Landslides and Flash Floods Caused by Extreme Rainfall Events/Cloudbursts in Uttarkashi District of Uttarakhand

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Abstract

Uttarakhand, an area of Himalayan region, has been studied for landslides and flash floods caused due to extreme rainfall and cloud bursts. Assessment of such disaster incidences is covered with the help of satellite based images and various geological intricacies are discussed.

Keywords: *Landslides, Flash Floods, Cloudburts, Uttarakhand, Uttarkashi* .

Introduction

Evolutionary history of the concentrated seasonal precipitation and cloudburst make the district of Uttarkashi prone to a number of natural hazards. The area is frequently devastated by landslides, cloudbursts, flash floods, floods, avalanches, lightning, hailstorms and earthquakes. These incidents cause sudden and severe damage to life and property in many parts of this area. Geological instability of the region, together with high atmospheric precipitation, is responsible for widespread landslide occurrences in the region. The rocks of the region are characterised by multiple structural discontinuities and the relationship of these with surface slopes often make conditions favourable for landslides to occur. Once instability is introduced, the hill slopes often become chronically prone to landslides. The problem of landslides is aggravated during the monsoon season due to (i) enhanced pore water pressure, (ii) increased weight of the rock mass and (iii) reduced frictional forces. There could be various reasons for such events but the main seems to be the inherent geology of the Himalayas and heavy rainfall. Torrential rains, generally called cloudbursts, or extreme rainfall are frequent events in the region. The cloudbursts occur suddenly, and are a short duration

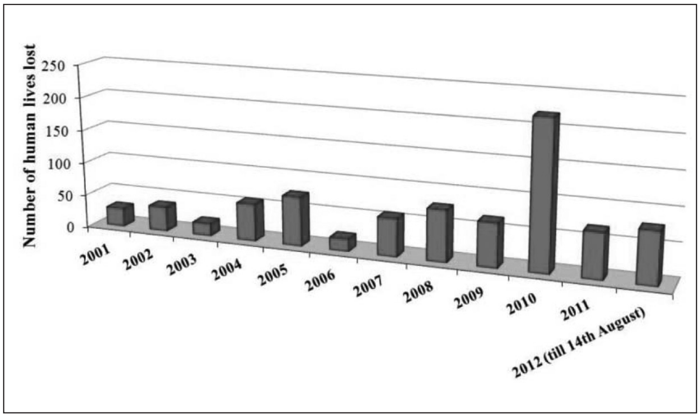

Figure 1: Year-wise loss of human lives due to landslides and flash floods in Uttarakhand.

concentrated precipitation phenomenon. During this time of concentrated precipitation in a particular location, specially at higher elevations, 100 mm to 250 mm of rainfall per day may occur. Most of the time cloudbursts/extreme rainfall events result in flash floods, causing enormous destruction of life and property in the area of occurrence. This type of incidents have been reported from all parts of Indian Himalayan region (1960, 1968, 1971, 1973, 2003, 2010 and 2012, etc.) causing huge loss of life and property. In general it is observed from almost all parts of the Indian Himalayan region that during the rainy season (June-September) many landslides at various locations are triggered, disturbing vehicular traffic, electricity, drinking water supply and telephones.

River System

The Ganga, Yamuna and Tons form the major river system of Uttarkashi district. All these rivers have various tributaries in their basin. In Himalayan Rivers, broad bed widths alternate with narrow constricted gorges. The majority of Himalayan Rivers have a tendency to flow for some distance in structural troughs parallel to the mountains, but again they take an acute bend to flow in deep transverse gorges, at places hundreds of metres in depth. The rivers have formed deep valleys, narrow or broad in accordance with lithology. Most of the rivers flowing in the Himalayan region are antecedent. In general, the dendritic pattern is common. All the main rivers make a steep descent in their longitudinal profiles in the first phase and afterwards their gradient is less steep. It is the land of Uttarkashi district that gives rise to two great and revered rivers of India, the Bhagirathi, called the Ganga in the plains, and the Yamuna. The Ganga coming up in the glaciers "gaumukh" traverses 128 km in Uttarkashi district before flowing down farther. Hardly ten km away from Gaumukh is the place "Gangotri" of great from the west of Bandarpuch peak, and revered highly is the place "Yamunotri" situated nearby, visited by pilgrims. The third important river of this district is Tons besides a host of tributaries that drain these areas.

Flash Floods

Most of the rivers in Himalayan terrain flow through narrow gorges abutting moderate to steep slopes, having sharp bends and meet tributaries on steeper slopes. As the river flows downstream the valley becomes comparatively wide and less steep. The occurrence of flash floods, particularly in a narrow river valley, seems to be one of the much feared causes of some of the major cloudbursts or landslides or glacial lake outburst. Rolling of debris by cloudburst or landslide along the constricted course of the rivers leads to a temporary damming of the

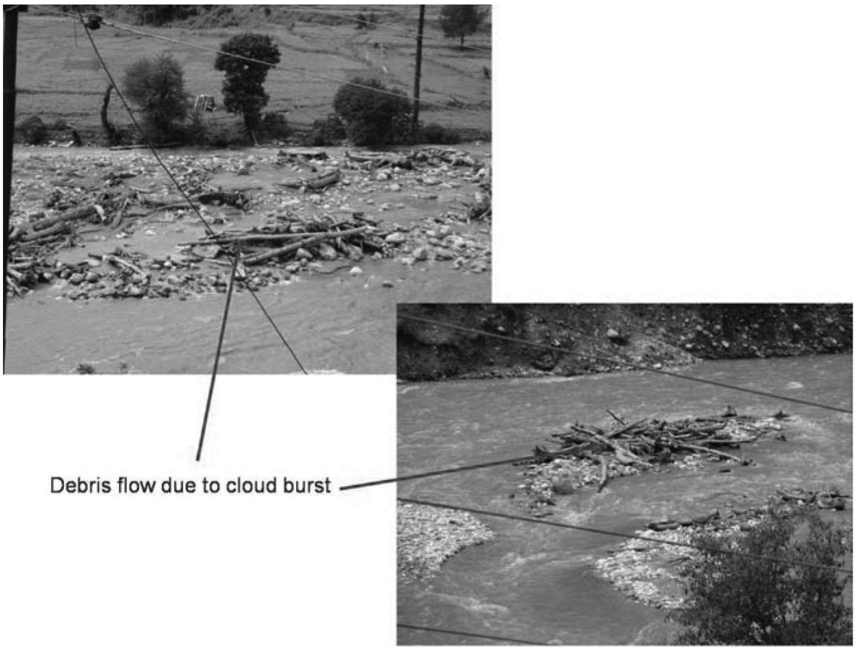

Figure 2: Human dwellings adjacent to river valley prone to flash floods.

river flow, resulting in the creation of temporary lakes. It is when the back water pressure of the lake exceeds the retention capacity of the barrier, that the accumulated water gushes downstream with mighty force inundating otherwise safe settlements. The majority of the settlements are located on the middle slopes. However, in the areas where fluvial terraces exist people would prefer to exploit such flat areas adjacent to the rivers (Figure 2).

A high discharge during the summer is an annual feature of all snow fed rivers of Indian Himalayas, which dumps a huge amount of sediment downstream. This melting is mainly due to change in temperature (winter to summer). This rise in temperature is basically responsible for the fast melting of snow and glacier lying in the source area of the respective rivers. Sometimes the high melting along the debris is able to choke the stream and create a temporary dam on the one hand, and on the other, the high melting is able to burst the temporary glacial lakes in the headwaters region.

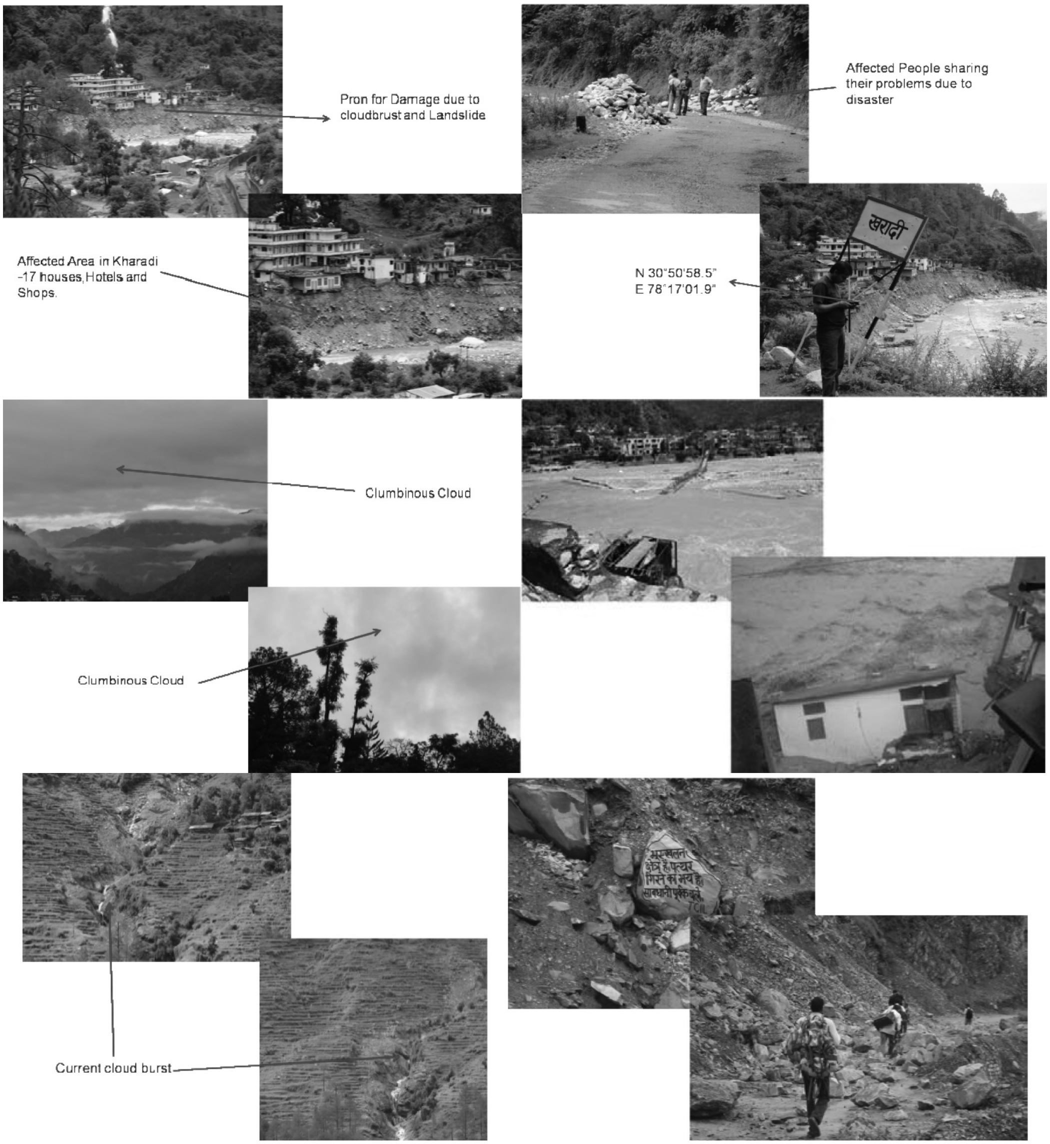

Figure 3: Ground observation of Metrological disaster affected area.

Cloudburst/Debris Flow on Yamunotri NH 94

Site observations were carried out from August 22 to August 24, 2012. The catastrophic landslides of Uttarkashi district, which took place on August 4, 2012, have been subjected to field investigation. Our study indicates that combinations of several factors were responsible for this tragedy, but the action of water during the cloudburst was the main triggering factor. A detailed survey of the area has revealed very heavy precipitation on that date and Uttarkashi, Bhatwari, SangamChatti, Maneri, Assi Ganga, Hanuman Ganga, Kharadi, Naitwar Umala Chani, Nuranu, Kalap and Pujeli were affected out of these Uttarkashi was the worst hit. The debris flow along the gullies uprooted the trees and removed heavy boulders because of the high velocity and turbidity of the water. Along the narrow margins trees and removed heavy boulders temporarily dammed the streams. According to the villagers, similar devastating tragedy had also taken place in Kharadi, situated on the left bank of the Yamuna River. Cloudburst occurred in the Hanuman Ganga, and maximum damage occurred in Kharadi.

Affected Area

The cloudburst/landslide affected areas are: Kharadi, Janki Chatti, Hanuman Chatti, Sangam Chatti, Assi Ganga, Bhankoli, Sauri gad, Mori, Naitwar, Pujeli, Liwari, Kalab, Nuranu, Fitari, Fafrala Sankri, Dharasu band, Dunda, Tiloth, Naitala, Bhatwari. Figure 4 represents the pre-disaster condition.

Metrology of the Study Area

In general the Indian Himalayan ranges are on the south facing slope and critical determinants of the Indian subcontinental climate. In winters they serve as

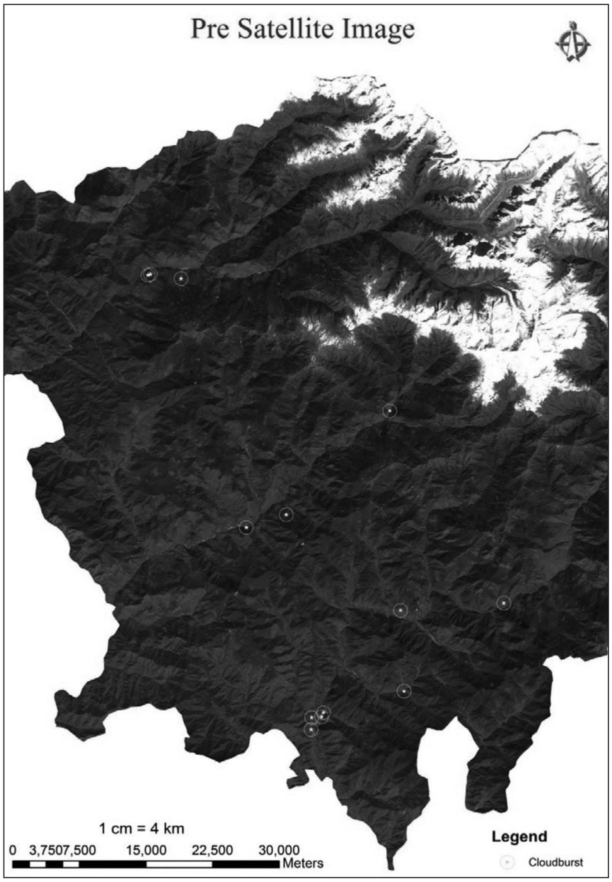

Figure 4: Pre satellite Image of Study Area.

an effective barrier to the intensely cold continental air blowing southward to India. This helps to keep India warm in the winter (Agarwal and Narain, 1991). Invariably climatic conditions fluctuate from hot and sub-humid, tropical to cold, temperate and alpine compounded with glacial features. According to Mani (1979), the climate of Indian Himalayas is governed by the extra-tropical weather systems of Asia, which during winter moves from west to east, bringing rains in western Himalayas, and during summer from east to west, causing monsoon rains in eastern and central Himalayas. The northern slopes of Himalayan ranges get more snow accumulation and glacial action. Due to difference in altitude there is high variation in the precipitation all across the IHR. Eastern and western Indian Himalayan ranges receive more than 60 per cent of its total rainfall during monsoon period (June-September). The temperature is also influenced by the altitude of IHR at various locations. The foothills and valleys are warmer than the middle and high altitude. Many of the high altitude areas experience snowfall in winter season and remain snow covered for four to five months. The incidents of mass movements and flash floods are more frequent and common during the rainy season. It is because of slope stability which is partly related to the water saturation caused by prolonged and sometimes high rainfall. Apart from duration, the intensity of rain also varies time to time. It is observed that the there are many occasions in the IHR when a day's (24 hours) rainfall exceeds 100 mm and leads to several types of mass movements.

The metrological stations are Hanuman Chatti, Harsil, Bhatwari, Tekla. They intimate air temperature, wind speed, wind direction, atmospheric pressure, humidity and rainfall from August 1 to August 10, 2012.

Table 1: Metrological Parameter

STATION	DATE	AIRTEMP	WIND_ SPEED	WIND_ DIRECTION	ATMO_ PRESSURE	HUMIDITY	RAIN_ FALL
HANUMAN CHATTI	08-01-2012	16.8	0	359.2	968.9	96	58
HANUMAN CHATTI	08-02-2012	17.8	0	359.2	967.2	95	58
HANUMAN CHATTI	08-03-2012	16.6	0	359.2	965.8	0	58
HANUMAN CHATTI	08-04-2012	13.7	0	359.2	969.3	0	58
HANUMAN CHATTI	08-05-2012	15	0	359.2	970.2	98	58
HANUMAN CHATTI	08-06-2012	18.6	0.9	309.9	969.7	82	58
HANUMAN CHATTI	08-07-2012	20	0	359.2	970.2	77	58
HANUMAN CHATTI	08-08-2012	18.3	0.6	326	969.5	81	58
HANUMAN CHATTI	08-09-2012	16.1	0	359.2	969	95	58
HANUMAN CHATTI	08-10-2012	16.9	0.5	345.1	970.2	84	58
HARSIL	08-01-2012	18.2	1.9	35.2	970.6	81	127
HARSIL	08-02-2012	19.4	1.1	37.1	968.4	78	127
HARSIL	08-03-2012	16.5	0.9	45.9	967.9	89	127
HARSIL	08-04-2012	14.6	0.8	16.1	970.8	90	128
HARSIL	08-05-2012	15.5	0.9	345.1	972.2	87	128
HARSIL	08-06-2012	17.6	1.4	246.8	971.9	84	128
HARSIL	08-07-2012	21.4	0.4	66	972.2	66	128
HARSIL	08-08-2012	20.2	2	147.1	970.8	70	129
HARSIL	08-09-2012	19.6	3.3	48.9	970.1	70	129
HARSIL	08-10-2012	16.3	0.1	113.9	972.3	85	129
BHATWARI	08-01-2012	19	0	359.2	925	90	320
BHATWARI	08-02-2012	19.3	0	359.2	925	91	320
BHATWARI	08-03-2012	-40	0	359.2	925	0	320
BHATWARI	08-04-2012	-40	0	359.2	925	0	320
BHATWARI	08-05-2012	-40	0	359.2	925	0	320
BHATWARI	08-06-2012	-40	0	359.2	925	0	320

(Table 1 continued)

BHATWARI	08-07-2012	-40	0	359.2	925	0	320
BHATWARI	08-08-2012	22.1	0	359.2	925	78	320
BHATWARI	08-09-2012	19.7	0	359.2	925	86	320
BHATWARI	08-10-2012	20	0	359.2	925	84	320
TEKLA	08-01-2012	22.8	0	359.2	925	75	246
TEKLA	08-02-2012	23.1	0.7	49.9	925	77	246
TEKLA	08-03-2012	22.6	0.1	0	925	79	246
TEKLA	08-04-2012	20.3	0.6	212.1	925	76	246
TEKLA	08-05-2012	23.5	0.3	348	925	78	246
TEKLA	08-06-2012	25	1.3	254.2	925	74	246
TEKLA	08-07-2012	26	0.4	16.1	925	72	246
TEKLA	08-08-2012	27.3	0.1	110	925	66	246
TEKLA	08-09-2012	25.9	0.2	266.9	925	72	246
Tekla	08-10-2012	25.2	0	359.2	925	74	246

(Source: MOSDAC-ISRO)

Geological Set-up

Tectonically the Himalayas comprise four separable major litho-stratigraphical units, i.e., Siwalik, Lesser, Central Crystalline and Tethyan group (Table 2). These groups are separated from each other by a major tectonic contact known as Main Boundary Thrust (MBT), Main Central Thrust (MCT) and Tethyan Thrust, and these thrust contacts are traceable all along the Himalayan belt. The Indo-Gangetic Plains in the extreme south are separated by the Himalayan Frontal Fault (HFF) from the ruggedly youthful Siwalik Hills. Highly rugged conical peaks and steep sided valleys are the prominent physiographic features in Higher Himalayas. Whereas lower Himalayas contain comparatively less steep slopes with truncated

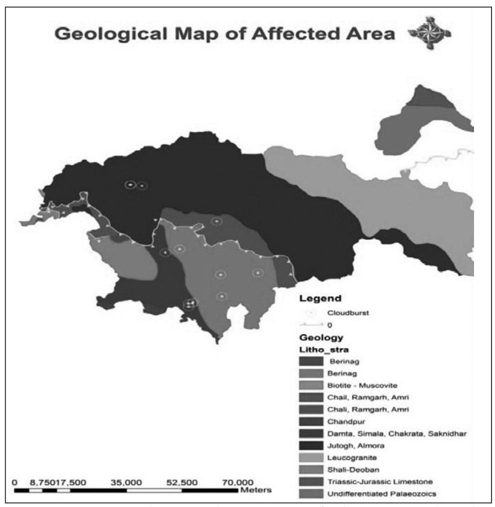

Figure 5: Geological set-up of the Uttarkashi district.

spurs and almost flat hilltops. The main ridge or major water divides generally follow the Himalayan trend, i.e., NW-SE and conform to the tectonic trends of the Himalayas. Thus, the area is geologically controlled by the major structures and lithology as well. The valley generally contains well developed fluvial and fluvioglacial terraces. The higher Himalayas generally contain thin regolith with scant vegetation and almost no population. The higher peaks remain snow-clad throughout the year. Gently sloping grounds are thickly populated. Various terraces lie along the valley sides, used for settlement and agriculture by the inhabitants.

Table 2: Stratigraphic sequence of Uttarkashi district.

S. No	Formation	Bhagirathi Valley	Jain's Classification (1971)
1	Nagni Thank	Pujargaon Metavolcanics Gamri Quartzites Kot Metavolcanics	Gamri Quartzite, Dunda Quartzite
2	Shyalana	Limestone and Dolomite	Part of lower Uttarkashi Limestone, Upper Uttarkashi Limestone, Khatturkhal Limestone Dilichi Dolomite
3	Uttarkashi	Sartali Slate	Pokhri and Dhanari Slate
		Netala Quartzite	Netala Quartzite, Bareti Quartzite, part of lower Uttarkashi limestone
Source: N. C. Agarwal and Gopendra Kumar, *Himalayan Geology*, vol. 3.			

Slope

Slope is an extremely significant characteristic in landslide incidents. In the shear slope areas landslides are gentler than the moderate slope areas. The majority of landslides occur on 100 and 250, although the areas of highest association occur in the slope between 40 to 45. Again, the high association of landslides with steeper slope angles is likely to be a reflection of widespread shallow superficial earth slide development on the steeper exposed slopes. In the rugged sloping areas landslides are more common than the gentle slope terrain. Whether laying a road section, constructing a dam, selecting a site for heavy industry, or planning a resort, the terrain slope characteristics of an area are a primary consideration. In fact, terrain slope characteristics affect the entire building process, from selecting a facility's location, to planning its layout in the area.

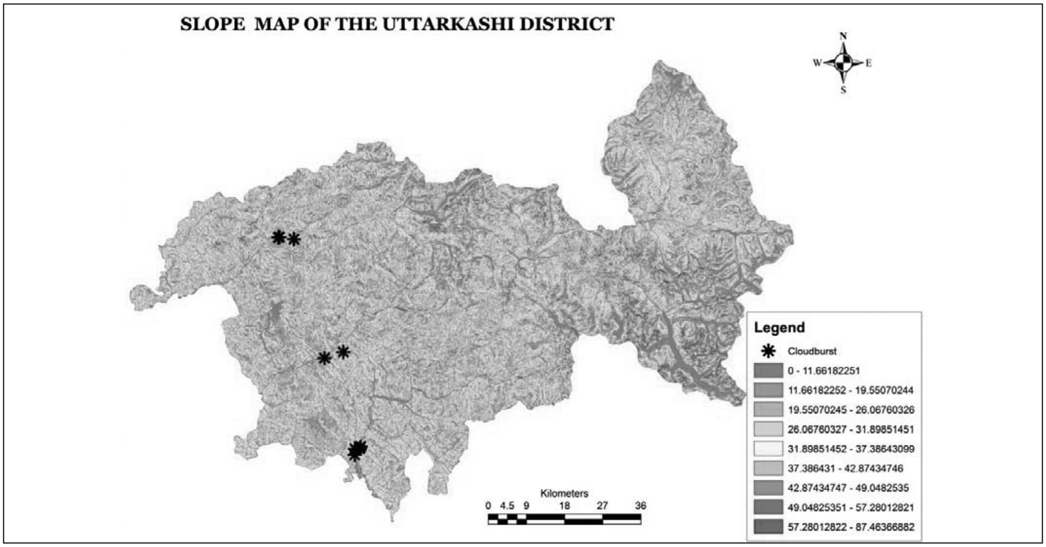

Figure 6: Slope map of the study area.

Slope Aspect

There is some association of landsliding with slope aspect, with a tendency for landslides to develop preferentially on south-east to east facing slopes. The number of landslides in these faces are, SE 12%, SW 20%, NW 18% , W 16% and South face 24%. This is consistent with directional trigger mechanism such as intense rainfall from tropical storms that mostly frequent the study area from ESE or SSE. A reasonable explanation of this pattern may be that slope aspect affects the density of shallow debris slides by limiting the development and thickness of drier slopes. To some extent, this interpretation may also be applicable to the

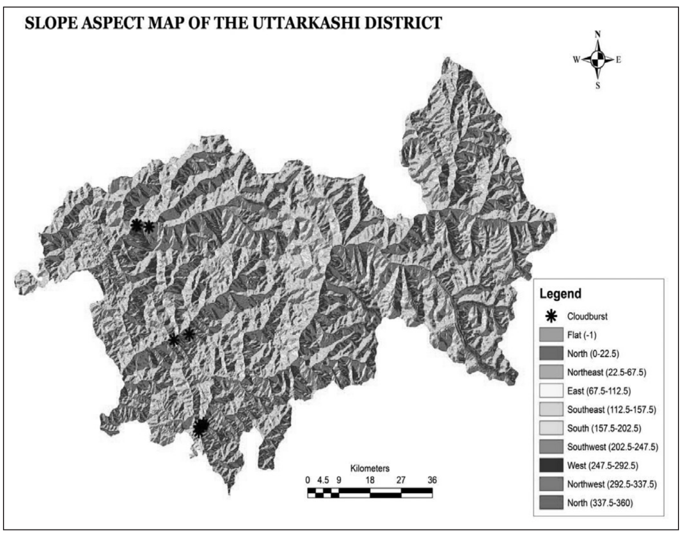

Figure 7: Slope aspect map of the study area.

development of debris slides in the study area slopes. Deep-seated landslides are less likely to be influenced by slope aspect, due to the overriding controls of lithology and structure. The elevation of study area varies from 800 m to 4,200 m within the distance of about 100 km. More than 50% of the catchments of Teesta basin lie above 800 m. Therefore the Teesta Basin of Sikkim can be classified as a high altitude basin. Only 25% of the catchments lie below 2,000 m. These are ridge, rocky, cliff, escarpment, landslide zone, low mountain (>1,000 m). The slope aspect categories represent the number of degrees of east and they increase in anticlockwise direction, that is, 90 degrees is north, 180 degrees is west, 270 degrees is south and 360 degrees is east. The slope directions in the study area are: North 0-22.50, North-east 22.5-67.50, East 67.5-112.50, South-east 112.5-157.50, South 157.5-202.50, South-west 202.5-247.50, West 247.5-292.50, North-west 292.5-337.50, North 337.5-360.0.

Landslide Hazard Zonation

Hazard indicates the probability of occurrence within a specified period of time and within a given area of a potentially damaging phenomena, e.g., a landslide. "Landslide hazard/susceptibility zonation" refers to the division of a land surface into homogeneous areas or domains and their ranking according to the different degrees of actual/potential hazard caused by the mass movement. In the recent past, various methods and techniques have been proposed to analyse the causative factors of landslides and produce maps portraying the probability of occurrence of similar phenomena in future. Broadly these methods can be classified as direct and indirect methods. The direct method consists of geomorphological mapping wherein the past and present landslides are identified and assumptions are made on the factors leading to instability, following which zonation is made of those sites where failures are most likely to occur. The indirect method includes two different approaches, namely, the heuristic (knowledge driven) and statistical (data driven) techniques. In the heuristic approach, factors influencing landslides, such as rock type, slope,

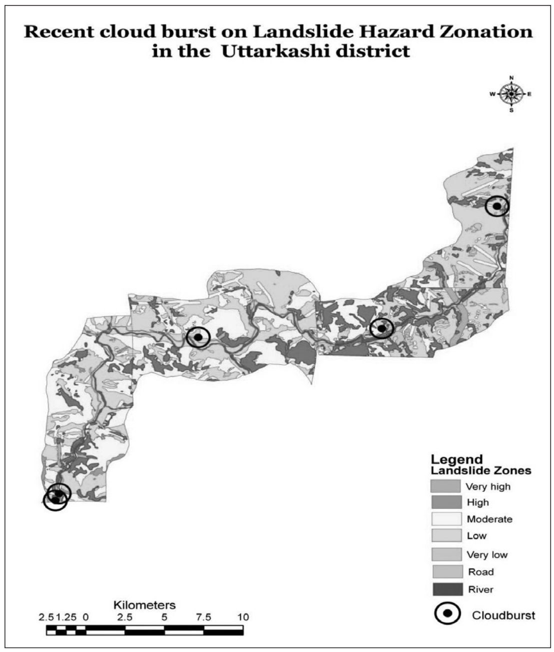

Figure 8: Landslide Hazard Zone with cloudburst location.

landform, land use, etc., are ranked and weighted according to their assumed or expected importance in causing mass movements. This is normally based on a priori knowledge available to experts on various causes of landslides in the particular area of investigation. In the present study, a combination of expert opinion and statistical technique has been used to arrive at weightages for landslide Hazard Zonation. Risk means the expected number of lives lost, persons injured, damage to property, or disruption of economic activity because of a particular natural phenomenon. Vulnerability means the degree of loss to a given element (or set of elements) at risk resulting from the occurrence of a natural phenomenon of a given magnitude. Element at risk means population, properties, economic activities and so on, at risk in a given area. Specific risk means the expected degree of loss due to a particular natural phenomenon. Basically terrain is analysed with respect to various geo-environmental factors and each factor or theme is divided into a number of classes. Then each theme and each class is evaluated according to their influence factor on causing landslide. Then finally all the themes are integrated using certain mathematical formulae to prepare the zonation map. This Hazard map is grouped into several classes of probability, i.e., very high, high, moderate, low and very low. Hazard maps aim to predict where failures are most likely to take place without any clear indication of when they will take place. However these hazard maps can be used as a guide for future development of infrastructure, settlements and any other construction to avoid future disasters. Figure 8 has been prepared by assigning the relative numerical weightage of each facet incorporating various thematic maps like lithology, structure, slope, relief, land use/land cover, soil, drainage density and rainfall, etc., through Geographic Information Systems (GIS). The results were validated for each of the hazard zones. The maximum cloudburst occurred in very high and high hazard zone.

Figure 9: High slopes are prone to sliding.

Causes of Flash Flood and Cloudburst Flood

A combination of factors appears to contribute to flash floods and cloudbursts. The fragile geology and torrential rain plays a significant role in destabilising the Himalayan terrain. The entire Himalayan belt is tectonically and seismically a very sensitive domain. Strong tetanised rocks and fragile mountain slopes (Figure 9) are vulnerable to the onslaught of rain. The cumulative effects of past earthquakes in such a zone certainly aggravates these phenomena. Apart from inherent character, natural factor, anthropogenic changes, such as change in land use, deforestation, increase in population, developmental schemes, etc., also play a significant role in increasing the frequency of landslides (Valdiya, 1987).

Though in each of the incidents the causative factors are incident-specific but still all the factors have a close relation with each other.

The gradient of bedrock channels is a semi-independent variable and is not directly determined by the hydraulic regime. Factors such as physical characteristics of local lithology and the tectonic movements in the Himalayan region influence the channel gradient. Compared to the small rivers, large rivers are most susceptible to even minor changes in their slope induced by active deformation. The precipitation threshold value for triggering landslide debris floods has not been studied for Indian Himalayan region, which takes into consideration all relevant parameters such as slope angle, geology, soil type, vegetation and soil situation. According to Li and Wang (1992) in Chinese mountain commutative precipitation of 50-100 mm in one to two days and daily precipitation of about 50 mm was enough to precipitate small-scale shallow landslides; two days commutative precipitation of 150-200 mm led to an abrupt increase in the number of large landslide of debris flow. Intense rainfall, even of short duration, causes shallow and quick landslides, whereas prolonged rainfall intensity over 10 minutes intervals (to identify short bursts of intense rainfall), of rainfall on the day before and of rainfall immediately before an event, predict the occurrence of landslides and debris flow.

Control and Management of Flash Floods and Cloudburst Floods

The most common natural hazards in the Indian Himalayan region is landslide and associated phenomena, which causes maximum damage to nature and man-made environment every year, particularly during the monsoon period. Generally the flash flood is associated with landslide (of different origin). Though a combination of several factors like tectonic disturbances, weak lithology geological structure (local/regional), seismic events, loose soil cover, hydrological behaviour, land use and anthropogenic activities in association with rainfall, temperature and aspect are responsible for triggering landslides or associated phenomena. Each such type of incident requires site specific control and management. Still some general measures are required for the entire Indian Himalayan region. It is evident from our study that maximum landslides or debris flow, the main reasons for flash flood, are rainfall induced. If systematic rainfall threshold values for triggering landslide/debris flow studies is done for the whole Indian Himalayan region, then a management plan for stabilisation can be suggested easily using bioengineering measures. Landslide hazard zonation on micro level is another important aspect of control and management of flash floods in the Himalayan region. Microzonation can help in prediction of any future occurrence of landslide/debris flow in the given set of conditions. If the early warning could float to local residents, at least lives could be saved. Due to increase in population, the village person sometimes migrates to the areas adjacent to the riverbed. On account of availability of water and fertile land for agricultural production, people prefer to stay there. These areas are most vulnerable to flash floods. The areas lying in the danger zone of floods should be demarked and banned from such cultivation/settlement. Flash floods and cloudbursts are natural calamities, and it is difficult to predict the exact place and time of such occurrence in the Himalayas. But still, if we can put in sincere efforts for understanding in depth the scientific reasons for flash floods and cloudbursts, we may certainly come away from the fury and havoc created by such incidents. The following suggestions may be helpful to cope up with or reduce the long-lasting effects of flash floods and cloudbursts:

- Awareness about hazards/natural disasters among villagers.
- Details on geology, land use and land cover and soil types.
- Detailed studies of long-term data including precipitation, intensity and duration.
- Identification of flash flood prone areas, construction should be banned in the areas prone to recurring flash floods and other such natural hazards.
- Threshold values for triggering landslide and debris flow (location specific).
- Micro Level Hazard Zonation.
- Implementation of mountain risk engineering techniques.
- Early Warning Systems.

Conclusion and Recommendations

The area around NH 94 faces serious slope stability and metrological disaster problem during the current monsoons (year 2012). As discussed in the previous sections, the area has a history of mass instability and interplay of many processes has rendered the area highly vulnerable. So far as possible excavation should be minimised and the slope material should not be disturbed. Enhanced pore water pressure during heavy rains facilitates slope instability. It is therefore required that excess water be drained out from the slope material. In view of the narrow valley habitation and landslide threat, the local population is advised to stay away from subsidence and landslide affected areas. The households living in the zone of narrow valley and landslide prone area are at the same time required to be shifted to alternative safer locations. Landslides occur frequently in Uttarkashi region. This is due to the inherent geology, slope conditions and the high intensity of rainfall that not only contributes to rapid erosion and weathering of rock mass but also increases the ground water level decreasing the stability of slopes. The increasing anthropogenic activity in the sensitive zones contributes to increase the instability of active slopes in the Indian Himalayan region. Incremental increases in such incidents and increase in population in the areas of IHR could be the cause of more damage to life and property in future. Owing to the remoteness of the affected, or in high altitude, areas generally the rainfall data are not available. If normal rainfall data is not available then we cannot think of the desired data for extreme rainfall from most of the affected areas. The extreme rainfall, threshold value of triggering of landslides in a particular region, and return period of extreme rainfall events, are also not available as on date. Therefore, such data and in-depth studies on those parameters are required to understand the phenomenon and to suggest preventive measures to cope with or minimise the damage to life and property in the Indian Himalayan region for future.

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