º / 130º and vertical with 000°-180° strike).

***Reconnaissance geological-geotechnical assessment*:** Around the village general thickness of the overburden was observed to vary between 1 to 2 meters but at places its thickness including weathered rock zone was observed to be up to 3 meters. The overburden material comprised of hill wash and debris and consisted of grey to brown, fine grained silty - sandy matrix and fragments of quartzite (Fig. 34).

The general slope angle in the area was moderate and the direction of slope was towards northeast. Slope instability did not appear to affect the natural slopes in the area. Presently there were no indications of major slope instability around the village.

Fig. 34: Panoramic view of Munar village.

Shum (Guram *tok*)

Guram *tok* is located on the left flank of Shum gad also called Koko nadi by the locals. It is situated at a distance of 14 kilometers from Kapkot and can be approached by Kapkot – Song - Munar motor road. The main *tok* is located at a distance of about 3 kilometers from the road head.

This *tok was* investigated on 10th June 2012 and traverses were taken along the nala bed, footpath section and around the village to examine the geological setup and to investigate the causes of slope instability.

***Geology of the study area*:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. The area was observed to be surrounded by protective canopy of dense oak forest cover. The area was observed to have moderate to moderately steep slopes with northeasterly slope direction. Lesser Himalayan phyllites were observed to be exposed on the Shum gad bed. The rocks were fine grained, grey, moderately weathered but at places highly weathered and highly to moderately jointed. The foliations were observed to dip at angles varying from 33º to 37º towards northeast while the joint sets were observed to dip towards SSW, S and NNE (57º / 215º, 85º / 180º and 75° / 030°).

Reconnaissance geological-geotechnical assessment: The general slope around the area was observed to be moderately steep. The overburden thickness including weathered rock zone was around 4 meters. This overburden material was observed to comprise of hill wash and debris consisting of brown, fine grained silty matrix with fragments of phyllites.

On the left bank of the Shum gad in Guram *tok* area the natural slope was observed to be parallel to the foliations planes. This has the potential of causing instability in the area. However, such instability was not observed to affect the natural slopes of the area. No indications of major slope instability around the area were observed. Assessment of shallow instability and soil creep could however not be undertaken due to the dense vegetation cover.

Minor slope failure was observed in front of a single house. No indication of slope movement was observed in agricultural lands around the village.

In the back slope area of an existing house quarrying was observed to have been undertaken on agricultural land and loose soil / quarried material was dumped in the area (Fig. 35).

Fig. 35: Quarrying at back slope of an existing house.

Mitigation measures: It is recommended that the quarried material be removed from back slope of the house and further quarrying on agricultural land be banned as this would result in ground subsidence and debris charged water to damage the houses on the down slope side.

Masonry retaining structure with adequate provision of weep holes can be constructed in front of the house where slope failure has occurred.

Shum (Thulkatyau *tok*)

Thulkatyau *tok* is located on the left flank of Shum gad also called Koko nadi by the locals. It is situated at a distance of 14 kilometers from Kapkot and can be approached by Kapkot – Song - Munar motor road. The main *tok* is located about 5 kilometers from the road head.

This *tok was* investigated on 10th June 2012 and traverses were taken along the nala bed, footpath section and around the village to examine the geological setup and to investigate causes of mass wastage and slope instability.

***Geology of the area*:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. The surrounding area was observed to have thick vegetative cover. The area was observed to have moderate to moderately steep slopes with slope direction towards northeast.

Exposures of Lesser Himalayan phyllites were observed on Shum gad bed below the affected area. The rock was fine grained, grey, moderately weathered but at places highly weathered and moderately to highly jointed. The foliations were observed to dip at angles varying from 33º to 36º towards north. The joint sets were observed to dip towards SSW, S and NNE (53º / 215º, 85º / 180º and 85° / 030°).

Fig. 36: View of the house in Thulkatyau *tok* showing evidence of local settlement.

***Reconnaissance geological-geotechnical assessment*:** The general slope around the village was observed to be moderate whereas overburden thickness including weathered rock zone was about 5 meters. The overburden comprised of hill wash and debris consisting of grayish to grayish brown, fine grained silty matrix with fragments of phyllite.

On the left bank of the Shum gad in Thulkatyau *tok* area natural slope was observed to be parallel to the foliations planes. This has the potential of introducing instability in the area. However no signs of such instability were observed on the natural slopes of the area. Assessment of shallow instability and soil creep could however not be undertaken due to dense vegetal cover. Some isolated evidences of local settlements in the houses and minor slope failures in agricultural lands were observed (Fig. 36).

***Mitigation measures*:** As a precautionary measure retaining structures could be provided in areas around the *tok* and in agricultural fields where minor slope failures have occurred. This would help in protecting the failure slopes and reducing slope instability of the area.

Shum (Bhechana *tok*)

Bhechana *tok* is located on the left flank of Shum gad also called Koko nadi by the locals. It is at a distance of 14 kilometers from Kapkot and can be approached by Kapkot – Song - Munar motor road. The main *tok* is located about 7 kilometers from the road head.

This *tok* was investigated on 10th June 2012 and traverses were taken along the nala bed, footpath section and around the site to examine the geological setup and investigate the causes of instability.

***Geology of the study area*:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. The area was observed to have moderate slope with slope direction towards northeast.

Exposures of Lesser Himalayan phyllites were observed at the eastern extremity and upslope of the *tok*. The rocks were moderately weathered, highly to moderately jointed and thinly foliated. The foliations were observed to dip at angles varying from 30º to 35º towards northeast.

The rocks were observed to be traversed by numerous joints. The prominent joint sets were observed to dip towards SSW and NNE (58º / 210º and 65° / 025°).

Fig. 37: View of the eroded rocky slope at the eastern end of Bhechana *tok*.

***Reconnaissance geological-geotechnical assessment*:** The general slope around the area was observed to be moderate and the overburden thickness including weathered rock zone was about 3 meters. The overburden material comprised of hill wash and debris consisting of brown to grayish brown, fine grained silty matrix with fragments of phyllite (Fig. 37).

In the eastern end of the *tok* a landslide was observed to have occurred and this was deduced to have contributed to the instability of the area.

The relative relief around the *tok* was fairly high with sub-vertical to vertical rocky scarp towards eastern end. This was attributed to heterogeneity, jointing and fracturing of rocks. Flooding in local seasonal streams during excessive rainfall events during the monsoons were deduced to have caused erosion in the area leading to slope instability (Fig. 38).

In the forest area up slope of the *tok* tension cracks and about 35 – 40 cm deep voids of were observed. This area was however fairly far from the *tok* (Fig. 39).

On the left bank of the Shum gad the natural slope was observed to be parallel to the foliation planes. This might cause instability in the area. However, signs of such instability were not observed on the natural slopes of the area. Assessment of shallow instability and soil creep could however not be undertaken due to dense vegetation cover.

Fig. 38: View of agricultural land uphill of *tok* area.

Fig. 39: Photograph depicting voids in the forest area.

***Mitigation measures*:** Sealing of voids at the southern extremity as well as up slope of the *tok* on forest area is recommended. At the eastern end of the *tok* rocky slope is required to be treated by erecting wire crate and concrete retaining / breast walls.

Shumgad (Bhamal *tok*)

Bhamal *tok* is located on the left flank of Shum gad also known as Koko nadi. It is at a distance of 14 kilometers from Kapkot and can be approached by Kapkot – Song - Munar motor road. The main *tok* is located about 3 kilometers from the road head.

This *tok* was investigated on 10th June 2012 and traverses were taken along the nala bed, footpath section and around the site to examine the geological setup and to investigate causes of slope instability and mass movement.

Geology of the area**:** The area was observed to be located amid agricultural fields in close proximity of the nala. At the right flank of Shum gad towards the western extremity of the *tok* steep rocky cut was observed.

Some exposures of Lesser Himalayan phyllites were observed in the area. The foliations were observed to dip at angles varying from 30º to 35º towards northeast.

The rocks in the area were observed to be traversed by numerous joints that constitute important structural discontinuities affecting the strength of rock mass and stability of slopes. The joint sets were observed to dip towards SSW and NNE (58º / 210º and 65° / 025°).

Reconnaissance geological-geotechnical assessment**:** General slope in the area was observed to be gentle and the overburden thickness including weathered rock was about 6 meters. This overburden material consisted of brown, fine to medium grained sandy matrix with large boulders and river borne material.

Shum gad was observed to be affected by bank erosion that was deduced to contribute to the instability of the area. In year 2010, the nala was reportedly diverted towards the *tok* and caused damage to a number of houses along its course (Fig. 40).

Fig. 40: Photograph showing the damage in Bhamal *tok* caused by flood in the nala.

Saling

Saling village is located on the right bank of Sarju river. It is at a distance of 12 kilometers from Kapkot and can be approached by Kapkot - Song motor road. The village is located just below the motor road.

The investigations around the village were carried out on 10th June 2012 and traverses were taken around the road section and affected site to examine the geological setup and to investigate the causes of instability.

Geology of the area: The area was observed to be occupied by outcrops as well as overburden. Exposures of tuffaceous slate, talcose and talc - mica schist belonging to Lesser Himalaya were observed in the area, particularly along the road section. The rocks were observed to dip at angles varying from 42º to 45º towards northeast.

The rocks were observed to be traversed by numerous joints. Prominent joint set was observed to dip towards SSW (53º / 195º).

Reconnaissance geological-geotechnical assessment: General thickness of the overburden including weathered rock zone in the area was observed to be around 6 meters. This overburden material comprised of hill wash and debris consisting of gray to grayish brown, fine grained silty - clayey matrix with fragments of tuffaceous slate boulders.

Several subsidence zones were observed around the road and around the affected site. The ground fissures were observed to have affected four residential houses of the *tok*. Of these some were observed to be tilted while and some showed movement towards both hillside and valley side (Fig. 41).

Voids and cracks were observed on the failure slope just below the *tok*. The failure slope was observed to have slope of around 45° and the slope direction was towards southeastern. Tilted and bent trees observed on the failure slope indicated creeping of tuffaceous debris material (Fig. 42).

Fig. 41: Photograph depicting deformation in the houses.

Fig. 42: View of bent trees indicating creep movement.

Jhuni (Gora *tok*)

Gora *tok* is located on the right flank of a local drainage, Gora gad. It is at a distance of 25 kilometers from Kapkot and can be approached by the Kapkot – Munar - Patiyasar motor road. The main *tok* is about 8 kilometers from road head. The area is drained by two eastward flowing streams that finally meet Sarju river.

This *tok* was investigated on 12th June 2012 and traverses were taken around the site and footpath section to examine the geological setup and to investigate the causes of slope instability and mass movement.

Geology of the area**:** The area was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. Exposures of Central Crystalline gneisses were observed along the footpath section around the *tok*. The foliations were observed to dip at angles varying from 20º to 23º towards northeast.

The rocks were observed to be traversed by numerous joints. The joint sets were observed to dip towards SSE and SW and the vertical joint was observed to strike NNE – SSW (70º / 145º, 75° / 240° and vertical joint strike is 30° - 210°)

Reconnaissance geological-geotechnical assessment**:** A seasonal water course was observed in the area upslope of the *tok* while a perennial stream was observed to be present on the northern side. Both were observed to have contributed to the instability of slope in this area.

Around the *tok* general thickness of the overburden material, including weathered rock zone was observed to be around 3 meters. The overburden material comprised of hill wash and debris consisting of grey to brown, fine grained silty matrix with angular fragments of gneisses.

In the northern extremity of *tok* bank erosion by Gora gad was observed to have damaged a number of agricultural fields and affected many houses. About 12 houses were affected by both seasonal water course and perennial stream (Figs. 43, 44 and 45).

Fig. 43: Photograph showing agricultural fields damaged by bank erosion.

Fig. 44: Panoramic view of Gora *tok*.

Slope material and debris in the area upslope of the *tok* was observed to pose threat to the Gora *tok*, especially during intense rainfall spells when the same is likely to be brought down by the seasonal nala (Fig. 46). Around 21 families were thus observed to be vulnerable to debris flow and bank erosion by Gora gad.

Fig. 45: View of the seasonal water course upslope of *tok*.

Fig. 46: Photograph depicting the house damaged by ground subsidence.

Mikhila Khalpatta (Kurchetti *tok*)

Kurchetti *tok* is located on the left bank of Sarju river and is at a distance of 25 kilometers from Kapkot. The area can be approached by Kapkot – Munar -

Patiyasar motor road. The main *tok* is about 3 kilometers from the road head. The area is drained by two streams at this location.

This site was investigated on 13th June 2012 and traverses were taken around the road and footpath section to examine the geological setup and to investigate the causes of slope instability and mass wastage.

***Geology of the study area*:** The *tok* was observed to be located amid agricultural fields and occupied by outcrops as well as overburden. Exposures of Central Crystalline gneisses were observed along the footpath section as also upslope of the area. The foliations were observed to dip at angles varying from 15º to 20º towards northeast.

The rocks were observed to be traversed by numerous joints that constitute important structural discontinuities affecting the strength of rock mass and stability of slopes. One prominent joint set was observed to dip towards SSW while the other one was vertical with NNE - SSW strike (80º / 200º and vertical with 10° - 190° strike).

***Reconnaissance geological-geotechnical assessment*:** The overburden thickness around the *tok* including weathered rock zone was generally observed to be 4 meters. This overburden material comprised of debris consisting of grey to brown, fine grained silty matrix with angular fragments of gneisses.

A rock cut slope was observed in the up slope of the *tok* and village Mikhila - Khalpatta was situated above that slope.

Bank erosion by Sarju river on its left bank was observed to pose threat to the stability of *tok*. Evidences of localized differential settlement were observed in some houses. However, no indication of the slope movement in agricultural land and in the area around *tok* was observed (Fig. 47).

Fig. 47: Panoramic view of Kulchetti *tok*.

***Mitigation measures*:** Construction of concrete slabs / deep founding wire crate retaining structures of appropriate height is recommended to prevent the toe cutting / bank erosion by Sarju river. This would protect the bank of river as well as the village.

Conclusion and recommendations

The villages of Kapkot tehsil of Bageshwar district covered under the present study were observed to face serious slope stability related problems. Based on the field information and data on the geology of the specific landslide affected sites, causative factors of slope instability and reconnaissance geological - geotechnical assessment appropriate site specific mitigation measures have been suggested in the previous sections. In order to be effective, all the slope stability related measures must be planned, and designed carefully under the supervision of experienced geotechnical engineer / civil engineer.

The suggested mitigation measures would help in reducing the vulnerability of the affected villages and provide stability to the slopes. However the possibility of these being reactivated by extreme precipitation events and high intensity seismic tremors cannot be ruled out.

Some families in various villages were identified as residing in the areas that are exposed to high risk. It is therefore advised that these families be relocated at alternate safer areas.

In the mean time it is suggested that attempts be made to communicate the threat to the residents so that they take the necessary precautions, especially during the monsoons. The details of the identified families are summarized below.

1.	Naukori village	Ukhrani *tok*	05 families
2.	Harkot village	Pass *tok*	04 families
3.	Jhuni village	Gora *tok*	21 families
4.	Rikhari village	Malla Rikhari *tok*	03 families
5.	Lamaghar village	Talla Lamaghar *tok*	04 families
6.	Leti village	Kimu *tok*	01 family and Primary School
7.	Kunwari village		All families