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Flash Floods!

Threatening the Himalayan Region

Geologically, Uttarakhand is located in a fragile and the world's youngest mountain range. It is inherently vulnerable to various kinds of disasters, such as high intensity rainfall, cloudbursts, landslides, flash floods and earthquakes. The recent ill-fated tragedy in Kedarnath happened due to a combination of several events.

BETWEEN 16 and 17 June 2013, the hills of Uttarakhand were subjected to intense rainfall – 370 millimetres of rainfall was recorded at Dehradun within a 24-hour period, which is exceptionally rare. The average monthly rainfall in Dehradun for the month of June is 210 millimetres while in July and August it is more than 600 millimetres.

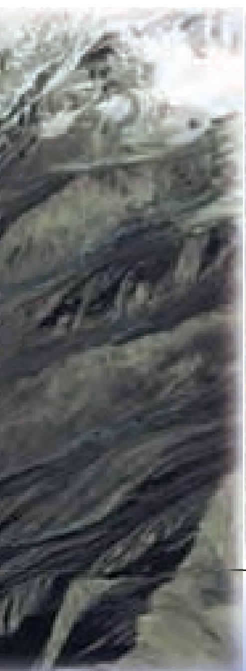
Single-day rainfall in excess of 400 millimetres has been recorded several times in the state, but none of these single-day extreme events happened in June. Instances of such extreme precipitation, of 370 millimetres or more, have been witnessed not just in the normally wet

Kedarnath area showing Chorabari glacier and steep valley

months of July, August and September but even in January, April and May, but never in June.

In fact, the 370 millimetres rainfall in Dehradun happens to be the highest-ever single-day rainfall in June for the state — the previous highest being 350.5 millimetres in 1970. It is this high amount of rainfall that created havoc in the state in June 2013.

It may also be noted that heavy rainfall was not just confined to the Mandakini valley. It covered a large region from the Western Himalayas to the Central Himalayas. Although the flood was a record high in Chisapani, Karnali in Nepal, because of an Early Warning System there was no human casualty in the Karnali flood.



Kedarnath area surrounded by steep hills

Kedarnath temple is situated in the Mandakini valley below the Chorabari glacier which is the source of the Mandakini. Its altitude is 3590 metres above sea level. The altitude of Gandhi sarovar or Chorabari taal is 3900 metres above sea level. Chorabari is a compound valley glacier having a total catchment area of 67 square kilometres (up to Rambara). Hill slopes upstream of Kedarnath are devoid of vegetation.

It is still not completely clear what actually happened in the Mandakini valley upstream of Kedarnath which generated so much of water and debris flow over a short time. Google Earth imagery of this area was taken in winter so the whole area is covered by snow and land features cannot be distinguished.

Some images available from the Indian CARTOSAT satellite available on the Bhuvan site of the National Remote Sensing Centre (NRSC), Hyderabad show a number of streams approaching Kedarnath town. Possible reasons for the disaster are a Glacial Lake Outburst Flood (GLOF) due to the failure of Chorabari

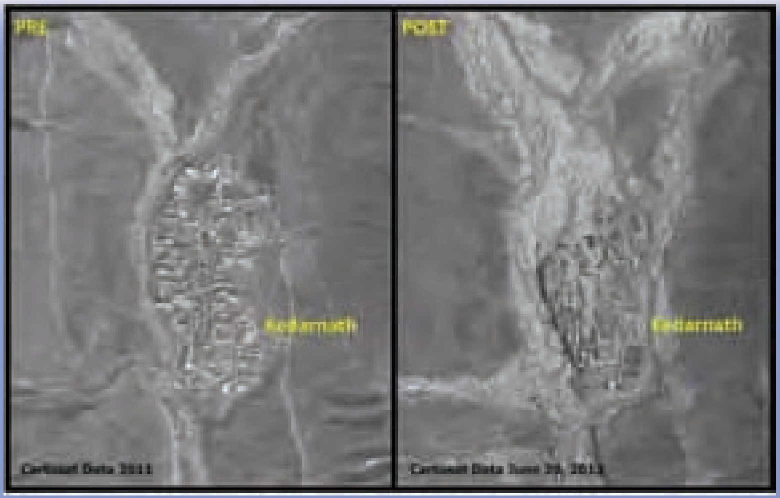
Satellite data of Chorabari glaciers and Kedarnath area shown as blue dot

taal (the lake is approximately 800 metres long and 200 metres wide) situated upstream of Kedarnath and a catastrophic landslide in the upper region. As a result, large volumes of water reached the town, having picked up huge amounts of loose sediment en route. One thing is clear that the heavy and unprecedented rainfall triggered a collapse event on the mountain, which turned into a debris flow downstream.

The devastation at Kedarnath can be seen in the Cartosat image of the study area after the disaster. Both streams approaching the site created havoc. According to a report based on high resolution satellite data collected using the RISAT-1 (Indian satellite) instrument, given by Dr. Dave on his blog (http://blogs.agu.org/landslideblog/2013/06/27/) and available on Internet, the flow occurred first from northeast and after that from the northwest.

On the basis of high resolution image, Dr. Dave reported that the debris flow from northwest was initiated by a landslide high on the hillside, which then ran down the slope entraining debris en route. At the slope toe it was channelized by the glacier into a narrow gully. It is clear that the flow eroded out a large amount of material in this area. The area down slope of the failure was already a zone of active erosion, so the likelihood of entrainment (carrying along of particles in a current) was very high.

The second event (morning of 17 June), which came from the glacial area to the northwest, was different from the first. The flow was so large that it over-topped the moraine (accumulation of boulders, stones, or other debris carried and deposited by a glacier) on the other side of the glacial area, such that three flows were formed. The first went southwest to join the valley from the earlier debris flow before swinging to the south to strike the town. This flow followed an existing channel. The second was a much smaller flow that reoccupied a palaeo-channel. Most of the debris flow (due to erosion) traveled south down the main channel. Thus, Kedarnath was struck by an earlier flow from the northeast, then a later flow from the northwest.



High resolution satellite data collected using the RISAT-1

The most significant chain reaction in this context is probably the danger from ice avalanches, debris flows, rock fall or landslides reaching a lake and thus provoking a lake outburst.

Some people are of the opinion that the Kedarnath disaster was caused due to construction of hydropower projects in the Upper Ganga basin. However, the project nearest to Kedarnath is about 10 kilometres downstream and is under construction. Obviously, hydropower projects had no direct role in the catastrophic event.

Hopefully, collection of field data, analysis of satellite data, and detailed investigation of the site will make the picture clear in the coming days. But to understand what happens during such catastrophic events in the hills, let us take a look at some of the natural events that frequent such regions.

Fury of the Floods

Every year floods play havoc in our country. The magnitude of the flood depends upon the intensity of the rainfall, its duration and also the catchment conditions. Out of the average annual rainfall of India, about 75% of it is received during the four months of the south-west monsoon season (June to September) and about 80 hours out of these four months account for most of the rains.

Kedarnath area after the tragedy (loose material can be seen in the background)

The flood problem faced by India is unique in several respects due to varied climate and rainfall patterns in different parts of the country. Also, soil erosion and silting lead to reduction in the carrying capacity of river channels, thus accentuating the flooding.

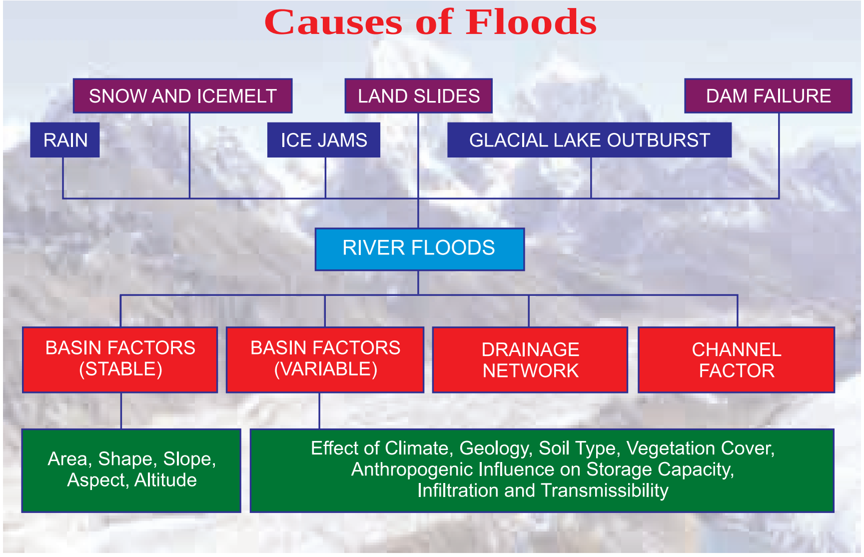
Flash flood is a sudden, localized flood of great magnitude and short duration, typically caused by unusually heavy rain. Most flash floods are local events relatively independent of each other and scattered in time and space. Although flash floods usually occur over a relatively small area and last only a few hours (sometimes minutes), they have an incredible potential for destruction. Flash floods carry a higher amount of debris than normal floods, and, as a result cause huge damage to buildings, roads, bridges, hydropower stations, and other infrastructure. Frequent occurrence of flash floods in the Himalayan region poses a severe threat to lives, livelihood, and infrastructure, both in the mountains and downstream.

Typical reasons for flash floods are cloudburst, that is, intense rainfall, the outburst of a landslide dam, the failure of an artificial dam, or a glacial lake outburst.

When the Cloud Bursts

A cloudburst is a weather event in which heavy rainfall (of the order of 100 millimetres per hour or more) occurs over a localised area at very high intensity. In India, cloudbursts usually occur during the monsoon season over orographically dominant regions like the Himalayas and the Western Ghats. These can also occur over the plains, but such occurrences are rare.

It is believed that cloudbursts occur because of rapid lifting of clouds



Climate Change and Extreme Rain Events

Climate change is the biggest threat facing humankind; extreme weather events, droughts and rise in diseases have been forecast for many parts of the globe over the coming decades. The Intergovernmental Panel on Climate Change (IPCC), the scientific body that advises the UN and governments on global warming, has stated that the changes in extreme events (floods and droughts) could affect the frequency of natural hazards such as avalanches and mudslides.

As per IPCC, a major problem related to climate change in many mountain regions is increased erosion and reduced slope stability. The combination of complex orography (physical geography of mountains and mountain ranges) with steep slopes, intense rainstorms, and, in some regions, frequent earthquakes, causes a high amount of mass movement, which eventually finds its way into rivers as heavy sediment load.

In the mountains, climate change and environmental degradation have started showing some profound impacts. Mountain regions from the Andes to the Himalayas are warming faster than the global average under climate change.

Climate change is a threat multiplier for instability in fragile Himalayan regions as well. This has led to most glaciers in the mountainous regions such as the Himalayas to recede during the last century and influence stream run-off of Himalayan Rivers.

Himalayan glaciers have been in a general state of recession since a long time. As per the report "Snow and Glaciers of the Himalayas: Inventory and Monitoring" released by the Ministry of Environment and Forests (MOEF) in 2011, out of 2700 glaciers which are monitored, 2184 are retreating, 435 are advancing and 148 glaciers show no change. Existing studies of Himalayan glaciers indicate that many have exhibited an increased receding trend over the past few decades.

Regular monitoring of Himalayan glaciers is important for improving our knowledge of glacier response to climate change. The widespread glacial retreat in the Himalayas has resulted in the formation of many glacial lakes. Glacier retreat and shrinking could form dangerous moraine lakes whose breaching may generate floods.

by the steep orography of the region. The clouds get vertically lifted and these convective clouds can extend up to the height of 15 kilometres above the ground. This process is called the "cumulonimbus convection condition" which results in formation of towering vertical dense clouds. The lifting is usually dynamic and this causes thermodynamic instability resulting in rapid condensation.

It is also believed that in the Himalayan region, the clouds which are being lifted rapidly are also accompanied by soil moistened by earlier precipitation. This soil perhaps acts as an additional source of moisture and might also have a role in the frequent cloudbursts in the region. Cloudbursts are more frequent during the monsoon season.

A number of cloudburst incidents have been reported during the last few years. These incidents have caused huge loss of lives and properties as given in the table.

In view of increasing frequency of cloudburst events, demarcation of sensitive areas that are prone to cloudburst is very much required. Areas that are highly populated have steep slopes and fall in the landslide-prone zone require special attention. No construction should be allowed in the zones where flow from such areas converges or that are close to river banks.

Threat from Glacial Lakes

A glacial lake is a water mass existing in a sufficient amount and extending with a free surface in, under, beside, and/or in front of a glacier and originating from glacier activities and/or retreating processes of a glacier. Triggering events for an outburst can be moraine failures induced by an earthquake, by the decrease of permafrost (permanently frozen ground) and increased water pressure, or a rock or snow avalanche slumping into the lake causing an overflow.

The dominant triggering mechanism of a Glacial Lake Outburst Flood (GLOF) event depends on the nature of the damming materials, the position of the lake, volume of the water, the nature and position of the associated mother

A glacial lake (left) and a glacial lake outburst flood (right)

Date	Cause of flood/Place	Extent of Loss
August 15, 1997	Cloudburst in Chirgaon in Shimla district, Himachal Pradesh	1500 people killed.
August 17, 1998	A massive landslide following heavy rain and a cloudburst at Malpa village	Killed 250 people including 60 Kailash Mansarovar pilgrims in Kali valley of the Kumaon division, Uttarakhand.
July 16, 2003	Flash floods caused by a cloudburst at Shilagarh in Gursa area of Kullu, Himachal Pradesh	About 40 persons killed.
July 6, 2004	Heavy landslides triggered by a cloudburst in Alaknanda river basin	At least 17 people killed and 28 injured when three vehicles were swept into the Alaknanda river by heavy landslides triggered by a cloudburst that left nearly 5,000 pilgrims stranded near Badrinath shrine area in Chamoli district, Uttarakhand.
August 16, 2007	Cloudburst occurred in Bhavi village in Ghanvi, Himachal Pradesh	52 people confirmed dead.
August 7, 2009	Landslide resulting from a cloudburst in Nachni area near Munsiyari in Pithoragarh district of Uttarakhand	38 people killed.
August 6, 2010	Leh town of Ladakh region in Jammu and Kashmir	Series of cloudbursts left over 1000 persons dead (updated number) and over 400 injured
September 15, 2010	Cloudburst in Almora in Uttrakhand	Drowned away two villages one of them being Balta, leaving a few people alive and the rest entire village dead and drowned. Almora has been declared as a town suffering from the brunt of cloudburst by authorities of Uttarakhand. Had there been a bit more swaying of clouds, the town of Ranikhet must have drowned also.
June 9, 2011	Cloudbursts near Jammu	Left 4 persons dead and over several injured in Doda-Batote highway, 135 km from Jammu. Two restaurants and many shops were washed away.
20 July 2011	Cloudburst in upper Manali	18 km away from Manali town in Himachal Pradesh state left 2 dead and 22 missing
14 September, 2012	Cloudburst in Rudraprayag district	39 people died.

Source: Wikipedia

glacier, physical and topographical conditions, and other physical conditions of the surroundings. Interaction between the processes linked to the above factors may strongly increase the vulnerability of the glacial lakes to GLOF hazard.

The most significant chain reaction in this context is probably the danger from ice avalanches, debris flows, rock fall or landslides reaching a lake and thus provoking a lake outburst. Only Moraine Dammed Lakes, Ice Dammed Lakes and Ice-cored Dammed Lakes are considered to be vulnerable from the GLOF point of view.

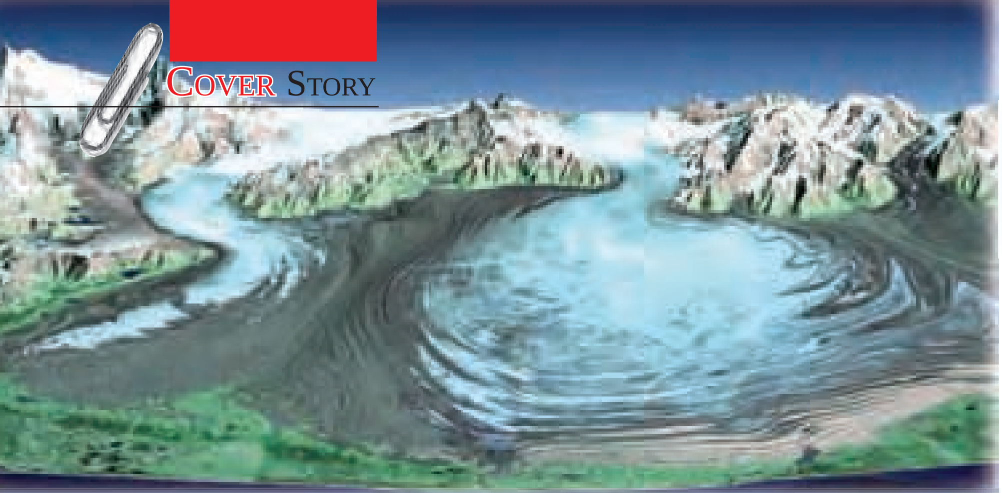
Usually the lakes at risk are situated in remote and often inaccessible areas. To assess the possible hazards from glacial lakes, it is essential to have a systematic inventory of such lakes formed at high altitudes. Remote sensing makes it possible to investigate simultaneously a large number of glaciers and glacial lakes in the inaccessible mountain regions. However, high quality remote sensing images are difficult to obtain for mountain regions due to cloud cover during the monsoon season and snow cover during winters.

Besides making a temporal inventory, a repeat monitoring of these lakes is also required to assess the change in their nature and aerial extent. But sole reliance on remote sensing data is inadequate as it cannot furnish the necessary repeat bathymetric information (underground depth of water), changes in the height of the damming moraine, or changes in lake level, which are also needed. Reliable determination of glacial lake instability will require detailed glaciological and geotechnical in-situ field investigation.

Since the beginning of the last century, the number of glacial lake outburst floods (GLOFs) has increased in the Himalayas. Studies have shown that the risk of lake development is highest where the glaciers have a low slope angle and a low flow velocity or are stagnant. The potentially dangerous lakes can be identified based on the condition of lakes, dams, associated mother glaciers, and topographic features around the lakes and glaciers. The criteria used to identify these lakes are based on field observations, processes and records of past events, geomorphological and geo-technical characteristics of the lake and surroundings, and other physical conditions.

Identification can also be done based on the condition of lakes, dams, associated glaciers, and topographic features around the lakes and glaciers. The Kathmandu-based International Centre for Integrated Mountain Development (ICIMOD) reports that 20 glacial lakes in Nepal and 24 in Bhutan have become potentially dangerous as a result of climate change. As per the ICIMOD report, no glacial lake in Uttarakhand Himalaya is vulnerable; however, there are 14 lakes in Tista river basin and 16 lakes in Himachal Pradesh which are potentially dangerous.

A number of studies pertaining to GLOFs have been carried out at the National Institute of Hydrology, Roorkee,



Satellite image of a glacier (left)
Glacier lake outburst floods can damage buildings and infrastructure (left below)

for river basins of Tista, Dhauli Ganga (Garhwal Himalaya), Twang (Arunachal Pradesh) and Bhutan. As per these studies, as such no lake is potentially dangerous in Dhauli Ganga whereas some lakes are vulnerable in Bhutan, Tista and Twang basins.

Breaching and the instantaneous discharge of water from glacial lakes can cause flash floods which are big enough to create enormous damage in the downstream areas. Different types of lakes may have different levels of hazard potential. For instance, moraine dammed lakes located at the snout of a glacier have high probability of breaching and thus may have high hazard potential whereas erosion lakes have little chances of breaching and thus have low hazard potential.

These floods pose severe geomorphological hazards and can wreak havoc on all manmade structures located along their path. Much of the damage created during GLOF events is associated with large amounts of debris that accompany the floodwaters. GLOF events have resulted in many deaths, as well as the destruction of houses, bridges, entire fields, forests, and roads. Unrecoverable damage to settlements and farmland can take place at large distances from the outburst source. In most of the events livelihoods are disturbed for long periods.

This is what happened in the recent Uttarakhand disaster – devastation all around.

Containing the Damage

Damages by disasters triggered by cloudburst or GLOFs can be considerably reduced by forecasts and early warning systems. It appears that in the Kedarnath incident, a time lapse of at least a few hours was available between the initiation of intense rainfall and the time floods hit the Kedarnath area. If warning about intense rain or incoming flood were available, a large number of lives could have been saved. It appears that the India Meteorological Department had indeed issued forecasts but nobody acted on these warning in time.

Clearly, there is a disconnect between scientific information and its use in decision making. It, therefore, becomes necessary to establish active links between disaster forecasting institutes and administration.

What needs to be done? A number of steps are needed to reduce the damage due to natural disasters in the Himalayan region. First, the areas likely to be impacted by different types of disasters like intense rainfall, earthquake and GLOF need to be identified. The mountains may face landslides, lake overflows, movement of moraines, activation of dormant river channels, and so on. As water, boulders, and debris move downstream, they have potential to cause damage and, therefore, it would be necessary to identify the areas which are likely to be impacted by extreme events of different magnitudes.

The events of June 2013 have shown that extreme rainfall can indeed occur over a large geographical area and so the cumulative impact of flooding in various tributaries on a downstream location needs to be considered. Another notable aspect of the June 2013 event was that intense rainfall is not confined to the monsoon season and one has to be vigilant all the time.

There are other areas in the Himalayas that are at risk of such events. Therefore, mapping of and monitoring of glacial lakes and landslide prone areas is urgently required. There is a need to prepare comprehensive reports of the entire Himalayan region for better planning and management of these kinds of disasters. There is need for Flood Forecasting and Early Warning System in the Himalayan region so that timely actions can be taken to avoid such types of disasters.

Water engineers are aware of the fact that extreme events can indeed be large; this is known as the "Noah effect". Hence, one need not panic at such events. While nature's fury cannot be completely controlled, its impacts can certainly be moderated if principles of hydro-ecology and engineering are carefully employed in planning and design of infrastructure and disaster preparedness.

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