Investigations in the areas around Okhimath in Rudraprayag district on the aftermath of landslide incidences of September, 2012

A report

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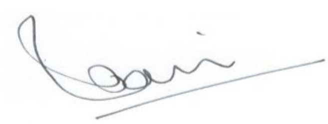
Foreword

Abnormally high precipitation in the area around Okhimath, in the catchment of Mandakini river that has its confluence with Alaknanda at Rudraprayag, on 13th and 14th September, 2012 induced landslides and debris flows around many villages. These inflicted heavy loss of human lives, property and infrastructure in Jua, Kimara, Bamankholi, Premnagar, Dangwari, Mangoli, Chunni, Salami and Giriagaon villages of Okhimath tehsil of Rudraprayag district. It was followed by landslides in Kirora Malla and Timli villages in Jakholi tehsil in the morning hours of 16th September, 2012. As many as 69 human lives were lost in these incidences. In terms of human lives lost this is thus the biggest tragedy since the creation of the state.

This report is the outcome of the field investigations carried out in the disaster hit areas between 17th and 23rd September, 2012 by Disaster Mitigation and Management Centre (DMMC) team comprising of Shri Bhupendra Bhaisora, Shri Sushil Khanduri and Shri Saklani. Site inspection and other investigations were carried out in the presence of the concerned Patwari, Gram Pradhan and local people.

Assistance provided by the officials of Rudraprayag district administration and other departments during the field work is duly acknowledged. Dr. P.K. Champatiray, Head, Geosciences Division of Indian Institute of Remote Sensing (IIRS), Dehradun is thanked for sharing pre and post – disaster satellite imageries of the area. GIS analysis and study of the satellite imageries was done at GIS Laboratory of DMMC by Ms Chanderkala, Ms Suman Ghildiyal, and Shri Ashish Rawat. All are thanked for their contribution and assistance.



8th October, 2012
Dehradun

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The area

The area devastated by disasters during monsoons of 2012 is located in Okhimath and Jakholi tehsils of Rudraprayag district and falls in the catchment of Mandakini river that has its confluence with Alaknanda river at Rudraprayag.

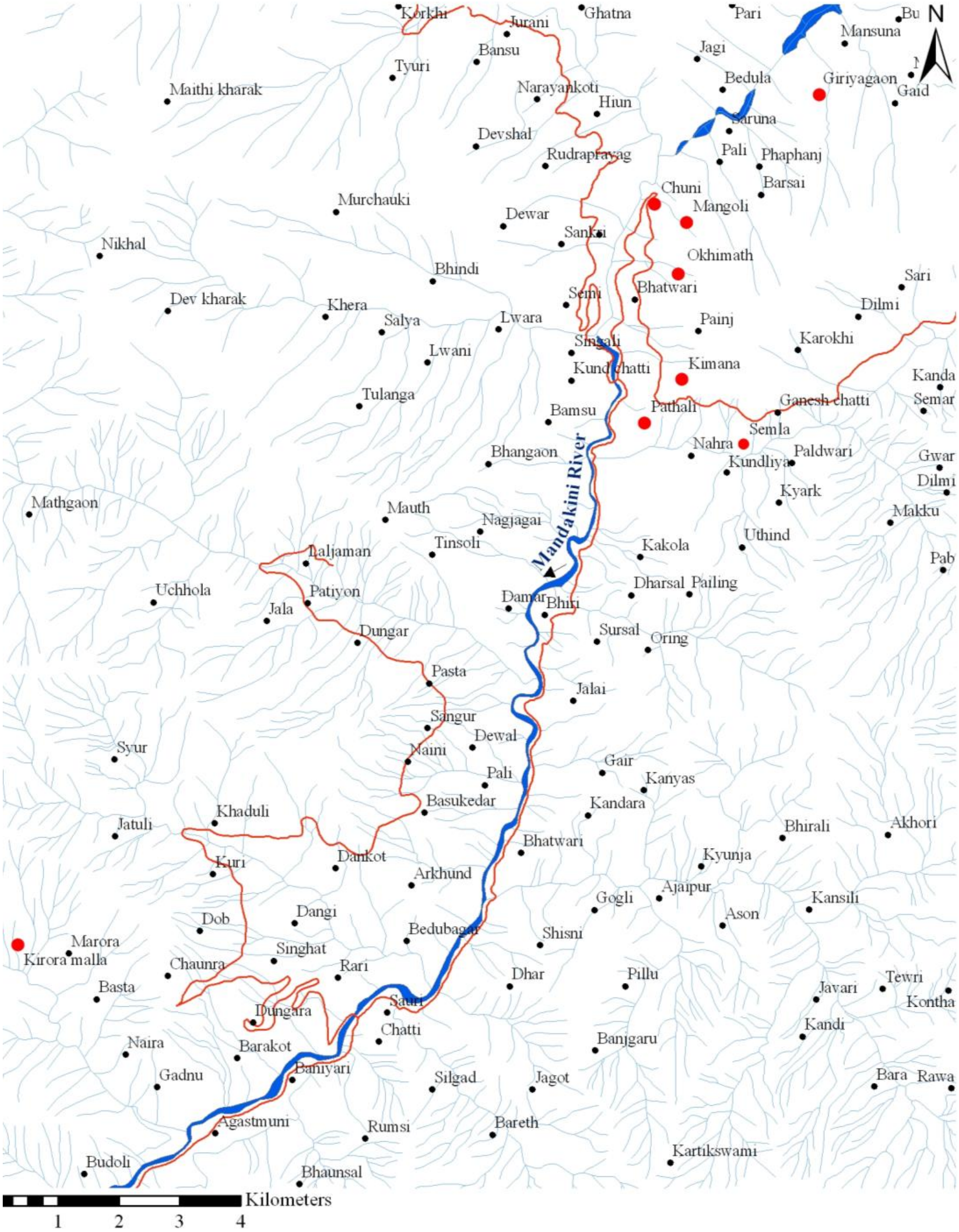

Fig. 1. Location map of the disaster affected area around Okhimath in Rudraprayag district. The affected habitations are shown in red.

The area can be approached by the link roads bifurcating from the Kedarnath National Highway and most areas are in close proximity of the road head. Okhimath (Fig. 2) is located at a distance of 37 km from Rudraprayag. For reaching Okhimath National Highway has to be left at Kund that is at a distance of 30 km from Rudraprayag. For reaching Kirora the National Highway has to be left at Agastyamuni, that is at a distance of 18 km from Rudraprayag, and one has to travel further on the link road to Jakholi for 22 km.

Fig. 2. Panoramic view of Okhimath town showing scars made by the debris descending down the steep slope.

The area is observed to be dissected by several ridges and the ground elevations generally vary from 1200 to 2600 meters above mean sea level. Hundreds of meter high steep cliffs are common feature of the topography of the area. Geomorphic features of fluvial / fluvio-glacial and colluvial origin are generally observed in the area.

The area is drained by Madhyamaheshwar and Kali Ganga rivers that are the main tributaries of Mandakini river. The streams and rivers in the area are generally observed to flow with great force through steep and narrow channels; often resulting in excessive bank erosion and ultimate collapse of the banks.

Subtropical and temperate montane type of vegetation is generally observed in the area. The area is generally observed to have moderate to thick forest cover.

The area has tropical climate and experiences high monsoonal rainfall. The summers are pleasant while the winters are cold. Average summer temperature remains around 25° C while the winter temperature may even drop to 0° C. The rainfall pattern in the area shows high spatial variability that is largely controlled by slope aspect.

Major disaster incidences in the district

Rudraprayag district is prone to multiple disasters. The district falls in Zone V of the Seismic Zoning Map of India (Fig. 3) and has been devastated by seismic tremors in the past.

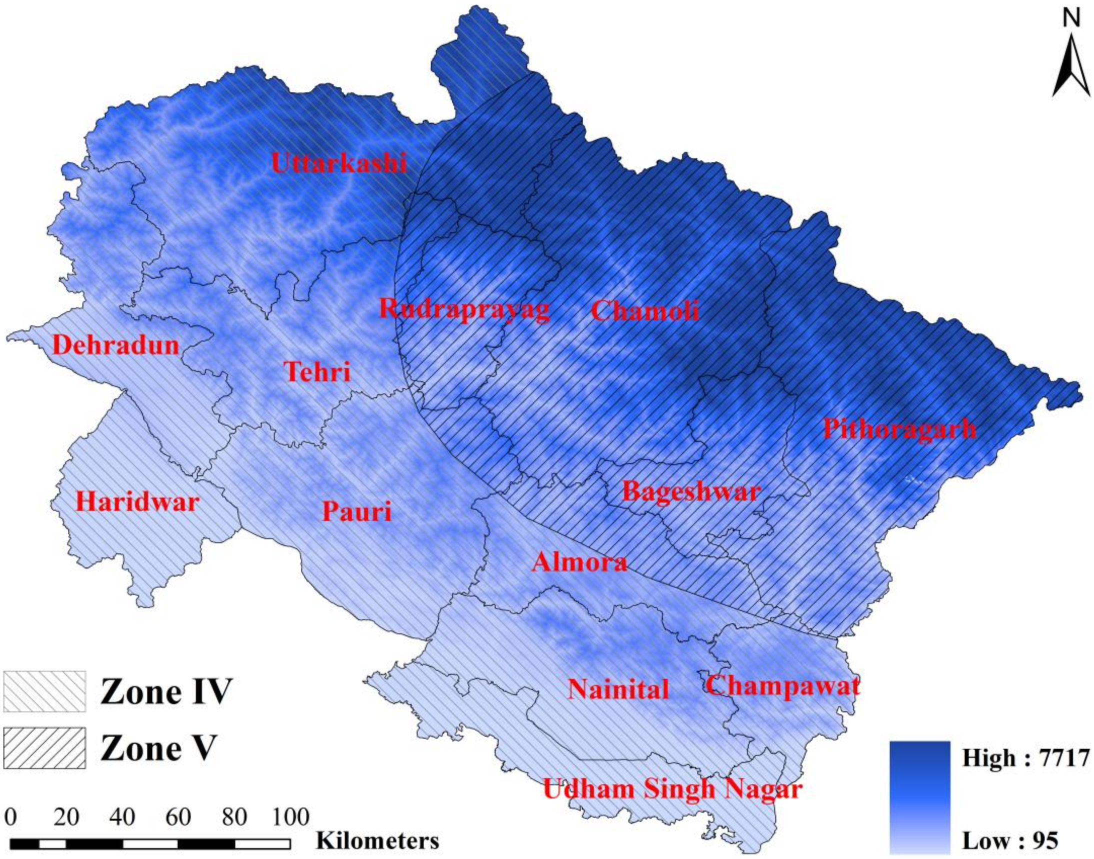

Fig. 3. Earthquake zoning map of Uttarakhand.

Earthquake is however not the sole disaster to which the district is vulnerable. Landslide, cloudburst and flash flood are other disasters common in the area. Geo – tectonic configuration of the rocks makes the area inherently unstable and prone to landslides. In the past the district has been devastated over and again by earthquakes, landslides and flash floods.

Earthquakes of 1803 and 1842 reportedly devastated Rudraprayag region. In 1857 the course of Mandakini river was reportedly blocked

for three days due to landslides. The course of Mandakini was again blocked by landslides in 1976.

Flash floods in Kunjya Gad (tributary of Mandakini) in 1979 inflicted heavy losses in Kontha, Chandranagar and Ajaypur. 29 persons were killed in this incidence and the course of Mandakini was blocked near Chandrapuri.

32 persons were killed in Sirwari landslide in Jakholi tehsil in 1986 and the Uttarkashi Earthquake of 1991 inflicted heavy losses to the residential and other structures in Jakholi, Okhimath and Rudraprayag.

During the monsoons of 1998 major landslides occurred at many places in Madhyamaheshwar and Kali Ganga valleys between 11th and 19th August. Massive landslide at Bheti – Paundar (in the vicinity of Mansuna) blocked the course of Madhyamaheshwar river for more than 24 hours causing serious concern in the downstream areas (Fig. 4). Summary of losses in this event is given in Table 1.

Table 1. Losses incurred by landslides in Madhyamaheshwar and Kali Ganga valleys in August 1998.

Sl. No.	Head	Number
1.	Human lives lost	103
2.	Affected villages	34
3.	Affected families	1,767
4.	Affected population	9,792
5.	Cattle loss	423
6.	Houses damaged	1,276
7.	Agriculture land loss (in ha)	411

Fig. 4. View of Bheti – Paundar landslide of August 1998.

Chamoli Earthquake of 1991 caused significant loss of human lives and property in Rudraprayag district (Figs. 5 and 6). Population of 11,500 in 34 villages was affected by the quake that caused loss of 36 human lives. 176 persons were injured in this incidence that took toll of 140 cattle.

Figs. 5 and 6. View of the devastation at Akhori (left) and Oring (right) villages of Rudraprayag district due to 1999 Chamoli Earthquake.

Landslides amid abnormally heavy precipitation on 15th and 16th July, 2001 in Phata area of Okhimath tehsil caused death of 28 persons (Figs. 7 and 8). Population of 3,924 in 15 villages of the area was affected by this incidence. 52 houses were damaged / destroyed in the incidence that took toll of 62 cattle and 43 hectare agricultural land.

Figs. 7 and 8. View of the Phata landslide of July, 2001.

04 persons were killed in the landslide around Vijaynagar in Agastyamuni on 21st July, 2005. 14 houses were damaged / destroyed in this incidence.

On 26th July, 2006 landslides and flash floods caused massive losses in Ladoli, Devali, Gholtir and Gursyal villages and in 2010 losses were reported from Jaili village of Jakholi tehsil.

The above description makes it amply clear that the areas devastated by the mass movement at present have been inherently vulnerable and have been repeatedly affected by various disasters in the past.

Present disaster event

In the Uttarakhand Himalaya, mass movement is often triggered by high precipitation during monsoon months, destabilization of the toe of the slope material by road construction and other developmental initiatives and undercutting of the banks by streams.

Very heavy rainfall was recorded in the area around Okhimath in Rudraprayag district in the night of 13th September as also in the morning hours of 14th September 2012 (Fig. 9). This triggered landslide and debris flow at many places in the vicinity of Okhimath. It is reported that landslides started around midnight and the dislodged mass continued to move down even till the morning.

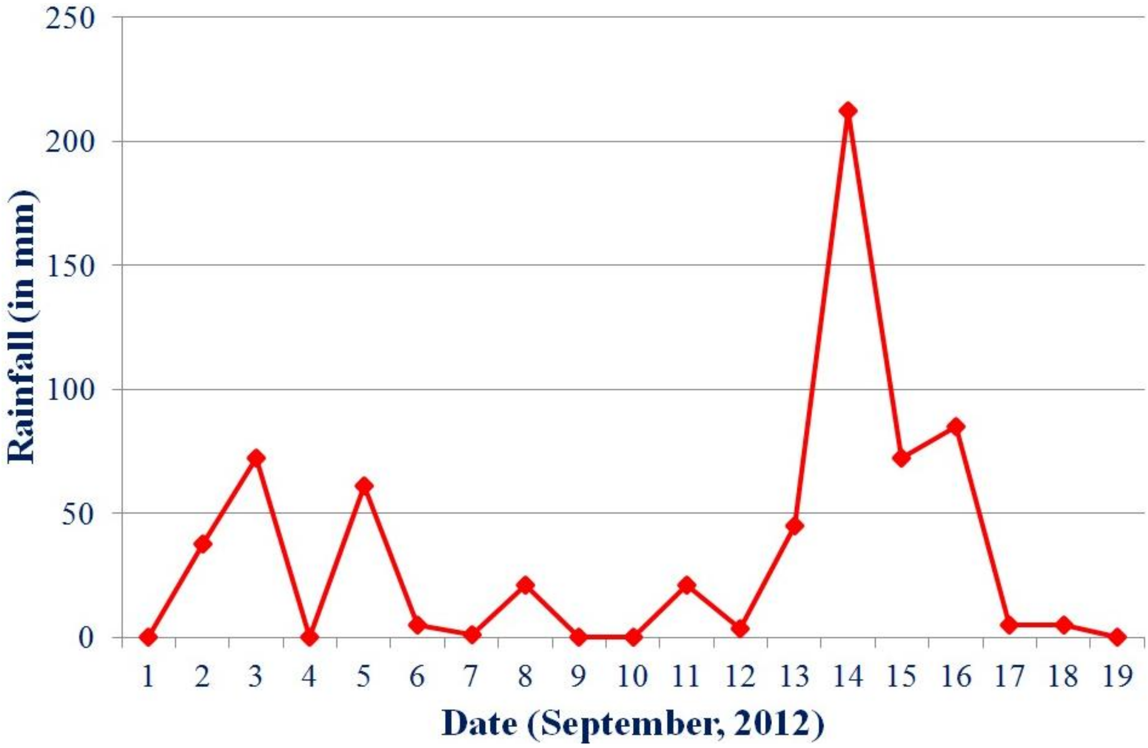

Fig. 9. Daily precipitation received at Okhimath in the month of September, 2012.

These landslides and debris flows devastated Jua, Kimara, Bamankholi, Premnagar, Dangwari, Mangoli, Chunni, Salami and Giriagaon villages. Many houses in these villages were overrun by debris and road connecting Kund to Okhimath was washed away at Kund and Chunni. The other road

connecting Okhimath with Chopta and Gopeshwar was also blocked at Mastura. No vehicular movement to Okhimath was thus possible after this tragedy.

Fig. 10. Damaged houses in Mangoli village.

Fig. 11. Damaged food grain storage facility at Bamankholi.

As if this was not enough Kirora Malla and Timli villages in Jakholi tehsil of Rudraprayag district, that are located in the vicinity of the area affected earlier by landslides, experienced heavy landslides in the morning hours of 16th September, 2012.

These incidences caused loss of 69 human lives and serious injuries were caused to 15 persons. More than 70 residential houses were reported to be destroyed in these incidences that caused heavy loss of other infrastructure and facilities (Figs. 10 and 11).

Administrative response

Even though assess to Okhimath was disrupted and it was raining heavily search and rescue teams of the Department of Disaster Management managed to reach the disaster affected area in the wee hours of 14th September and started search and rescue operations. Officials of the district administration including the District Magistrate and police force also reached the site of the incidence in the morning. By the evening Army and ITBP personnel also reached the site of the disaster and started rescue operations (Figs. 12 and 13).

Figs. 12 and 13. Army and ITBP personnel engaged in search and rescue operations.

Foot paths connecting the villages having been washed off extra effort had to be put in to evacuate the survivors to safer locations (Fig. 14). Injured persons were also quickly evacuated to Base Hospital, Srinagar for advance medical care by helicopter (Fig. 15).

Fig. 14. Survivors being evacuated.

Fig. 15. Air evacuation of the injured.

As the incidence has rendered large number of people without shelter, clothing and other essential items and food relief camp was set up at Government Inter College (GIC), Okhimath and Bharat Sewa Ashram, Okhimath where around 550 persons were accommodated. These persons were provided clothes and bedding together with other necessities. Community kitchen was set up in the relief camp with the help of Shanti Kunj, Haridwar (Figs. 16 and 17).

Fig. 16. Community Kitchen at GIC Okhimath.

Fig. 17. People being provided food at the relief camp.

A temporary medical post was also set up in the relief camps to attend to medical exigencies of any sort (Fig. 18). Apart from this a central store was established at GIC Okhimath for storing the relief material (Fig. 19).

Fig. 18. Medical post at GIC Okhimath.

Fig. 19. Relief material storage facility at GIC Okhimath.

Together with this various logistics related arrangements were also made for the search and rescue personnel, organizations bringing in relief material, media personnel and the VIPs visiting the disaster affected area.


Figs. 20 and 21. Rescue operation in Okhimath by NDRF and rescue team of disaster management, Uttarakhand

In view of fresh incidences in Jakholi tehsil one platoon of PAC was mobilized from Srinagar. One company of NDRF also reached the site of the incidence on 16th September.

Search and rescue teams of the Department of Disaster Management and NDRF were present at the incidence site till the search operations were not called off in the evening of 21st September. Despite best efforts from all quarters only 53 dead bodies could be recovered (Figs. 20 and 21).

Landuse / land cover

Characterization of the landuse was undertaken using satellite imageries of the area (Fig. 22). It shows that 57 percent of the area falls under forest cover and half of this is actually under dense forest cover. 38 percent of the area is observed to be under agricultural operations.

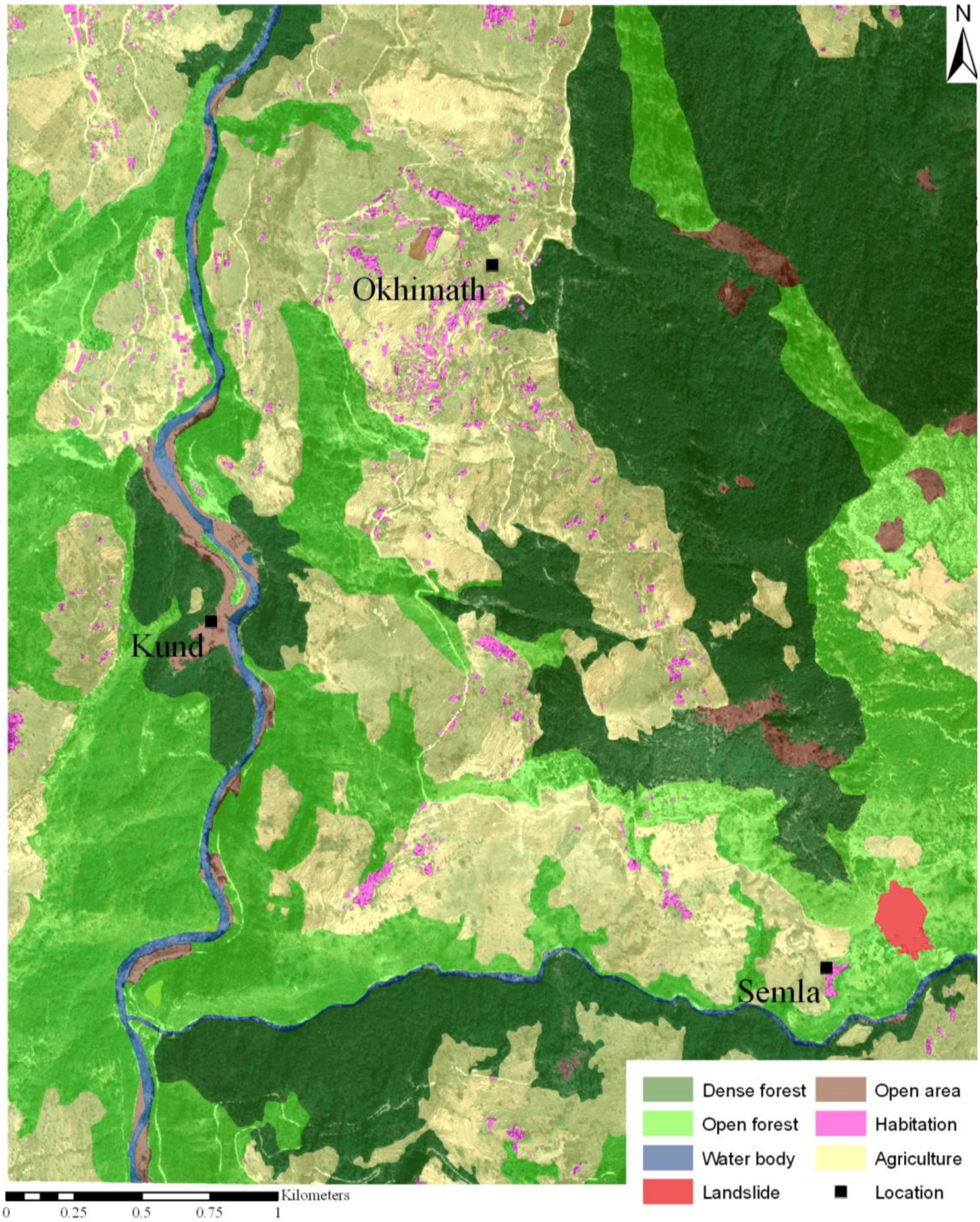

Fig. 22. Landuse map of the area around Okhimath in Rudraprayag district (Satellite imagery of 30th March, 2012).

Comparison of the pre and post disaster satellite imageries clearly shows that more than 0.5 sq km area has been directly affected by landslides (Fig. 23, Table 2).

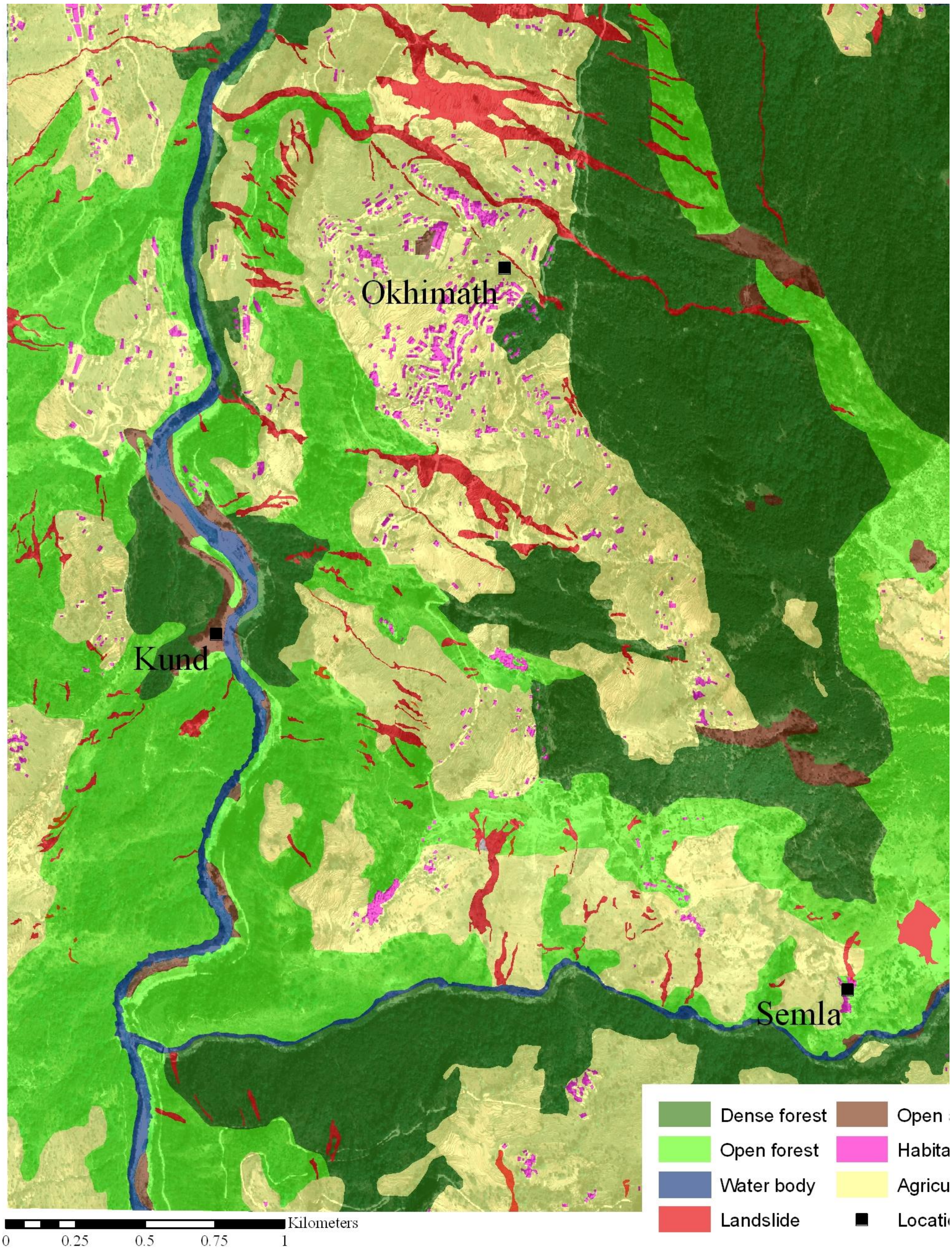

Fig. 23. Post – disaster landuse map of the area around Okhimath in Rudraprayag district (Satellite imagery of 19th September, 2012).

Post – disaster satellite imagery clearly shows that most of the devastating landslides initiated in the higher reaches of the N – S trending steep ridge to the east – northeast of Okhimath. Initiating mostly in forest area these gathered mass and momentum while descending down. This is responsible for the devastating power of these slides.

Most of the habitations were observed to be situated amid agricultural lands with thick cover of overburden material. This added to the devastation and a number of houses were completely swept away by the landslide debris.

Table 2. Statistical details of the landuse / land cover changes brought forth in the area due to the mass movement of September 2012 (Data based upon the satellite imageries of 30th March, 2012 and 19th September, 2012).

Landuse / landcover class	Area (in sq km)			Percent change
	30th March, 2012	19th September, 2012	Change in area	
Dense Forest	4.44	4.56	0.12	2.8
Open Forest	4.49	4.61	0.12	2.7
Agriculture	6.03	5.28	-0.75	-12.4
Open Area	0.30	0.21	-0.08	-27.9
Landslide	0.04	0.55	0.51	1342.1
Water Body	0.22	0.27	0.05	24.1
Habitation	0.28	0.26	-0.02	-7.4

The analysis clearly shows that overwhelming proportion of the area (59 percent) affected by landslides and debris flows was erstwhile under agricultural operations. Of the total area ravazed by landslides 27 percent is accounted for by open forest, 10 percent by dense forest and 4 percent by habitations. This amply highlights the impact the landslides on human interests as 64 percent of the area ravazed by landslides falls under agriculture and habitation.

General geology of the area

The rocks exposed in the Uttarakhand Himalaya range from Archaean to Holocene in age and are grouped into 15 super-sequences whose spatial distribution is often controlled by NW-SE trending tectonic discontinuities that as disposed from south to north are i) Main Frontal Thrust (MFT), ii) Main Boundary Thrust (MBT), iii) south Almora Thrust (SAT), iv) North Almora Thrust (NAT) and vi) Main Central Thrust (MCT).

Super-sequence (litho-package) I (Archaean Central Crystalline) to XI (Late Paleocene to Middle Eocene Subathu Group) are exposed in part of Lesser, Great and Tethyan Himalayan zones. The super-sequence XII (Upper Eocene to Early Miocene Murrees - Dagshai) and XIII (Early Miocene to Lower Pleistocene Siwalik Group) are restricted to the Sub Himalayas. The Super-sequence XIV (Middle to Late Pleistocene older terrace alluvium and lateral moraines) and XV (Holocene newer alluvium and terminal moraines) occur as valley fill deposits.

The Garhwal Group is extensively developed in the Inner Lesser Himalaya from Kali valley in the east to Tons valley and beyond in the west. In the Ganga valley, it is limited by the MCT in the north and North Almora Thrust (NAT) in the south. It represents super-sequence II that comprises of low to medium grade meta-sediments. These include quartzite with penecontemporaneous mafic metavolcanics and carbonates intruded by epidiorite and granite - gneiss. The Garhwal Group is intruded by two types of granites viz. biotite granite and tourmaline granite. The Garhwal Group has been folded into a series of NW-SE trending doubly plunging anticlines and synclines which have been refolded into NE-SW trending cross folds.

Central Crystalline (Super-sequence I) forms a part of a linear belt that can be traced from the Yamuna Valley in the west to the Kali Valley in the east and beyond in the Nepal Himalaya. Main Central Thrust (MCT) forms its southern contact with the Garhwal Group while it forms basement for the deposition for various sequences ranging in age from Meso - Proterozoic to Quaternary. It possibly forms the oldest crystalline basement of the Himalaya. Although, it has witnessed different Precambrian orogenies prior to the strong Himalayan Orogeny, much of the original composition is preserved. The gneisses, migmatites, crystalline schist, thick quartzite with conspicuous horizons of calc-silicates and para-amphibolite with psammite gneisses in the upper part form bulk of the metasediments. Details of lithostratigraphy are given in Table 3.

Table 3: Lithostratigraphy of the Central Crystalline and Garhwal Group (After Agrwal and Kumar 1980, Kumar, 2005).

FORMATIONS	LITHOLOGY	METAMORPHIC GRADE
Central Crystalline Group (Supersequence- I)		
Rilkot	Kyanite, sillimanite-staurolite, biotite schist; banded calcsilicates.	
---------------------------------- Unconformity --------------------------------		
Badrinath	Garnet, sillimanite, muscovite and kyanite bearing gneiss, mica schist, migmatite, calc-silicate, leucogranite, pegmatite and garnet mphibolites.	Sillimanite zone
Pandukeshwar	Banded quartzitic gneiss and interbedded quartz mica schist, para-amphibolite.	Kyanite zone
Munsiari (Joshimath)	Garnet mica gneiss, garnet, staurolite and kyanite gneisses, tourmaline-mica gneiss, garnet mphibolites.	Kyanite and Staurolite zone
Bhimgora Quartzite	White quartzite with gneiss and schist.	

Ragsi	Mica schist, gneiss, para-amphibolite.	Kyanite zone
-------------------------- Main Central Thrust (MCT) --------------------------		
Garhwal Group (Supersequence- II)		
Berinag	Quartzite with/without penecontemporeneous mafic metavolcanic intruded by epidiorite.	
Deoban	Limestone, dolomite and phyllite	
Rautgara	Quartzite with Penecontemporaneous mafic metavolcanic intruded by epidiorite.	
Uttarkashi (= Agastmuni)	Grayish black to grayish blue limestone and dolomite with thinly bedded grey slate. Banded grey, green and slates interbedded with quartzite. White to buff, fine-grained, current bedded quartzite and interbedded slate with minor lenses of limestone.	
-------------------------------- Alaknanda Fault ----------------------------------		

The exposed rocks in the Mandakini valley mainly belong to Central Crystalline and Garhwal Group that are separated by MCT and the township of Okhimath lies to the north of this tectonic plane.

Most areas affected presently by landslides are observed to show exposures of Central Crystallines.

Observations made around the affected villages

1. Giriyagaon (Pangran tok)

Giriyagaon is located on the left flank of southwesterly flowing Madhyamaheshwar river and can be approached by Okhimath - Mansuna motor road. After travelling for 07 km one however has to leave the vehicle and walk for 2 km from the road head in the upslope direction to reach the village.

The investigations were carried out in the area on 19th September, 2012 and traverses were taken around the site, nala bed, footpath section and upslope to examine the geological setup as also to investigate the causes of instability.

The area was observed to be located amid agricultural fields that are intervened by both rock outcrops and overburden. The rock exposures in area were observed to comprise of gneisses belonging to the Central Crystallines. General trend of the rocks was observed to be NW - SE with moderate dips towards 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 foliation planes were observed to dip towards NE at angles varying from 30º to 35º. Other two prominent structural weaknesses (joints) were observed to dip towards WSW at steep angles (75º / 245º) and towards NW at moderately steep angles (45º / 310º).

Reconnaissance geological - geotechnical assessment: Overburden thickness in the area including weathered rock zone was generally observed to be as much as 2.0 meters. The overburden material was observed to comprise of hill wash and debris consisting of grey to grayish brown, fine grained silty matrix with fragments of gneiss.

The slope failure was observed to have occurred on the northern slope of Pangran tok. The area was observed to be prone to instability due to foliation plane dips being parallel to the surface slope.

The width of the failure surface around the crown was observed to be about 12 meters while the height of the crown was about 8 meters from the houses destroyed by the mass movement. The inclination of failure slope was observed to be 35°.

The water laden down slope moving mass was observed to have overrun the houses and cultivated lands in the western side of Pangran tok (Figs. 24 and 25).

Fig. 24. View of the house ravazed by landslide.

Fig. 25. View of the agricultural land overrun by landslide debris.

Saturation by rainwater would have led to increased pore water pressure in the overburden mass on the hill slope and would have significantly reduced the shear resistance of the slope forming materials. This seems the most probable reason for triggering the destructive landslide.

Mitigation measures**:** Debris accumulated in the back slope of the houses needs to be cleared. After the debris has been removed concrete breast wall with adequate provision of weep holes or perforated pipes for draining out excess water is recommended. This has to be accompanied by provision for safe disposal of rain water through a

network of interconnected drains into the main stream. This would help in stabilizing this site.

2. Salami

Salami village is located on the left flank of southwesterly flowing Madhyamaheshwar river and can be approached by Okhimath - Mansuna link road. After travelling for 3 km one has however to trek for 1.5 km in the upslope direction to reach the village. The area was observed to be drained by three local streams.

The area was investigated on 19th September, 2012 and traverses were taken around the site, nala bed, road section and upslope to examine the geological setup of the area as also to investigate the causes of instability.

The area was observed to be located amid agricultural fields that were interrupted by both outcrops and overburden material. Rock exposures of Central Crystalline gneisses were observed along the road section and as also upslope of the village. The general trend of the rocks was observed to be NW-SE with moderate dips towards 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 the slopes. The foliations were observed to dip towards NE at angles varying from 28º to 33º. The other two weak planes (joints) were observed to dip towards W and NNE (60º / 270º and 75º / 010º).

Reconnaissance geological-geotechnical assessment: General overburden thickness including weathered rock zone in the area was observed to be up to 2.0 meters. The overburden material was observed to comprise of hill wash and debris consisting of grey to grayish brown, fine grained silty matrix with fragments of gneiss.

A number of agricultural fields around the village were observed to be damaged due to shallow water saturated debris flows (Figs. 26 and 27). Water is deduced to be the main driving force of these debris flows.

Fig. 26. Photograph showing slope failure and ensuing damage to a number of agricultureal fields around Salami village.

Fig. 27. View of the houses damaged by water saturated debris in Salami village.

The debris flows were observed to have overrun five residential houses of the village. Amongst these, one house was severely damaged while the others were partially damaged.

Mitigation measures: In this area there exist a number of severely damaged structures that are located on highly vulnerable area falling in close proximity of the course of seasonal drainage channel. These are therefore endangered by bank erosion during coming monsoons. These are required to be removed immediately.

Debris accumulated around the houses needs to be cleared. After this oblique concrete retaining structures of appropriate height would have to be constructed upslope of affected site. Particular caution is required to ensure that these structures are founded on compact rocks and compact soil materials. This would help in protecting the remaining houses.

New constructions and other anthropogenic interventions are required to be avoided in the proximity of seasonal streams.

It is required that anthropogenic intervention of all kinds be strictly regulated in the proximity of both seasonal and perennial streams. Appropriate legislative intervention in this regard is a must and this recommendation applies equally for all the areas under the present focus as also for rest of the state.

3. Chunni, Mangoli, Brahmankholi, Premnagar, Dangwari, Jua and Sansari villages

These villages are located on the Kund – Okhimath - Mansuna motor road and are all located in close proximity of each other. These villages are situated at distances varying between 0.5 to 2.5 km from the bus stand at Okhimath. All these villages are situated on the left flank of south flowing Mandakini river. A number of other local seasonal / perennial streams also drain the area.

The areas were investigated on 18th and 20th September, 2012 and traverses were taken around the site, nala bed, footpath section and upslope to examine the geological setup of the area together with the causes of slope instability.

The areas under present focus were observed to be located in close proximity of the motor road amid agricultural fields that are occupied by outcrops as well as overburden. The upslope area was observed to have very steep rock cut slope with N-S trending ridge.

Exposures of Central Crystalline gneisses were observed along the road section. The general trend of the rocks was observed to be NW-SE with gently to moderately steep dips towards NE. The rocks in the area were observed to be traversed by numerous joints that constitute major structural discontinuities affecting the strength of rock mass and stability of slopes. The foliation planes were observed to dip in northeasterly

direction at angles varying from 20º to 45º. The joint sets were observed to dip at steep angles towards W and S (70º / 270º and 75º / 180º).

Reconnaissance geological-geotechnical assessment: The landslide debris that descended down from the area upslope of the villages was observed to have overrun both agricultural fields and houses (Fig. 28). The thickness of the debris accumulated in the houses was observed to be 1.5 to 2.0 meters. This overburden material is observed to comprise of hill wash and debris consisting of gray to grayish brown, fine grained silty matrix with rare boulders and fragments of metabasics and gneisses.

Fig. 28. View of debris flows around Mangoli, Bamankholi, Premnagar and Dangwari villages.

The disposition of weak planes in the rocks in relation to the direction and amount of slope was observed to be unfavourable while the

crumbled nature of the rocks attributed to jointing and local folding was responsible for low rock mass strength.

The landslide that devastated this area was a huge mass of water saturated debris. While moving down along the steep slope from the uphill area it generated enough momentum to ravage everything that came in its way. High flash-flood discharge of the local streams contributed to the instability of the hill slopes of the area.

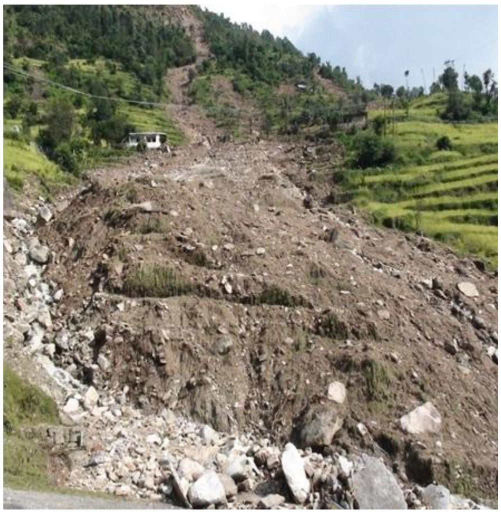

Fig. 29. Photograph dipicting debris flow in Jua Kimana village.

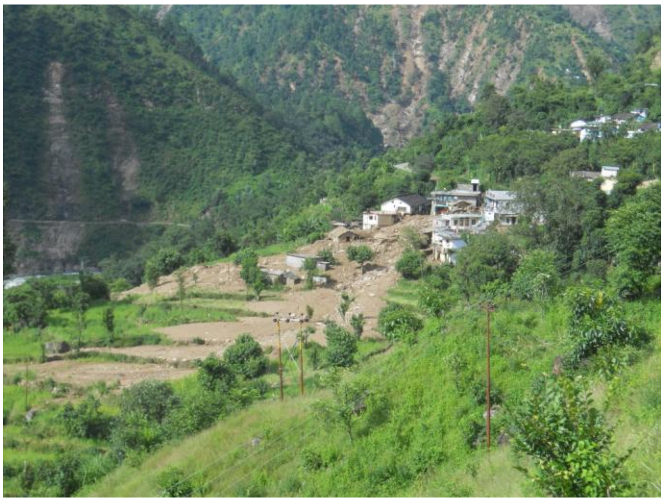

Fig. 30. Photograph showing debris flow around Chunni village.

Number of agricultural fields and houses were damaged due to shallow debris flows in the area (Fig. 29, 30 and 31). Rapidly running water and gravity driven movement induced by lubricating action of ground water were largely responsible for driving the debris down slope at fast pace.

A seasonal stream was observed to flows through Sansari village. The agricultural fields in the vicinity of this stream were observed to show signs of ground subsidence on its left flank. Ground fissures as wide as 1.5 m were also observed around this location (Fig. 32).

Fig. 31. Photograph showing devastation caused by debris flow around Mangoli.

Fig. 32. Photograph depicting subsidence in agricultural lands due to bank eroion by seasonal nala around Sansari.

Mitigation measures**:** Removal the transported material which is come from the upslope through local streams/gulley's into agricultural lands. After removing the materials local community will be further utilize the agricultural lands.

There should be thorough geotechnical assessment of affected sites of important exists houses whereas infrastructures in the verge of damage and/or partially damaged by destructive debris flows.

Eastern side as well as upslope of villages, all nalas need to be channelizing with cascade form downhill into the main stream. This will help to protect rest of exists houses from excessive rise of water level during the monsoon.

It is suggested that all exists houses near and on specific affected sites along newly developed nalas bed area be immediately removed.

Good lining/gradient/cleaning of road-side drains to prevent further water percolation/stagnation and erosion. These measures focus at preventing development of the harmful saturation, pore pressures and

erosion, and flooding in the weak slopes/zones due to heavy precipitation.

Presently the village Sansari area questioned site is highly susceptible to landslide so the local population is advised not to stay in this highly vulnerable site.

4. Kimana

Kimana vilalge is located above the Okhimath - Chaupta motor road at a distance of 1.0 km from the junction of Mansuna – Okhimath and Chaupta - Okimath motor roads. It is located on the right flank of southwest flowing Kakra Gad, a tributary of Mandakini river.

The affected area was investigated on 20th September, 2012 and traverses were taken around the site, footpath section and upslope to examine the geological setup.

Geology of the area: The village was observed to be located amid agricultural fields and occupied by outcrops as well as overburden material. Upslope side was observed to have very steep rock cut slope with N-S trending ridge. Exposures of Central Crystalline gneisses were observed on the upslope side of the village as also along the road section. The general trend of the rocks was observed to be NW - SE with moderate dips 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 slopes. The foliation plane was generally observed to be well developed and dips at angles varying between 30^o to 35^o towards northeast. The joint sets were observed to have steep dips towards SW and SSE respectively (65^o / 240^o and 70^o / 165^o).

Reconnaissance geological-geotechnical assessments: The overburden thickness including weathered rock in the area was observed to be up to 3.0 meters. The overburden material comprised of hill wash and debris consisting of grey to brown, fine grained silty matrix with fragments of gneisses.

The spatial disposition of joint sets was observed to result in the formation of wedges that facilitated detachment of the rock mass (Fig. 33). The same was observed to slide down and overrun the agricultural fields near the Panchayat Ghar (Fig. 34).

Fig. 33. Photograph depicting rocks detached due to wedging.

Fig. 34. View of rock fall zone near Panchyat Ghar in Kimana village.

Mitigation measures: Devastation caused by the down slope moving mass is a direct function of the rock mass and fragmentation of large detached blocks is sure to reduce the impact. It is therefore recommended that the large detached rock mass be broken into small pieces so that the area situated on the down slope direction is safe.

5. Pathali and Semla

These villages are located on the right flank of southwest flowing Kakra Gad, a tributary of Mandakini river and can be approached by Okhimath - Semla link motor road. Pathali and Semla are at a distance of 2.0 and 5.0 km respectively from Okimath.

These areas were investigated on dated 20th September, 2012 and traverses were taken around the site, road section and upslope to examine the geological setup.

Geology of the area: A rock cum debris slide reportedly occurred in Semla village on 15th September, 2012. This affected the agricultural fields located below the road. The agricultural fields were observed to be occupied by both outcrops and overburden material. In the upslope direction the area was observed to have very steep rock cut slope with E-W trending ridge. Exposures of Central Crystalline schists were observed along the road section. The rocks in the area were traversed by numerous joints. The foliation plane is generally observed to be well developed and observed to dip angles varying between 35º to 40º towards northeast. The joint sets were observed to have steep dips towards SW and SSE respectively (65º / 250º and 70º / 170º).

Reconnaissance geological-geotechnical assessment: The overburden thicknesses in the area around the villages was observed to be 2.0 m. This overburden material comprised of hill wash and debris that consisted of gray to grayish brown, fine grained silty matrix with rare boulders and fragments of schist.

Intense rain facilitated the slide by providing lubricating effect between the competent rocks that reduced the shear resistance of the slope forming materials together with the overburden material. This triggered

the destructive landslide that inflicted widespread damages in Semla village (Figs. 35 and 36).

Fig. 35. Photograph showing damaged agricultural fields and houses due to rock cum debris slide.

Fig. 36. View of the damaged house.

In the eastern side of the Pathli village number of agricultural fields were observed to be damaged due to shallow debris flows (Fig. 37). Rapidly running water and gravity movement induced by lubricating action of ground water are deduced to be the main driving force causing the debris flows.

Fig. 37. Photograph showing agricultural fields damaged by debris flow around Pathali village.

***Mitigation measures*:** The slope is required to be modified at different level in the area affected by debris slide at Semla village by benching and erection of appropriately designed buttress / retaining walls with suitable provision of weep hole.

Well anchored concrete wall has to be constructed at the toe of the landslide where maximum damage has been inflicted to the houses. It would help in protecting the rest of the houses in case of future instances of slope instability.

Burst wall with appropriate height is required to be constructed on the uphill side of Semla village around the road.

It is recommended that the debris and rock mass accumulated by the slide in the agricultural lands of Pathali village be cleared so as to enable masses to continue with routine agricultural chores.

6. Kirora Malla

A disastrous landslide occurred on 16th September, 2012 at Kirora Malla village in Jakoli tehsil that is located at a distance of 22 km from Augustmuni on Mayali link road (Fig. 38).

Fig. 38. Photograph showing devastation due to landslide in Kirora Malla.

The area was observed to be located just below the road amid agricultural land and occupied by outcrops as well as overburden. The overburden thickness including weathered rock mass around the village was observed to be 3.0 meters. This overburden material comprised of hill wash and debris consisting of gray to grayish brown, fine grained silty matrix with fragments of quartz schist phyllite.

Rock exposures of quartz schist and phyllites belonging to Lesser Himalaya were observed along the road section as also upslope of the village. 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 foliation planes were generally observed to be well developed and dipping at angles varying between 35º to 40º towards northeast. The joint sets were observed to have steep dips towards NNW and W respectively (80º / 350º and 55º / 270º).

Fig. 39. Photograph showing debris flow at kirora Malla.

Fig. 40. View of completely damaged house at Kirora Malla.

Reconnaissance geological-geotechnical assessments: A family of five persons was reportedly buried under the debris of the destructive landslides caused by excessive precipitation. Intense rainfall in the area resulted in high stream discharge and soil saturation with reduction of

the coefficient of internal friction of the slope forming materials. This induced massive mass movement that completely destroyed a house that came in its way (Fig. 39 and 40).

Another landslide was observed to be mass of water saturated debris that descended down the steep slope through the nala and ravaged a house that came in its way at Bengar tok (Figs. 41 and 42). Fortunately the flow of water was diverted upslope of the house towards western side and this limited the magnitude of damage.

Fig. 41. Photograph showing slight debris flow at backslope of the house.

Fig. 42. View of debris overrunning a toilet at Bengar tok.

Mitigation measures: In the Bengar *tok* the affected site falls in the course of perennial nala and therefore the population residing in the surrounding area needs to be shifted to alternate safe locations.

Discussion and future strategy

Though often dubbed as being a menace for the mountain areas landslide is a powerful landscape building process. It helps in soil development and often provides good aquifers. Large number of habitations in the hills are therefore located in close proximity of stabilised old landslides.

Our ancestors however very well understood the basic fact that howsoever stabilized the old slide material be it is likely to be reactivated by excessive precipitation and other factors like seismic shaking. They therefore choose not to settle over the stabilized slides. Review of the habitation pattern of the hills brings forth the fact that despite practicing agriculture over stabilised old landslides they deliberately settled down over stable rocks at locations that were in the middle and upper hill slopes. This clearly implied that they had to negotiate long distances daily for both mending fields and fetching water. They thus preferred safety over comfort and this is the simple underlying fact that saved them from the fury of both landslides and flash floods.

Our ancestors could also appreciate the interrelationship between landslides and saturation of soil and other slope forming materials. They therefore devised ways of disposing off excess precipitation in the main stream by a network of drains in the upper reaches of vulnerable slopes. Remnants of these can still be observed in Madhyamaheshwar valley. They at the same time kept the far flung fields outward sloping and unbunded.

Unplanned construction of roads on the vulnerable slopes in the recent times and unscientific disposal of the excavated debris have induced instability in the hill slopes and many areas in the proximity of the roads have became chronically prone to landslides. Detorioration of hill agriculture and concentration of economic opportunities and other facilities in close proximity of the roads encouraged people to settle down by the road side.

Increased inflow of tourist and pilgrim traffic in the area only encouraged this trend.

With the passage of time traditional practices of landslide management were forgotten and more and more people started to settle in areas vulnerable to landslides. This reflects increasing trend of giving priority to comfort over safety in all the spheres of life. This resulted in enhanced landslide risk in the hills.

It needs to be understood very well that landslide is a natural process in the hills and it is not possible to rule out their occurrence. Their impact can however be reduced to a great extent by proper planning and timely implementation of appropriate mitigation schemes.

It is suggested that the following measures be discussed, debated and acted upon, with amendments where required, for making the hills safer from the threat of landslides:

Revival of traditional practices of landslide management: Traditional landslide management practices of the region are required to be studied and documented in detail. These can be suitably amalgamated with the modern technical inputs and put to practice in landslide prone areas.

Ban on the use of explosives: Use of explosives in the fragile Himalayan terrain for infrastructure developmental works introduces instability in the rocks and therefore use of explosives should necessarily be banned.

Limiting construction of roads in the hills: Construction of roads is often highlighted as one of the prime reasons for landslides to occur. Construction of roads is therefore required to be checked and limited. Alternative connectivity options, such as rope-ways would be better suited for the hills.

Discontinuing target driven schemes: Target driven schemes for connecting all the habitations with particular characteristics by road are required to be given a second thought in the hills. These roads, as

constructed under PMGSY, have in no way added to the prosperity of the region but have certainly disturbed its ecological balance. It is required to be clearly understood that attempts to connect every village, tok and house in the mountainous areas are not going to be beneficial in the long run.

Geological studies: It is highly required that detailed geological investigations be carried out before finalizing the alignment of the roads in the hills. This would help in judiciously avoiding the stretches that are likely to become landslide prone.

Debris disposal policy: Unplanned and unscientific disposal of the excavated material along the hill slopes often initiates landslides besides causing loss of forest resources, agricultural land and water sources. A clear cut policy for the disposal of excavated material is immediately required for the hills. The cost of planned disposal of the excavated material would then have to be made part of the routine budget of the developmental initiative. It might sound like additional financial burden but for larger good of the society provision for this would have to be made.

Hazard zonation: At present there exists to mechanism of checking developmental initiatives on the pretext that the area is prone to certain hazard. So long as there is no dispute with regard to the title of the land one is free to use it in the manner he deems appropriate. Areas that have become chronically prone to mass movement and other hazards are therefore required to be identified and officially notified and all anthropogenic interventions in these areas have to be banned by law. This provision would automatically ban habitation in the close proximity of seasonal streams and rivers. In case people are already residing in such areas provision has to be made for their timely relocation. This provision in the long run would encourage people to settle down at safer places due to enhanced awareness

in this regard and differential land pricing and insurance premium depending on its hazard proneness.

Landslide treatment: Landslides have to be scientifically treated in their initial stages. This would ensure that the problem does not become chronic.

Landslide prediction: With establishment of rainfall thresholds for mass movement on different lithologies and slopes it is possible to develop a predictive model for landslides. For this close network of automatic rain gauges would have be established in the region and data would have to be collected on various rock parameters and slope characteristics. To begin with this exercise can be initiated in some of the vulnerable areas and the same can be gradually extended to other areas.

Though put forth plain and simple it all is not going to be easy. Strong lobbying would be required for legislative action and bringing forth policy changes, formation of rules and regulations. Firm executive action in accordance with letter and spirit of the legislative decisions would then be required to ensure compliance of the same.