Investigations in the Asi Ganga valley on the aftermath of flash flood / landslide incidences in August, 2012

A report

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

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Foreword

Abnormally high precipitation in the catchment of Asi Ganga, that has its confluence with Bhagirathi at Gangori, on 3rd and 4th August, 2012 induced flash floods that devastated the downstream areas up to Uttarkashi. Motor bridge at Gagori over Asi Ganga on Rishikesh - Gangotri National Highway was washed off in the incidence together with road stretches and bridges on various link roads. Entire area of Bhatwari tehsil ahead of Gangori was thus physically cut off from the outside world and tourists and pilgrims in large numbers were stranded at different places.

This report is the outcome of the field investigations carried out in the area with particular focus on Asi Ganga valley of Bhatwari tehsil of Uttarkashi district. The field investigations were undertaken between 31st August and 7th September, 2012 by the team of Disaster Mitigation and Management Centre (DMMC) consisting of Dr. Piyoosh Rautela, Shri Sushil Khanduri and Shri Ashish Rawat in compliance of the request to this regard from the office of the District Magistrate, Uttarkashi forwarded to DMMC through letter No. 9700/13-24(2012-13) dated 27th August, 2012. The site inspection and other investigations were carried out in the presence of the concerned Patwari, Gram Pradhan and local people.

Shri Devendra Patwal, Disaster Management Officer, Uttarkashi and Shri Mukesh Mishra, SAR Trainer, DMMC together with various officials of Uttarkashi district administration facilitated infrastructural support during the field work. GIS analysis and study of the satellite imageries was done at GIS Laboratory of DMMC by Ms Suman Ghildiyal, Ms Chanderkala and Shri Ashish Rawat. All are thanked for their contribution and assistance.

8th October, 2012
Dehradun

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The incidence

During the course of the fieldwork in the area devastated by flash floods and landslides geological observations were taken all along the Asi Ganga valley with specific focus on Gangori - Dodi Tal section that falls in Survey of India toposheet numbers 53 J/5, 53 J/6 and 53 J/9.

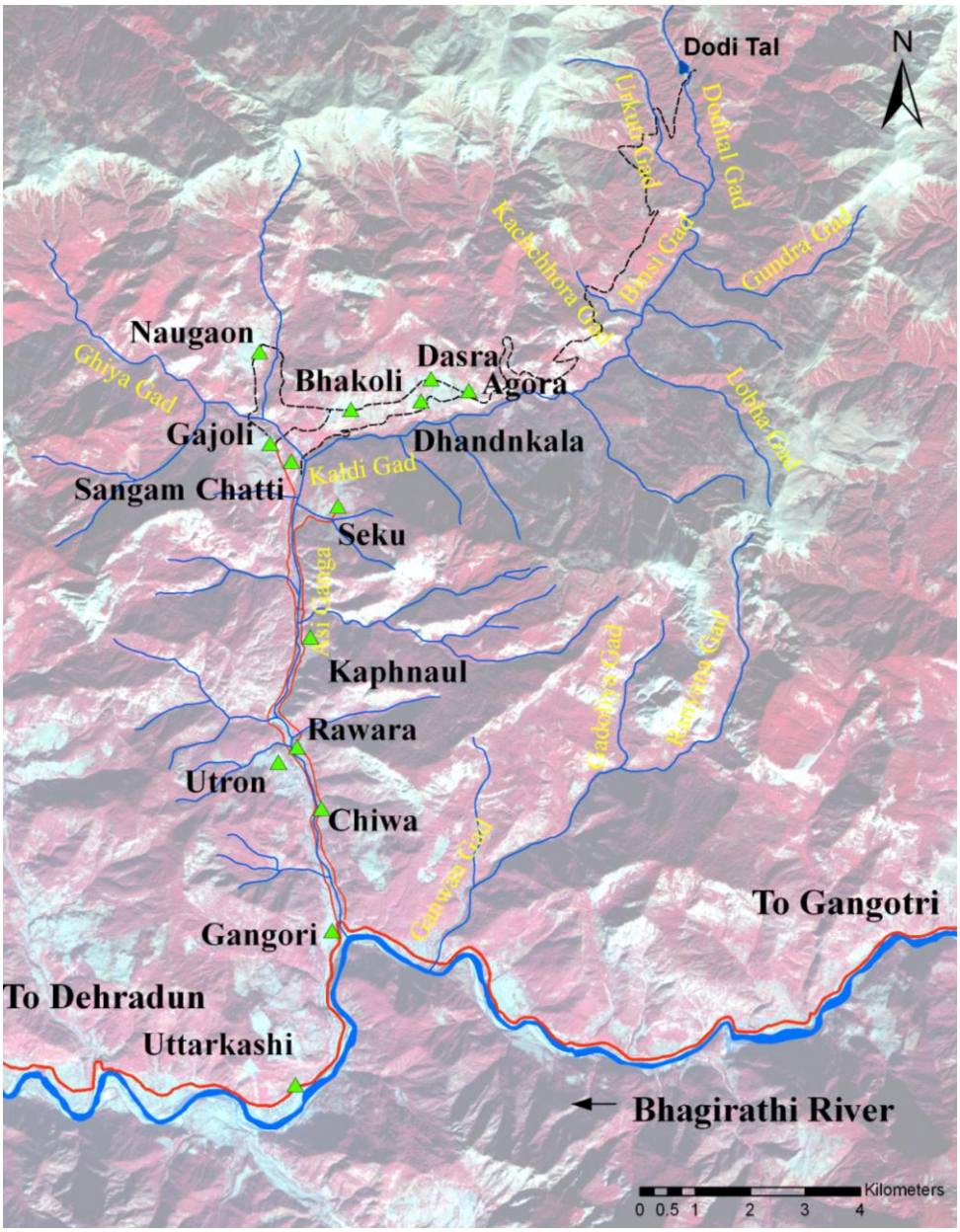

Fig. 1. Location map of the area around Uttarkashi – Gangori – Dodi Tal.

Uttarkashi town is located in the hilly terrain of Lesser Himalaya and enjoys good road connectivity and can be approached from Dehradun by Mussoorie – Suakholi – Chinyalisaur – Uttarkashi and Rishikesh - Chamba – Dharasu – Uttarkashi motor roads. In the Asi Ganga valley most motor roads were disrupted by landslides and flash floods and the area was largely approached on foot (Fig. 1).

In the year 2012 the monsoon was relatively weak and both during June and July the rains were deficient throughout the state. It seemed as if the Rabi crops were to face drought conditions heavy and concentrated rainfall was witnessed in the month of August.

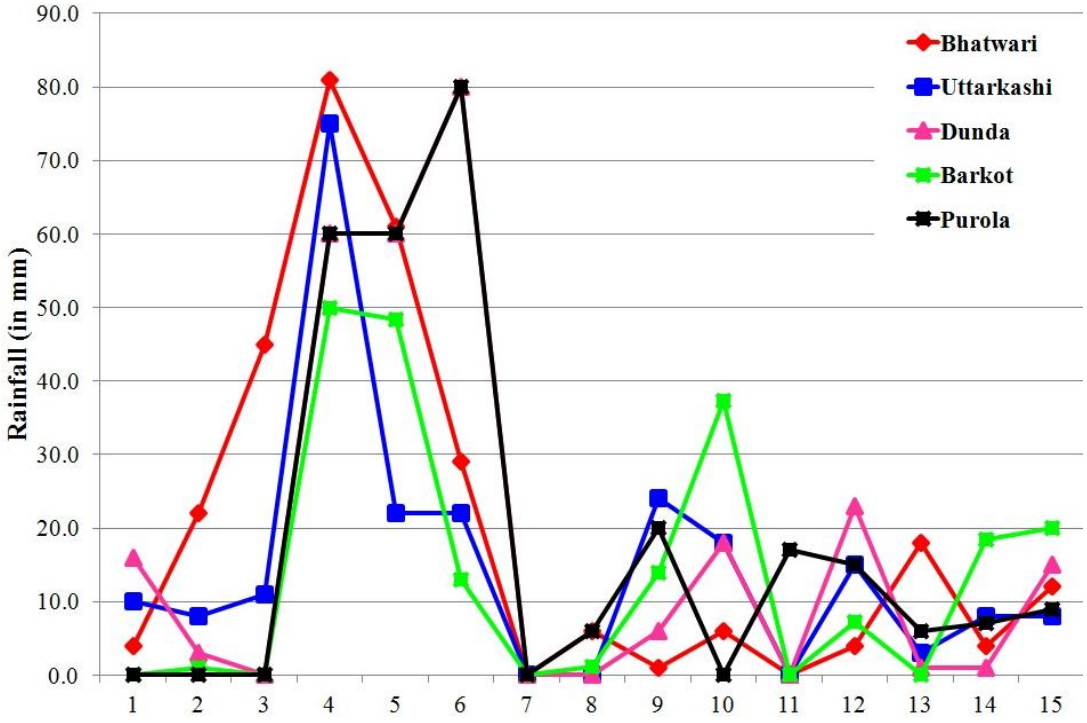

Fig. 2. Daily rainfall received in Uttarkashi district in the month of August, 2012.

Particularly high rainfall was received in the first week of August, especially in Uttarkashi district between 4th and 6th August, 2012 (Fig. 2). Localised heavy rains in the early hours of 4th August, 2012 in the catchment of the tributaries of

Bhagirathi river, particularly Asi Ganga and Swari Gad, caused the waters of Bhagirathi to rise as much as 04 meters above the danger level at Uttarkashi. Water level thus rose to 1127 meters above msl as against danger level of 1123 meters. This caused widespread devastation in the district and even the district headquarter was not spared by the fury of nature.

Heavy precipitation and ensuing flash flood resulted in washing off of a number of vehicular and pedestrian bridges including motor bridge at Gangori on the Rishikesh – Gangotri National Highway. The entire area ahead of Gangori was thus physically cut off from the outside world. In the Asi Ganga valley many stretches of Gangori – Sangam Chatti motor road were washed off together with the motor bridge over Asi Ganga near Kaphnaul.

A number of stretches of the Rishikesh – Gangotri National Highway and other connecting roads were also washed off in the event. Connectivity to as many as 85 villages was disrupted by this event and more that 500 persons were stranded at various stretches of the Rishikesh – Gangotri National Highway beyond Uttarkashi.

The event at the same time caused widespread devastation in the area. As many as 29 persons, including 03 Fire and Emergency Service personnel, were washed off in the event and 06 are still missing. Besides this heavy losses were incurred by public infrastructure and other properties.

Administrative response

High alert was sounded on the aftermath of the flash flood event and the ensuing devastation in the area around Uttarkashi (Figs. 3 – 6). The State Government deployed all its resources and all possible measures were taken to manage the situation. All educational institutions of the district were closed down and leave of all the government officials was immediately cancelled. Additional Revenue officials (04 SDMs and 05 Tehsildars) were sent to the district to assist the local administration. Support was sought from Army, ITBP and NDRF and IAF was called in for rescue, evacuation and distribution of relief.

Figs. 3 and 4. Photographs depicting devastation by flash flood in Uttarkashi.

The losses in the event were aggravated due to the topographic affects and inherently fragile nature of the terrain. High relief of the area promoted fast and high surface runoff and enhanced pore water pressure together with reduced frictional forces promoted mass wastage in the area. Heavy and concentrated rainfall in the upper reaches of the catchment of Asi Ganga resulted in flash flood like situations in the downstream areas. Evidences of blockade of the course of Asi Ganga at many places and their subsequent breach added to the

fury of flash floods. Sudden and unexpected rise in the water levels thus overwhelmed masses and administration.

Figs. 5 and 6. View of the bridges damaged by the flash flood in Uttarkashi.

Transport sector was hit particularly hard by landslide and flash flood events (Fig. 7 and 8). Rishikesh - Gangotri National Highway, along with link roads were disrupted and the State Government had to strive hard to maintain normal supply of essential commodities in the remote areas. The summary of traffic disruption along the Char Dham Yatra route is enough to highlight the situation (Table 1). It is worth noting that both the National Highways of Uttarkashi; Gangotri and Yamonotri, remained closed all through in the month of August.

Table 1. Details of traffic disruption along Rishikesh - Gangotri as also other National Highways in the state between June and August (till 18th).

Sl. No.	Highway	Number of days when traffic was disrupted on the Highway			
		June (30 days)	July (31 days)	August (18 days)	Total (79 days)
1.	Rishikesh – Gangotri	05	09	15	29
2.	Yamunotri	03	09	16	28
3.	Rishikesh – Badrinath	00	08	10	18
4.	Kedarnath	02	07	05	14

The monsoon season coincides with the peak pilgrim season of the State and people in large numbers from across the nation visit Badrinath, Kedarnath, Yamunotri, Gangotri and Hemkunt Sahib Shrines situated in the Higher Himalayas. Pilgrims and tourists in large numbers were thus stranded at various places during the current monsoon season.

The situation however became serious on Rishikesh - Gangotri National Highway that was blocked continuously for a long period due to the washing off of the vehicular bridge at Gangori. Resuming the vehicular traffic to Gangotri was thus taken up on high priority and material for construction of a Bailley bridge was mobilized and the same was put in place on 26th August and traffic was resumed up to Gangotri on 3rd Sepetember, 2012.

Figs. 7 and 8. View of the roads damaged by the flash flood in Uttarkashi.

In the mean time the State Government ensured that the pilgrims and tourists are evacuated at the earliest. IAF helicopters were thus pressed into action to evacuate the stranded pilgrims as also those requiring medical aid (Fig. 9 and 10). Every effort was made to ensure the supply of essential commodities and medicines and medical teams were air dropped at remote locations.

The blockade of traffic along the link roads, however, hampered supply of essential commodities to the far flung remote areas and extra effort had to be put in for ensuring that the masses do not face scarcity of the essential supplies. On many occasions the State Government resorted to manual or animal transportation of essential supplies to ensure that there is no scarcity in remote areas.

Figs. 9 and 10. View of the evacuation of stranded pilgrims and medical relief post at Matli, Uttarkashi.

Geomorphology and physiography

The Asi Gnaga valley exhibits characteristically distinct rugged mountainous topography of the both Lesser and Higher Himalayan terrains. The imprints of geological structures and lithology are observed in the area in the form of strike ridges and deeply incised valleys. The area is observed to be dissected by several ridges and the ground elevations vary from about 1150 to 3045 meters above mean sea level.

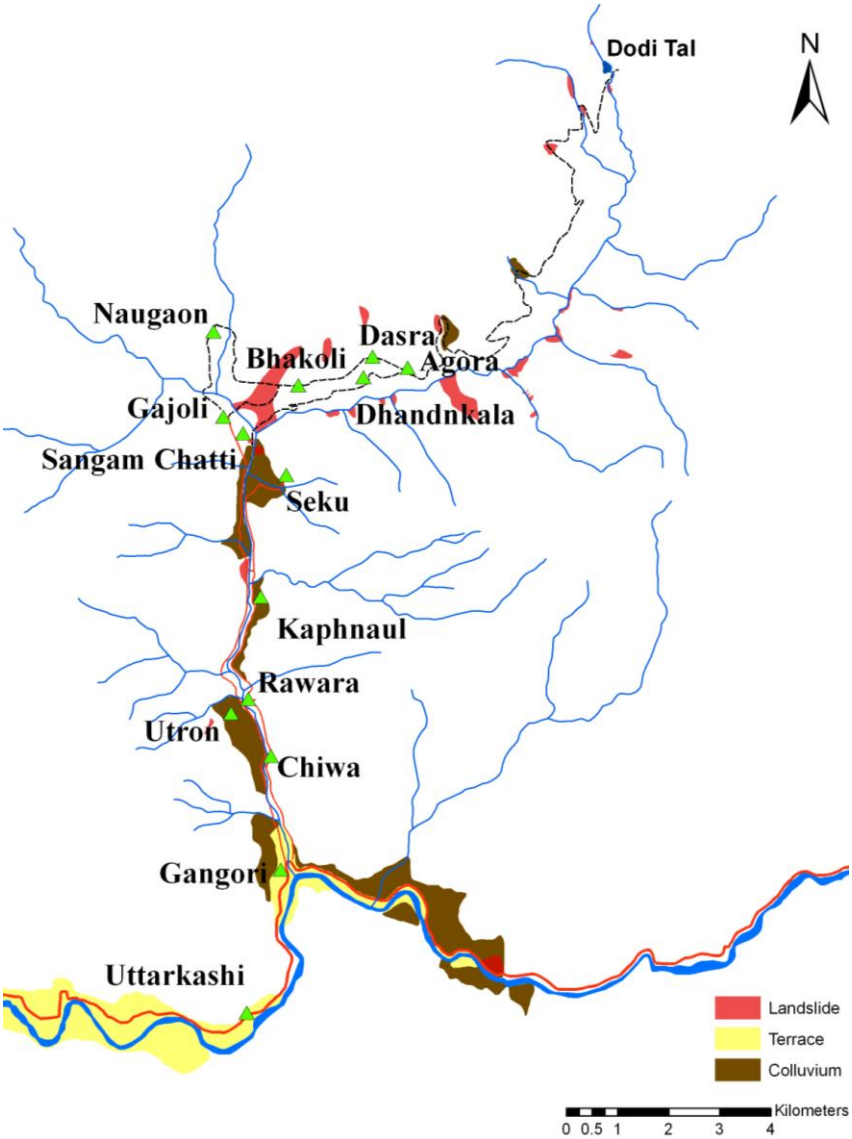

Fig. 11. Map showing distribution of Quaternary deposits in the area.

Appreciable exposures of Quaternary deposits are encountered at several places in the area together with active slides (Fig. 11). Landslides often initiate in these deposits due to toe erosion and heavy precipitation.

The geo-hydrological condition of the hill slopes is an important parameter influencing the stability of the slopes as water reduces the shearing strength of the slope forming materials causing instability. Several streams are observed to be present in the study area. Ghiya Gad and Kaldi Gad meet at Sangam Chatti to form Asi Ganga that has confluence with Bhagirathi at Gangori. Other important tributaries of Asi Ganga include Dodi Tal Gad, Dirga Gad, Urkuti Gad, Gundra Gad, Kachchhora Gad, Indri Gad, Lobha Gad and Kaldiyani Gad.

Asi Ganga is generally observed to flow in N-S direction. The hills on either side of the stream are observed to form high rocky surfaces that clearly reflect the action of snow and these rocky surfaces are observed to rise up to 3000 meter elevation. The local streams of the area are generally observed to flow with great force through steep and narrow channels. This is largely responsible for excessive erosion and collapse of the banks. This area is thus observed to be prone to landslides due to high relief, presence of overburden and high precipitation.

The area has sub - 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.

Landuse / land cover

Subtropical and temperate montane vegetation are observed in the area that has appreciably dense forest cover. Based upon the ground truthing during the field work landuse / land cover characterization of the satellite imagery of the area around Uttarkashi – Gangori – Dodi Tal has been carried out. Eight broad landuse / land cover classes have thus been identified (Fig. 12).

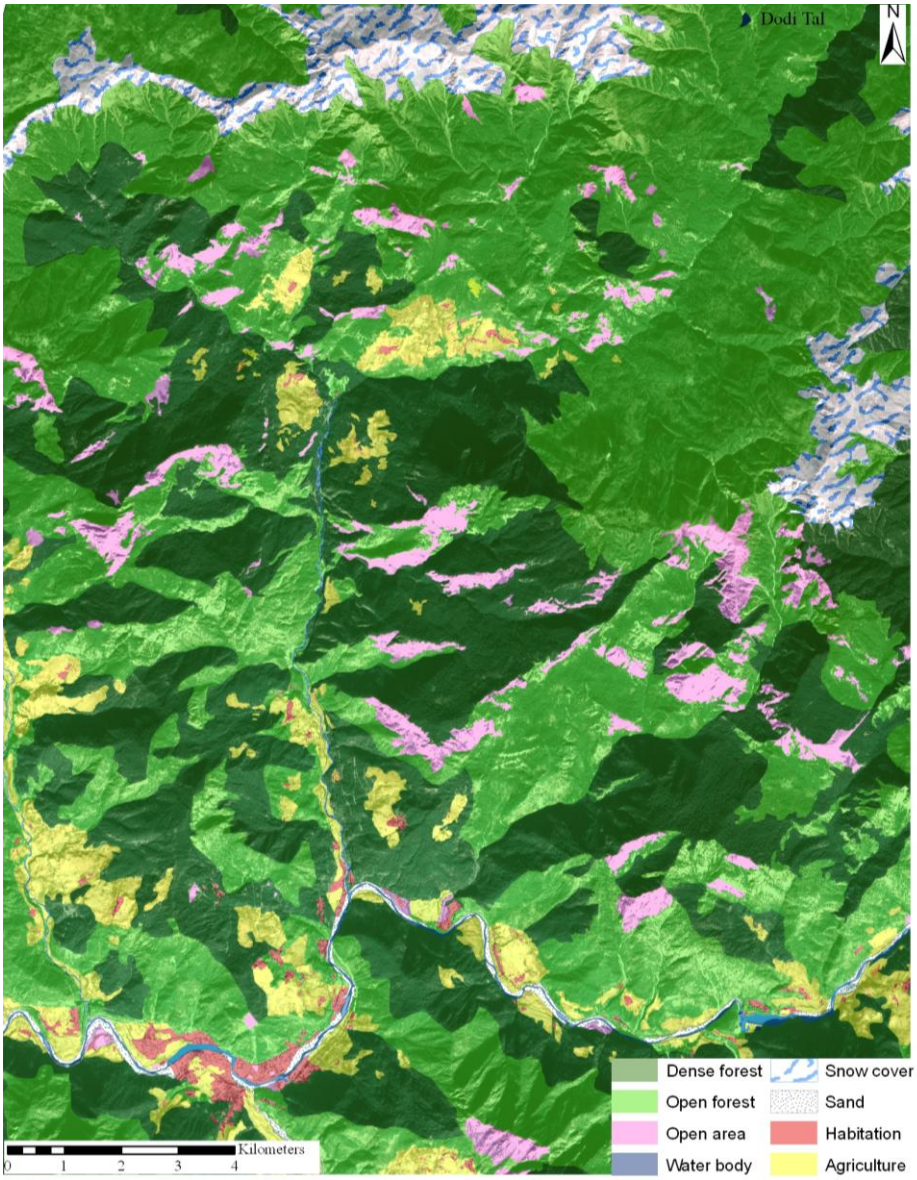

Fig. 12. Landuse map of the area around Uttarkashi – Gangori – Dodi Tal.

The satellite imagery shows that the area has appreciable forest cover and agriculture is restricted to just 6.5 percent of the total area (Table 2) that is confined in the vicinity of the habitations. This is attributed to the fact that the area is sparsely populated and the density of population is low.

Table 2. Land use / land cover details of the area around Uttarkashi – Gangori – Dodi Tal.

Land use / land cover class	Area under the Land use / land cover class (in sq km)	Percent of the area under Land use / land cover class
Dense Forest	102.1	31.7
Open forest	164.1	50.9
water body	1.5	0.5
sand	1.6	0.5
Agriculture	20.9	6.5
Habitation	3.4	1.1
Snow covered area	14.6	4.5
Open area	14.1	4.4
Total	322.4	100

Geology and tectonics

The Uttarkashi region is observed to consist of two main tectonic units namely Lesser Himalaya and Central Crystalline. The Lesser Himalaya rocks are observed to be thrusted over by Central Crystalline rocks along the Main Central Thrust (MCT).

The Lesser Himalayan rocks of the Garhwal group are observed to be exposed in the Asi Ganga section along the foot track to Dodi Tal. These rocks are observed up to Kachchhora Gad beyond Gajoli and Naugaon villages. These are observed to comprise of quartzite, limestone, metavolcanics, chlorite schist and metabasics with quartzite being the prominent lithology. These rock types are observed to form prominent high rising hill ranges on either side of Asi Ganga and are exposed in the road and foot path sections as also along the tributaries.

Table 3. General litho-tectonic succession of rocks exposed in the Asi Ganga valley.

Tectonic zone	Formation	Lithology
NORTH		
Central Crystalline	Martoli Fm.	Banded augen gneiss, kyanite gneiss, mica schist and interbedded augen and porphyritic gneiss. Banded augen gneiss and garnet - mica schist containing tourmaline. Migmatite zone of mica schist, gneiss, granite, marble / calc-silicate with amphibolites.
---------- Main Central Thrust ----------		
Lesser Himalaya	Nagni Thank Fm.	Gamri Quartzites that are white to purple in colour and are medium to coarse-grained and show massive current and graded bedding and occasionally has lentiform conglomerates in basal part. Kot Metavolcanices that consist of green, amygdaloidal schist with thin bands of quartzite and slate.

	Uttarkashi Fm.	Netala Quartzite that consist of white to buff coloured, fine grained, current bedded quartzites and interbedded slate with lentiform limestone.
SOUTH		

The rocks are generally observed to dip towards northwest to northeast at angles varying between 20° to 65° but some of the places southwesterly dips are observed due to local folding. The rocks are intruded by quartz veins of varying dimension. The metavolcanic rocks between Simori and Utron are observed to form a local antiform.

In Kachchhora Gad to Dodi Tal section in the northeastern part of Sangam Chatti Centre Crystalline gneisses are observed to be exposed. These are thrusted over the Lesser Himalayan metasedimentaries.

Major portion of the area is thus observed to fall under the Lesser Himalayas that include meta-sedimentary and plutonic igneous rocks. The litho-tectonic succession of the area is given in Table 3.

Seismicity

Uttarkashi district has a long and devastating history of disasters, particularly earthquakes. The district falls in Zone IV and V of the Seismic Zoning Map of India and the area under investigations lies in Zone IV (Fig. 13).

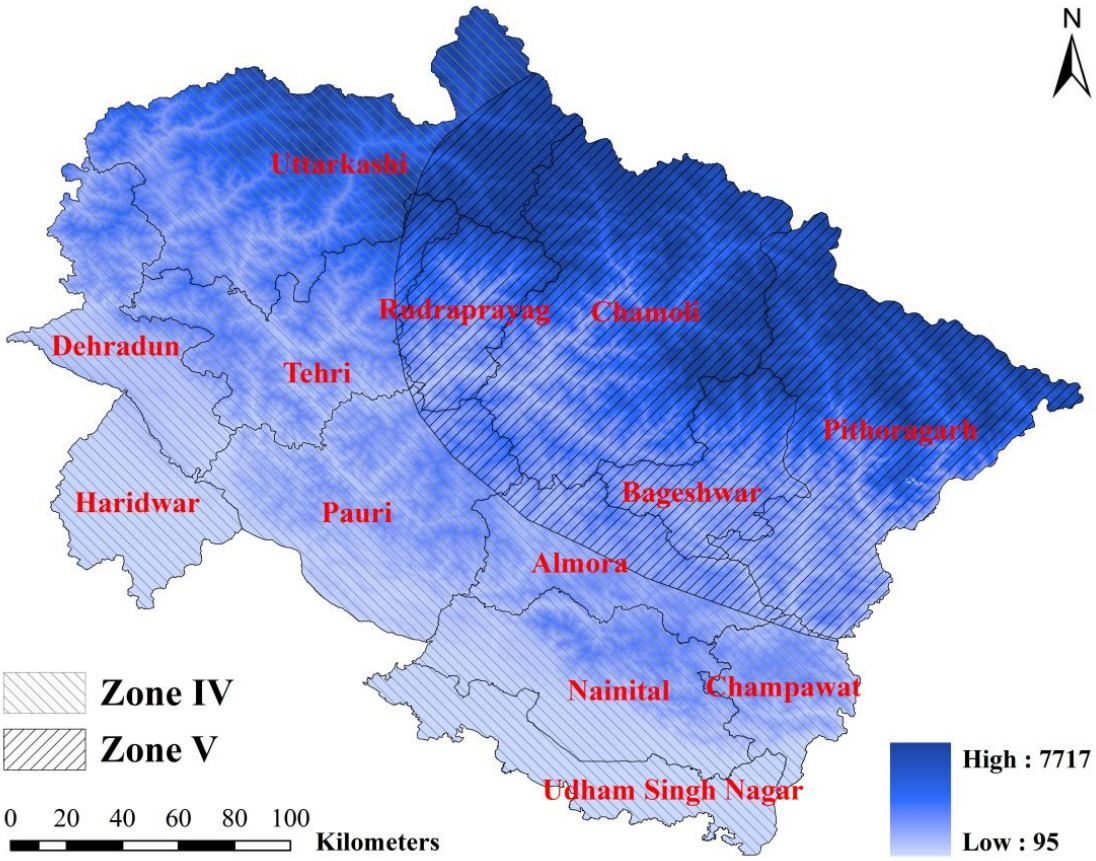

Fig. 13. Earthquake zoning map of Uttarakhand.

20th October 1991 Uttarkashi Earthquake that has its epicenter at Agora that falls in the area under present focus took a toll of 768 human lives while 5,066 were injured in the event. The summary of the losses incurred by this earthquake is given in Table 4.

Table 4. Details of the losses incurred by 1991 Uttarkashi Earthquake.

Head	Numbers
Human lives lost	768
Injured humans	5,066
Cattle lost	3,096
Houses damaged (full)	20,242
Houses damaged (partial)	74,714

Besides causing massive loss of infrastructure and property this earthquake triggered a number of rock slides. Large number of ground fissures were reported in the area. The earthquake also brought forth changes in spring discharge besides the chemistry of the hot springs in the region (GSI, 1992). This 6.6 magnitude earthquake had its epicenter at Agora, to the north of Uttarkashi town. The epicentral region thus falls under the area under present focus. The epicentral tract of 1991 earthquake occupying an area of 20 sq km around Maneri in Bhagirathi valley recorded an intensity of IX on MSK- 64 Scale. The main shock was followed by a series of over 2000 aftershocks in a period of two months.

Details of the investigations around the identified habitations

1. Gangori

Gangori is located on Rishikesh – Gangotri National Highway at a distance of 04 km from Uttarkashi town towards Gangotri. South flowing Asi Ganga meets Bhagirathi at this place on its right bank.

This area was investigated on 30st September, 2012 and traverses were taken around the site, nala bed and road section to examine the geological setup.

Gangori is observed to be located on the terrace of Asi Ganga. On the left bank of Asi Ganga quartzites are observed to be exposed. These are medium grained, white to gray, moderately weathered, moderately jointed and thinly to medium bedded. These dip towards northwest at angles varying from 37º to 40º towards NW. The rocks in the area are traversed by numerous joints which are the important structural discontinuities affecting the strength of rock mass and stability of slopes. The joint sets are observed to dip towards NNE and SSE (73º / 020º and 50° / 170°).

***Reconnaissance geological - geotechnical assessment*:** The overburden thickness including weathered rock in the area around the village is generally observed to be 3.0 to 5.0 meters. This overburden material is observed to comprise of river borne material that consists of grey to brown, fine grained sandy - silty matrix with fragments of quartzite.

High discharge in Asi Ganga during heavy rainfall incidences in the region is responsible for bank erosion in the area that has introduced instability in the slopes around Gangori as also in the terraces (Figs. 14 and 15).

Abnormally high sediment laden discharge of Asi Ganga has eroded the terrace on its right bank and has also completely damaged the approach road to power house. Terraces are observed to have been cut vertically by Asi Ganga. An eroded terrace with around 3.0 m vertical cut is observed on the right bank of Asi Ganga. Some houses on this destabilized terrace have not been destroyed but the possibility of these being affected by continuing erosion of the terrace cannot be ruled out. These are therefore required to be relocated.

Fig. 14. Photograph depicting the state of houses on the eroded terrace together with the damaged approach road to the power house on the right bank of Asi Ganga at Gangori.

Fig. 15. Photograph depicting the state of houses located on the eroded terrace of Asi Ganga on its right bank. Even though spared by the present tragedy these houses pose a major risk due to the instability of their foundations.

Mitigation measures: In this area there exist several severely damaged structures located on extremely critical slopes that are continuously threatened by bank erosion by Asi Ganga. These are required to be removed immediately.

Construction of concrete slabs / retaining structures of appropriate height is recommended so as to prevent the toe cutting / bank erosion by Asi Ganga. It would help in protecting the bank of Asi Ganga as also rest of the village.

It is recommended that construction / anthropogenic intervention in the area in close proximity of the river channel be strictly banned. This applies equally for all other areas including Uttarkashi town. For this detailed survey of the area and identification of high risk prone zones is recommended.

2. Utron village

Utron village is located at a distance of 06 km from Gangori on the right bank of south flowing Asi Ganga and can be approached by Gangori - Utron link road. The main village is located about 0.5 km upslope of the road head. The area is drained by two local streams.

The area was investigated on dated 31th August, 2012 and traverses were taken in the vicinity of the village to examine the geological setup. At the time of the visit to the village the motor road was disrupted due to flash floods and the area ahead of Gangori was approached on foot.

The area is observed to be located over thick cover of overburden material. The failure slope is observed to be located fairly far from the last *tok* of the village towards the hill side. In between the failure slope and the last *tok* fairly flat agricultural fields are observed in two stretches. The exposures of metavolcanics belonging to the Lesser Himalayan Nagni Thank Formation are observed along the road section and upslope of the village. General trend of the rocks is observed to be NW - SE with gentle dips towards SW. The rocks in the area are observed to be highly jointed and these constitute important structural discontinuities affecting both rock mass strength and stability of the slopes. The foliation plane is generally observed to be well developed and dips angle 20º towards northeast. The joint sets are observed to have steep dips towards NE and Se respectively (70º / 120º and 57º / 30º).

Reconnaissance geological - geotechnical assessment: Around the village thickness of the overburden is observed to vary between 1.0 – 2.0 meters but at places its thickness including weathered rock zone is observed to be 4.0 meters. This overburden material comprises of hill wash and debris that

is grey to brown in colour and has fine grained silty matrix with rare boulders and angular fragments of metavolcanics.

The rock slide is observed to have occurred on the northeastern slope of E-W trending ridge. The inclination of failure slope is observed to be 35°. Around the crown of the failure the inclination is around 45°. The width of the failure slope is about 35 m along the cultivated fields and height of the crown from cultivated fields is about 85 meters (Fig. 16).

No indications of major slope instability towards the village as also towards the valley side were observed during the field investigations. There are two large benches of cultivated fields that would prevent the dislodged mass from causing any major damage. There is no threat to the village from the slide.

Fig. 16. Photograph depicting rock slide zone uphill of agricultural lands in Utron.

3. Kaphnaul village

Kaphnaul village is located on the left bank of south flowing Asi Ganga river and can be approached by Gangori – Sangam Chatti link road. It is at a distance of 06 km from Gangori and little upslope of the road head.

The area is observed to be drained by four seasonal streams. The investigations around the village were carried out on 31st August, 2012 and traverses were taken around the site, road section and upslope to examine the geological setup.

The area is observed to be located in between agricultural fields and occupied by outcrops as well as overburden. The rock exposures of quartzite belonging to Nagni Thank Formation of the Lesser Himalaya are observed along the road section as also upslope of the area. The general trend of the rocks is observed to be NW - SE with moderate dips towards NE. The rocks in the area are observed to be traversed by numerous joints that comprise important structural discontinuities affecting the strength of rock mass and stability of the slopes. Foliation plane is generally observed to be well developed and dips at angle varying from 35º to 37º towards northeast. The second joint sets are observed to dip towards SW and NNW (45º / 240º and 80º / 350º).

***Reconnaissance geological - geotechnical assessment*:** Around the village the general thickness of the overburden is observed to vary between 2.0 and 3.0 meters but at places its thickness including weathered rock zone is observed to be up to 5.0 meters. The overburden material comprises of hill wash and debris and consists of grey to brown, fine grained silty matrix with rare boulders and fragments of quartzites.

Back slope of the area around the village is observed to be a vertical rocky scarp. Four seasonal streams are observed to descend from that very steep rock cut slope and these contribute to the instability of the area (Fig. 17).

Mitigation measures: The streams towards the eastern as also upslope side of the village are required to be diverted along a gully into the main stream with suitable gradient towards southeast. This would help in protecting the village from excessive rise in pore water pressure during the monsoons.

Fig. 17. Photograph showing the vertical rocky cut slope above the village along which the seasonal streams come down.

4. Rawara village

Rawara village is located on the left bank of south flowing Asi Ganga river and can be approached by Gangori – Sangam Chatti motor road. The village is at a distance of 04 km from Gangori and extends on both upslope and down slope side of the road. The investigations at this site were carried out on 31st August, 2012 and traverses were taken around the site, along the road section and upslope to examine the geological setup.

The village is observed to be located amid agricultural fields and largely occupied by overburden material. No outcrop is observed in the vicinity of the village. In the road section exposures of Lesser Himalaya quartzites are however observed. The general trend of the rocks is observed to be NW-SE with moderately steep to steep dips towards NE.

The rocks in the area are observed to be traversed by numerous joints that constitute important structural discontinuities affecting rock mass strength and instability of the slopes. Foliation plane is generally observed to be well developed and dips angle varying from 38º to 50º towards northeast. The joint sets are observed to dip at steep angles towards SW and SE (70º / 220º and 80º / 140º).

***Reconnaissance geological - geotechnical assessment*:** In the area around the village overburden thickness including weathered rock zone is observed to be as much as 4.0 meters. The overburden material is observed to comprise of top soil, hill wash and debris and consists of grey to brown, fine grained silty matrix with rare boulders and fragments of quartzite.

The slope failure is observed to have occurred on the southwestern slope of Rawara village. The width of the failure slope is about 8.0 m along the road and height of the crown from the road is about 18.0 meters. The inclination

of failure slope is observed to be 35° and the debris is observed to have partially damaged a house (Fig. 18).

On the left bank of Asi Ganga a structure is observed to be completely destroyed due to flash floods (Fig. 19).

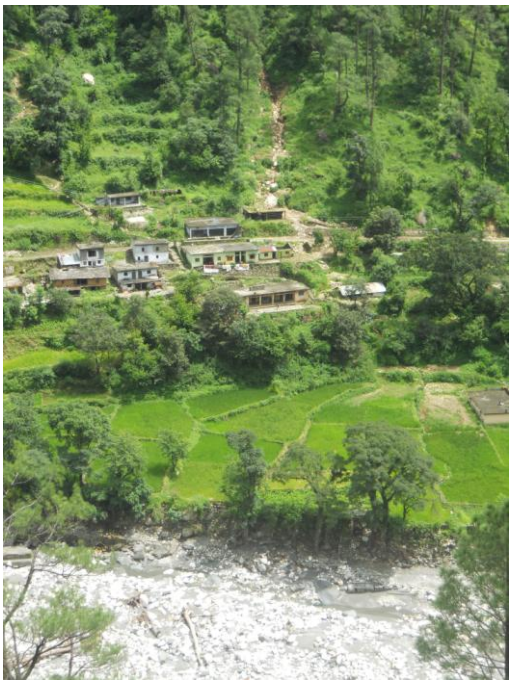

Fig. 18. Photograph depicting the debris slide upslope of the road with partially damaged structure.

Fig. 19. Photograph depicting completely destroyed structure on the left bank of Asi Ganga.

***Mitigation measures*:** Adequately designed stepladder buttress structures are required to be erected to prevent the slope failure. This would protect the area.

Damaged structures are required to be removed from the left bank of Asi Ganga and construction of structures in close vicinity of the river should be banned.

5. Chiwa village

Chiwa village is located on the left bank of south flowing Asi Ganga and can be approached by Gangori – Sangam Chatti link road. It is at a distance of 03 km from Gangori and extends upslope of the road head. The area was investigated on dated 31st August, 2012 and traverses were taken around the site, along the road section and upslope to examine the geological setup.

The area is located amid agricultural fields and largely occupied by overburden material. No outcrop is observed in the vicinity of the village. The exposures along the road section as also on the Asi Ganga river bed are however observed to be that of Lesser Himalayan quartzites. The general trend of the rocks is observed to be NW-SE with moderate to moderately steep dips towards NE.

The rocks in the area are observed to be traversed by numerous joints that constitute important structural discontinuities affecting rock mass strength and stability of the slopes. Foliation plane is generally observed to be well developed and dips at angles varying from 35º to 45º towards northeast. The joint sets are observed to dip at steep angles towards SW and SE (65º / 240º and 75º / 150º).

***Reconnaissance geological - geotechnical assessment*:** The overburden thickness in the area around the village is generally observed to be 1.0 – 2.0 meters. The thickness including weathered rock zone is however observed to be up to 4.0 meters at some places. This overburden material is observed to comprise of hill wash and debris that consists of brown, fine grained silty matrix with rare boulders and fragments of quartzite.

The Asi Ganga river is observed to indulge in erosion of its left bank down slope of the motor road. This has induced instability in the hill slope that is

particularly steep. Shallow debris materials with number of pine trees further contribute to slope failure (Fig. 20).

Fig. 20. Photograph depicting bank erosion by Asi Ganga on its left bank below the Chiwa village.

***Mitigation measures*:** Retaining structure with suitably deep foundation needs to be erected below the road where the failure has occurred. Concrete blocks on the river bed would further protect the bank as also the retaining wall.

At the same time tilted and dislodged pine trees around failure surface and subsided parts of landslide are required to be removed.

6. Seku village

Seku village (Fig. 21) is located at a distance of 07 km from Gangori on the left bank of south flowing Asi Ganga and can be approached by Gangori – Sangam Chatti road. The main village is located about 5.0 km upslope of the road head. This area was investigated on dated 01st September, 2012 and traverses were taken around the village and upslope to examine the geological setup.

Fig. 21. Panoramic view of Seku village in Asi Ganga valley.

The area is observed to be drained by two streams and the village is located on agricultural land and occupied by outcrops as well as overburden. The

overburden material comprises of hill wash and debris that consists of brown, fine grained silty matrix with rare boulders and fragments of metabasics.

Exposures of metabasics belonging to the Lesser Himalayas are observed in the nala bed and upslope of the village. The general trend of the rocks is NW-SE with moderate dips towards NE. The rocks in the area are traversed by numerous joints that constitute important structural discontinuities affecting the strength of rock mass and stability of the slopes.

The foliation plane is generally observed to be well developed and dips at angle varying from 28º to 32º towards northeast. The second joint sets are observed to dip at steep angles towards SW and NNE (65º / 225º and 73º 010º).

***Reconnaissance geological - geotechnical assessment*:** The overburden thickness in the area around the village is generally observed to be 2.0 – 3.0 meters. This overburden material comprises of hill wash and debris consisting of grey to brown, fine grained silty matrix with angular fragments of metabasics.

Minor slope failure was observed in front of the primary school. No indication of slope movement was observed in agricultural lands around the village.

***Mitigation measures*:** Suitably designed retaining structure with adequate provision of weep holes can be constructed in front of the primary school where slope failure has occurred. This would help in protecting the primary school.

7. Gajoli village

Gajoli village (Fig. 22) is located on the right flank of southeast flowing Ghiya Gad at a distance of 03 km from Sangam Chatti. The village extends upslope of the road head and can be approached by Sangam Chatti - Gajoli motor road. During the fieldwork the area had however to be approached on foot due to the disruption of road at many places by the flash floods. The area is observed to be drained by a seasonal stream.

This area was investigated on 1st September, 2012 and traverses were taken around the site, footpath section, road section and upslope to examine the geological setup.

Fig 22. Panoramic view of Gajoli village in Asi Ganga valley.

The area around the village Gajoli is observed to be located amid agricultural lands and occupied by outcrops as well as overburden (Fig. 22). In the road section below the village Lesser Himalayan quartzites are observed to be exposed. These rocks are observed to be medium grained, white with staining, slightly weathered, moderately jointed and medium bedded. These dip towards northwest at moderate angles. The rocks in the area are traversed by numerous joints which are the important structural discontinuities affecting the strength of rock mass and stability of slopes. The rocks dip at angles varying from 25º to 30º towards northeast. The joint sets are observed to dip towards SSW, SSE and E (75º / 205º, 80º / 155º and 55° / 090°).

***Reconnaissance geological - geotechnical assessment*:** The overburden thickness including weathered rock in the area around the village is generally observed to be 2.0 to 3.0 meters. This overburden material is observed to comprise of hill wash and debris consisting of grey to brown, fine grained silty - sandy matrix with fragments of quartzite.

Very steep rock cut slope with N-S trending ridge is observed to the upslope of the village. No indications of slope movement were observed in the area around the village.

8. Naugaon village

Naugaon village is located on the right flank of southwest flowing Godi Gad and is at a distance of 15 km from Gangori and can be approached by Gangori – Sangam Chatti motor road. This village is located about 5.0 km from the road head. The area is observed to be bound by two perennial streams.

This area was investigated on 2nd September, 2012 and traverses were taken around the site, footpath section and upslope to examine the geological setup.

The area around the village is observed to be located amid agricultural lands and is occupied by outcrops as well as overburden. Exposures of Lesser Himalayan quartzite with bands of chlorite schist are observed below the village along the footpath section. The general trend of the rocks is observed to be NE-SW with moderate to steep dips towards NW.

The rocks in the area are 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 is observed to dips at angles varying from 30º to 60º towards north to northwest. The joint sets are observed to dip towards WSW and S (63º / 240º and 55º / 180º).

***Reconnaissance geological - geotechnical assessment*:** The overburden thickness including weathered rock in the area around Naugaon village is observed to be about 3.0 to 4.0 meters. The overburden material comprises of hill wash and debris consisting of grey to brown, fine grained silty - sandy matrix with fragments of quartzite. Upslope of the village towards the hillside vertical rocky scarp is observed.

A seasonal stream is observed at the northwest end of village. During high rainfall events it has the potential of bringing down debris laden discharge that could damage the houses (Fig. 23).

On the northeast side of the village shallow debris slide is observed. A number of agricultural fields are observed to be damaged by this slide (Fig. 24).

Fig. 23. Photograph showing the seasonal stream upslope of Naugaon village.

Fig. 24. Photograph showing shallow debris slide that damaged numbers of cultivated fields.

Potential of rock slide is also noticed on the southeastern slope of NE-SW trending ridge.

***Mitigation measures*:** A seasonal nala is observed to be present in the northwestern side of the village as also in the upslope side of Naugaon village. This nala is required to be diverted with the suitable gradient

towards northeast side so as to join the perennial stream named Tiyuna Nala. This would help to protect the rapid bank erosion in the upslope parts of the stream and the village would be safe from excessive rise of water level during the monsoon.

Landslide debris is required to be removed from the agricultural lands so that these are put to productive use by the community.

9. Bhakoli village

Bhakoli village is located on the right flank of southwest flowing Kaldi Gad and is at a distance of 13 km from Gangori and can be approached by Gangori – Sangam Chatti motor road. The village is located about 3.0 km from the road head. The area is observed to be bound by two streams at this location.

The site was investigated on 2nd September, 2012 and traverses were taken around the site, nala bed, footpath section and upslope to examine the geological setup.

The area around village is observed to be located amid agricultural fields and that are invented by both outcrops and overburden. Lesser Himalayan quartzites with bands of chlorite schist are observed to be exposed both below and above the village along the footpath section. The general trend of the rocks is NE-SW with moderate to moderately steep dips towards NW. The rocks in the area are traversed by numerous joints that constitute important structural discontinuities affecting the strength of rock mass and stability of slopes. The rock dips at angles varying from 27º to 45º towards northwest. The joint sets dip at moderately steep angles towards WSW and S (63º / 240º and 55º / 180º.

***Reconnaissance geological - geotechnical assessment*:** The overburden thickness including weathered rock zone in the area around the village is generally observed to be 3.0 to 4.0 meters. This overburden material comprises of hill wash and debris consisting of grey to reddish brown, fine grained silty matrix with fragments of quartzite and chlorite schist.

No indications of the slope movement and instability were observed in the area around the village.

The western end of the village was reportedly affected by landslides about fifty five years before. The past landslide is observed along southwesterly slip surface where a number of tilted atish trees are also observed. This is indicative of likely future risk. Crown portion of the failure slope is observed to have slope of around 45° (Fig. 25).

Fig. 25. Photograph depicting old slide zone to the west of Bhakoli village.

Debris slide was observed along the nala bed on the northeast side as well as upslope of the village at Nagna - Damka tok. This has damaged a number of agricultural lands. Both the above described failure sites are however little far away from the village.

***Mitigation measures*:** In order to control the flow of water of the seasonal nala in the northeastern side as well as upslope of Nagna - Damka tok of Bhakoli village the channel bed is required to be turned into a series of cascades. Both the sides of the nala are also required to be protected by wire crate retaining walls. This would protect the banks in the upslope part of the stream from being eroded and the village would be safe from excessive rise of water level during the monsoon.

10. Dasra village

Dasra is located on the right flank of southwest flowing Kaldi Gad and is at a distance of 14.50 km from Gangori and can be approached by Gangori – Sangam Chatti motor road. It is located about 4.5 km from the road head. The area is observed to be bound by two streams.

This site was investigated on 3rd September, 2012 and traverses were taken around the site, nala bed, footpath section and upslope to examine the geological setup.

The area around the village is located on agricultural lands and occupied by outcrops as well as overburden (Fig. 26). The Lesser Himalayan quartzites and metabasics are observed to be exposed in the area upslope of the village. The general trend of the rocks is NE-SW with moderate to steep dips towards NW. The rocks in the area are traversed by numerous joints which constitute important structural discontinuities affecting the strength of rock mass and stability of slopes.

Fig. 26. Panoramic view of Dasra village in Asi Ganga valley.

Fig. 27. Photograph depicting slope failure along a perennial stream up slope of Dasra village.

The rock dips at angles varying from 30º to 50º towards north to northwest. The joint sets dip at moderately high to steep angles towards SW and SE (60º / 215º and 65º / 110º).

***Reconnaissance geological - geotechnical assessment*:** The overburden thickness including weathered rock around the village is generally observed to be 2.0 to 3.0 meters. The overburden material comprises of hill wash and debris consisting of grey to brown, fine grained silty matrix with fragments of quartzite and metabasics.

Perennial stream name as Patiyar nala in the western side of the village is observed to be affected by bank erosion due to intense rain fall on 3rd August 2012. Presence of loose soil material and high water content makes this bank prone to slides (Fig. 27).

Since the area is characterized by steep to moderately steep slopes it is very likely that this overburden would tend to move initially as a slump and then transform in to a mudflow during the monsoons. This has the potential of

endangering the human settlement that is located in the downstream direction.

***Mitigation measures*:** Wire crate retaining / bursts walls of appropriate height should be constructed to prevent the slope failure at the area presently affected by mass wastage. It would protect the failure slope.

11. Dhandnkala village

Dhandnkala village (Fig. 28) is located on the right flank of southwest flowing Kaldi Gad and is at a distance of 14 km from Gangori and can be approached by Gangori – Sangam Chatti motor road. This village is located about 4.0 km from the road head. The area is drained by three streams.

The site was investigated on dated 3rd September, 2012 and traverses were taken around the site, nala bed, footpath section and upslope to examine the geological setup.

Fig. 28. Panoramic view of Dhandnkala village in Asi Ganga valley.

The area around the village is located on agricultural land and is occupied by outcrops as well as overburden (Fig. 28). Lesser Himalayan quartzites and metabasic are observed to be exposed near the village as also on the nala bed. Upslope of village area metabasics are encountered.

General trend of the rocks is NE-SW with gentle dips towards NW. The rocks in the area are traversed by numerous joints that constitute important structural discontinuities affecting the strength of rock mass and stability of slopes.

The rock dips at angles varying from 20º to 25º towards northwest. The joint sets dip at steep angles towards SSW and ESE (80º / 200º and 70º / 110º.

***Reconnaissance geological - geotechnical assessment*:** The overburden thickness including weathered rock in the area around the village is generally observed to be 2.0 to 3.0 meters. The overburden material comprises of hill wash and debris consisting of grey to brown, fine grained silty matrix with fragments of quartzite and chlorite schist. No indication of the slope movement is observed in the area around the villages. However indications of differential settlement are observed in houses.

12. Agora village

Agora village (Fig. 29) is located on the right flank of southwest flowing Kaldi Gad and is at a distance of 15 km from Gangori and can be approached by Gangori – Sangam Chatti motor road. Agora is located about 5.0 km from the road head. The area is drained by two streams.

The village was investigated on 3rd September, 2012 and traverses were taken around the site, nala bed, footpath section and upslope to examine the geological setup.

Fig. 29. Panoramic view of Agora village in Asi Ganga valley.

The area around the village is observed to be located on agricultural land and occupied by outcrops as well as overburden (Fig. 29). Exposures of metabasics are observed near the village on footpath section and in the area upslope of the village. The general trend of the rocks is NE-SW with gentle dips towards NW. The rocks in the area are traversed by numerous joints which constitute important structural discontinuities affecting the strength of rock mass and stability of slopes.

The foliation planes dip at angles varying from 22º to 25º towards northwest to northeast. The joint sets are observed to dip at steep angles towards SSW and SE (70º / 190º and 90º / 125º).

***Reconnaissance geological - geotechnical assessment*:** The overburden thickness including weathered rock in the area around the village is generally observed to be 4.0 to 6.0 meters. The overburden material comprises of hill wash and debris consisting of blackish grey to grayish brown, fine grained silty matrix with fragments of metabasics.

Local ground settlements and minor slope failures are observed in the area around the village. These are attributed to unusually high rainfall during the monsoons of 2012. No indication of major slope movement is however observed in the area around the village.

Construction of houses on unconsolidated soil is the cause of settlement cracks in the structures. Some houses are observed to be constructed on the course of the seasonal streams. This is the causes of seepages observed around sill level in many houses during monsoons (Fig. 30).

Fig. 30. Photograph depicting seepage around the base of a house.

***Mitigation measures*:** The upslope area of the village, particularly towards the toe of the hill slope, should be kept free of anthropogenic intervention of any sort. Constructions should only be carried out at respectable distance from both seasonal and perennial stream courses. Construction should at the same time be avoided on vulnerable slopes as also over unconsolidated soil. Retaining / bursts walls of appropriate height with suitable provision of weep holes should be constructed at the site of the area affected by mass movement. The foundation of these structures should be on solid rocks and compact soil materials.

13. Dodi Tal

Dodi Tal is located at a distance of 35 km from Gangori and can be approached by Gangori – Sangam Chatti motor road. Dodi Tal is located about 25.0 km from the road head. It is the source of southwest flowing Dodi Tal Gad. The area is drained by several streams.

The area was investigated on dated 5th September, 2012 and traverses were taken around the site, along the Dodi Tal Gad and footpath section to examine the geological setup.

***Geology of the area*:** The area around the Dodi Tal is located on Higher Himalayas and is surrounded by rocky cliffs and has thick forest cover. Centre Crystalline gneisses are observed to be exposed in the area up slope of Dodi Tal as also on both the banks of Dodi Tal Gad. These rocks are observed to be medium to course grained, grey, slightly to moderately weathered, moderately jointed, medium to thickly foliated and dipping towards northeast at moderate to moderately steep angles.

Fig. 31. Photograph showing the transported materials deposited at the far end of the lake.

Fig. 32. Photograph showing a seasonal stream towards the Forest Guest House side.

The rocks in the area are traversed by numerous joints that constitute important structural discontinuities affecting the strength of rock mass and stability of slopes. The foliation planes are observed to dip at angles varying from 30º to 45º towards northeast. The joint sets are observed to dip at steep angles towards WSW and ESE (65º / 245º and 70º / 100º).

***Reconnaissance geological - geotechnical assessment*:** High monsoonal discharge has resulted in accumulation of large volume of sediments at the northern end of the lake (Figs. 31 and 32). No major damage is however observed except for some instances of bank erosion along the Dodi Tal Gad.

Discussion and future strategy

The fieldwork carried out in the area brings forth the fact that almost all the devastation has taken place in the proximity of the river bank and is caused primarily by abnormally high precipitation in the catchment of the streams. This is however no abnormal phenomenon and the river morphology in the area shows evidences of occurrence of similar events in the past.

One can therefore deduce that the infrastructure and other facilities that got destroyed in the event were located at wrong place and due consideration was not given to the possibility of high floods in the adjoining rivers and streams. This can be attributed to long recurrence interval of such events and short disaster related memory of the masses. Construction of a number of structures on the river ward side of the embankment built on the aftermath of 1978 floods in Uttarkashi gives strength to this assertion.

It needs to be understood that it is not possible to erect embankments at all places and embankments only provide a temporary solution to such problems. Moreover water would always find its path to flow past to lower grounds and erosion of banks is a natural process.

It is a general practice in the hills to align roads along rivers and streams. Apart from convenience and comfort, ever increasing economic opportunities in the vicinity of the roads encourages people to settle down in the proximity of the roads even if it implies being exposed to disaster risk. Increasing tourist and pilgrim traffic further promotes this tendency.

Terrain characteristics limit the availability of agricultural land in the hills and therefore terraces with relatively high productivity were traditionally utilized for agricultural pursuits rather than for the construction of residences. Commercial interests in the recent times, particularly in the vicinity of the roads however led

to construction of commercial and other establishments in the land available in the proximity of the roads and rivers.

All these changes are responsible for enhanced flash flood risk in the area.

It is therefore highly important to strictly regulate developmental initiatives in close vicinity of streams and rivers. Appropriate legislative interventions would be required for formulating a policy in this regard and firm executive action in accordance with letter and spirit of this policy would be required to ensure compliance of the same.

The suggestions for mitigative measures have been included in this report, along with the site specific surface geological-geotechnical information. In order to be effective, these mitigative measures must be designed in detail by adequately qualified and experienced geotechnical / civil engineer, with due respect to the ground conditions and details of the specific sites.