Chamoli Valley Flood and its Impact on Hydro-Power Projects in The Uttrakhand

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ABSTRACT

The 2021 Chamoli Valley flood began on 7 February 2021 in the environs of the Nanda Devi National Park, a UNESCO World Heritage Site in the outer Garhwal Himalayas in Uttarakhand state, India. It is believed to have been caused by a landslide, an avalanche or a glacial lake outburst flood. It has caused flooding in the Chamoli district, most notably in the Rishiganga river, the Dhauliganga river, and in turn the Alaknanda – the major headstream of the Ganges. According to some reports, the flooding may have been caused by a portion of the Nanda Devi glacier breaking off early on 7 February,2021, releasing the water trapped behind the ice, and perhaps causing a glacial lake outburst flood. Whatever be the cause, it resulted in loss of life and damaged several bridges, barrages and hydro-power works in the valley

In the present paper, Authors have studied the probable cause of the flood disaster with the help of satellite imageries and other sources. Impact of the flood on hydro-power development in the state has been discussed with figures and photographs.

Keywords *: Glacier, Land slide, Flood, hydro-power, sedimentation,*

1. INTRODUCTION

The Feb-2021 flood event took place in the Tapovan area of Joshimath in Chamoli District, Uttarakhand State. The region consists of high mountain ranges with steep topography including the second highest peak in India, Nanda Devi, located at an elevation 7816 meter above sea level (masl) as shown in Fig. 1(a). The mountain ranges are made up of high grade metamorphic and volcanic rocks. The Lower Himalayan range in the south is composed of sedimentary and low-grade metamorphic rocks. The Chamoli flood occurred in an area about 60 km northeast of Kedarnath valley, Uttarakhand, where a devastating flash flood occurred in the year 2013.

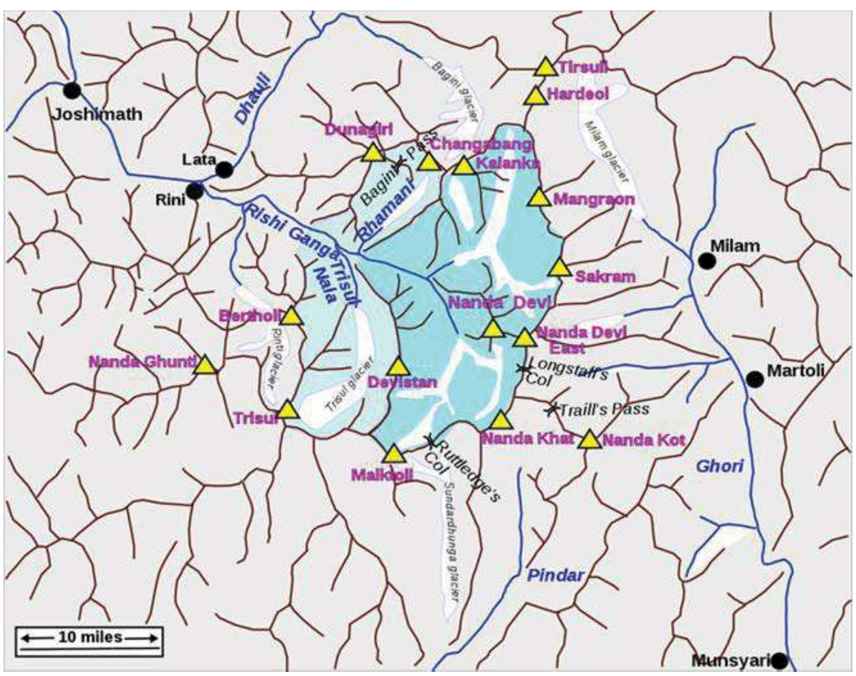

Fig. 1(a) : Location map of River System: Ronti Gad, Rishi Ganga and Dhauliganga Rivers

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The Chamoli flood took place on the Rishi Ganga River on the northern side of Nanda Ghumti peak at 7050 masl. The Rishi Ganga is a tributary of the Dhauliganga River, which originates from the Raikhana Glacier at 5375 masl to the north and meets the Alaknanda River further downstream. This high-altitude area consists of glaciers and snow peaks which melt during the spring and summer season and provides melt water to downstream areas. Because of the perennial sources of water and steep topography, a number of hydro-power projects have been constructed or under construction and many more are proposed to be constructed in the area across many of the tributaries as shown in Fig.1(b).

2. PROBABLE CAUSES OF CHAMOLI FLOOD

Exact cause of the Chamoli flood during 7-8 Feb.2021 is still under investigation. However, some of the factors which triggered the event are discussed underneath.

2.1 Climatic Factors

Uttarakhand flood began on 7 February 2021 in the environs of the Nanda Devi National Park, a UNESCO World Heritage Site, in the outer Garhwal Himalayas in Uttarakhand state where the average minimum temperature in the area falls below zero degree (Fig.2a). There is a steady rise in maximum temperature in the area (Fig. 2b) over the years (1980-2019) due to global warming. Also, the area is subjected to high rainfall (Fig.3) in February and July. It is believed these climatic factors caused landslide, avalanche or a glacial lake outburst flood (GLOF), resulting in flooding of Chamoli district, most notably in the Rishiganga River, the Dhauliganga River, and in turn the Alaknanda–the major headstream of the Ganges. The disaster struck Uttarakhand's Chamoli district on February 7, 2021 in the form of an avalanche and deluge, after a portion of the Nanda Devi glacier broke off. The sudden flood in the middle of the day in the Dhauli Ganga, Rishi Ganga and Alaknanda rivers – all intricately linked tributaries of the Ganga – caused widespread panic and large-scale devastation in this high mountain areas.

A large ice avalanche was previously released somewhere between 19 September and 9 October 2016 (Fig.4), which caused deposition of ice ~1.5 * 107 m3 and bedrock in the valley below. The resulting destabilization of the rock due to the lack of ice cover, glacial debuttressing, stress-release fracturing and increased exposure to solar radiation. Hence an increased freeze thaw cycle, in combination with a large snowfall event, preceding the event of 7 February 2021 and rapid melt water production, may have favored the fracturing of rock. This can, however, not explain the depth of the fracture (~150 m), which must have evolved over a longer period of time. Fracture zones at the runout of the rockslide visible before

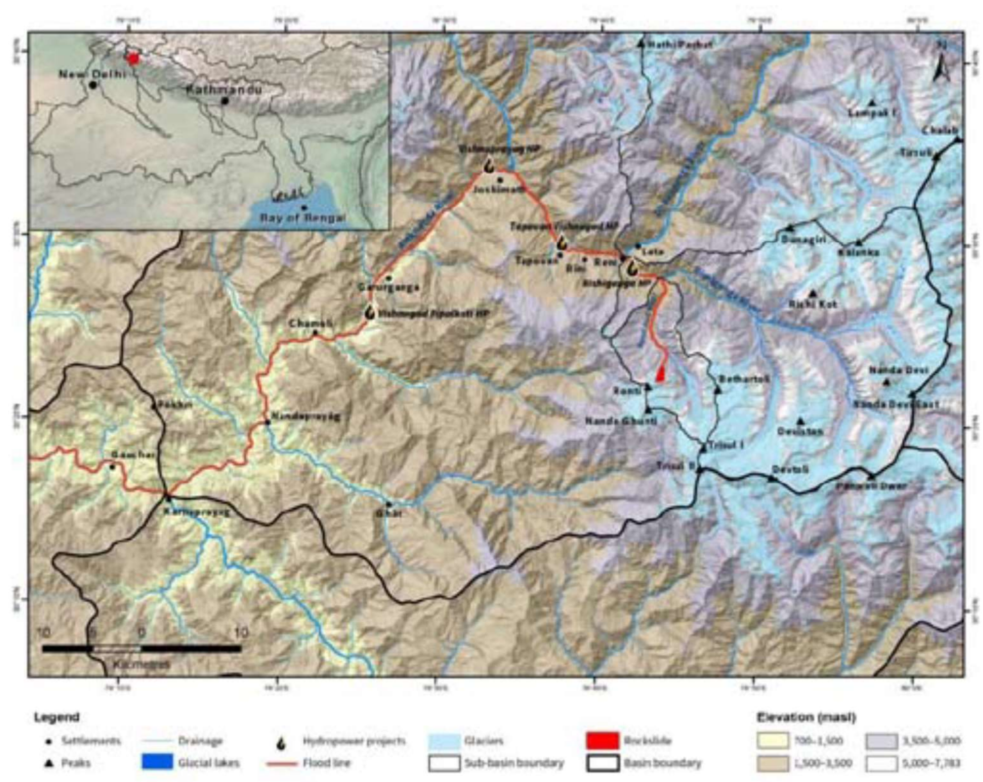


Fig. 1(b) : Rockslide origin, flood path, Hydro-Power Plant Sites etc.

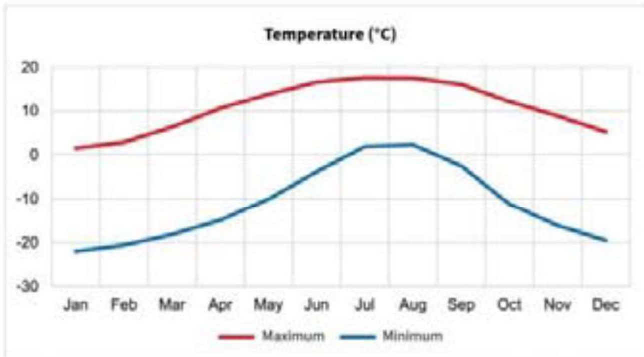


Fig. 2(a) : Average monthly temperature

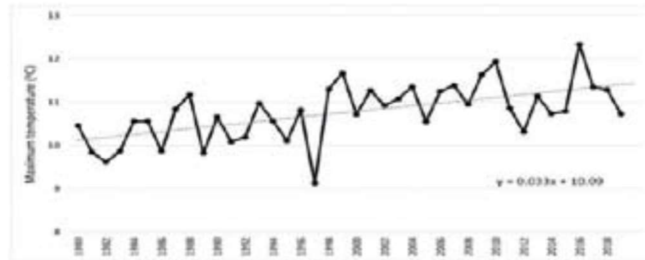


Fig. 2(b) : Maximum temperature trends in the Chamoli area (Data source: ERA5 reanalysis data, 1980-2019).

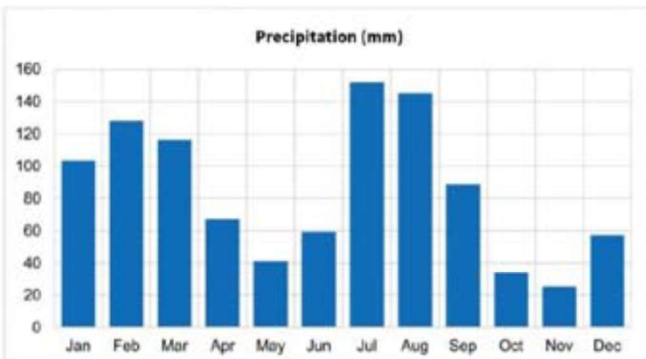
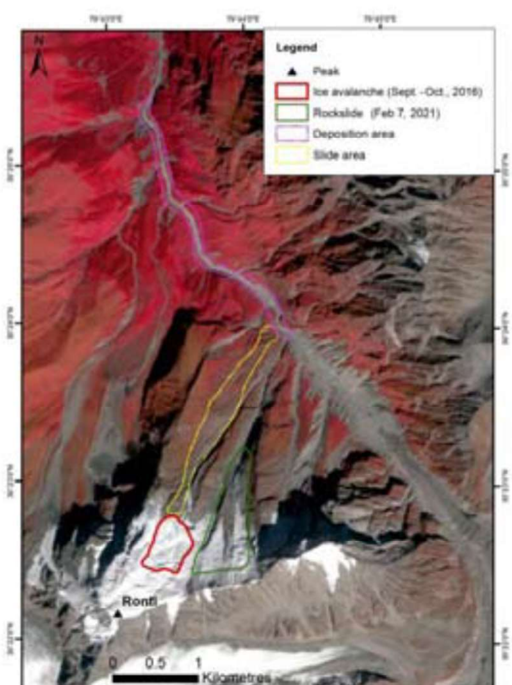


Fig. 3 : Average monthly precipitation of the area (1980-2019). Data source: ERA5 reanalysis

the event suggest that such detachments have happened at the same location previously too. Permafrost thaw and frost cracking has been used to explain increased rockfall activity in the Alps (Deline et al. 2014); (Gruber and Haeberli 2007); however, that generally applies for the first ~10 m of bedrock only.

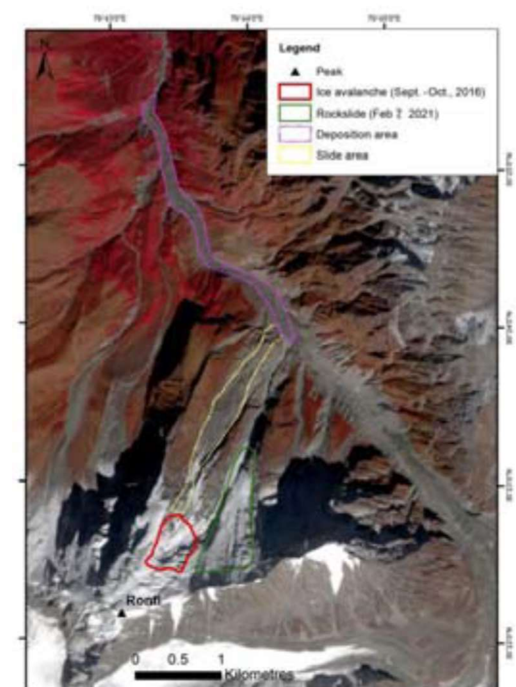
2.2 Glacial Outburst

According to glaciology and hydrology department of IIT-Indore, "Glacial bursts are very rare. Satellite and Google Earth images do not show any glacial lake; but there is possibility of water pockets and lakes inside the glaciers in the region. A water pocket may have erupted leading



Pre-event sentinel MSI image - 19 September, 2016

Fig. 4(a) : The ice avalanche breakoff between 19 September 2016



Post-event sentinel MSI image - 9 October, 2016

Fig. 4(b) 9 October 2016 (solid red outline on top) with the area covered by resulting deposits along the Ronti Gad River valley (dotted pink line) and flow surface (dotted yellow line). The green outline shows the present rockslide scarp in Feb.2021.

to the event of Feb.7-8, 2021. But more data and further analysis is needed to arrive at a conclusion.

The meteorological department,Govt. of India, reported sunny weather for February 6-7 around the disaster site. Though avalanches are common in the Himalayas, such an occurrence alone is unlikely to have caused the sudden and alarming rise in water levels in Alaknanda's tributaries. Featuring satellite images captured before and after the catastrophe, Prof. Dan Shugar (Refer twitter) associate professor with the department of geosciences at Canada's University of Calgary, twitted that a portion of the glacier might have fallen after it was struck by a massive rockfall.

2.3 Crack Formation in Rock Mass

At roughly 5,600 masl, a crack had formed on the side of the mountain. Researchers monitored sattelite images to investigate the cause of landslide; but it is difficult to conclude. Crack can be seen in Fig. 5(a) in a satellite image of the peak, which was captured on 2 February - five days before the disaster. The horizontal line of the crack is much more visible when the satellite is zoomed in, as shown in Fig.5 (b). Using satellite imageries, it was possible to see that the crack had been developing for some time - with evidence of the first crack visible in the satellite image from 1 January 2020. Scientists believe it was this crack that further increased causing an enormous block of Scientists believe it was this crack that further increased causing an enormous block of rock and ice to fall into the valley on 7 February. It is estimated that the block was over 2 million cubic metres in size and fell nearly 2 kilometers, almost vertically, before impinging on the valley floor. The graphic shown in Fig.6(a) shows the path the rock fall and the distance it travelled (in red line). As it rolled down the valley, the mass of fragmented rock ploughed through an ice deposit leftover from a previous (2016) avalanche in the area, leaving a trail of dust in its path shown in Fig.6(b).

2.4 Heat Generation/ Melting of Snow

As mentioned, the block fell 1800 metres (from 5600 to 3800 masl) into the valley below. Dr Scott Watson, (Anon n.d., 2021), COMET, University of Leeds, believes that the mass of rock and ice ploughed through a deposit of rock and ice from a previous avalanche in 2016 triggering landslide with a huge trail of dust as it travelled down the valley generating immense heat and melting of ice illustrated in Fig.6 (a) and 6(b)

(a)

(b)

Fig. 5 : Close-up View of the Crack Propagating in The Mountain (Pic: SentinelHub)

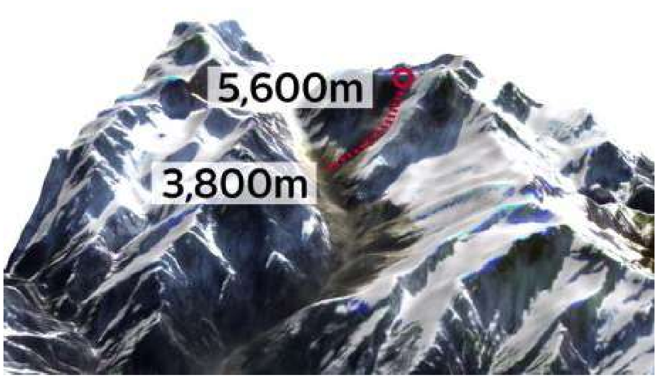


Fig. 6(a) : Rock/Ice mass Fall Hilltop to Valley

Fig. 6(b) : Huge trail of dust (red)in the Valley (Satellite Image: Dr Scott Watson, COMET, University of Leeds)

Dr. Scott Watson(Anon n.d.,2021) observed "It was probably moving very fast. On the way it scooped up ice and rock debris from the valley floor". Professor Dave Petley of Sheffield University concluded "The ice was melted by the heat from the rock avalanche and it changed into a debris flow. This scooped up water and sediment from the valley as it reached lower elevations. It was this huge flow that hit the dam sites". Professor Petley (Anon n.d.2021) was one of the first scientists to analyse the satellite imagery of the area in the following days, which was provided by Planet Labs. The colossal wall of water, rock and ice ploughed through the Rishiganga power project (near Raini village), washing it away completely.

2.5 Glacial Lake Outburst Flood (GLOF)

Initial suggestions were that a glacial lake outburst flood (GLOF) must have burst causing high floods in the streams. Some media outlets even called it a “glacier burst”, a term not recognized by the scientific community. As the upstream areas from the location of the first videos were investigated, it became clear that no lakes were present in the catchment prior to the event. The first high resolution images (taken by coincidence just as the debris flow passed the valley) were available, approximately 7 hours after the event. It was clear that an avalanche, landslide or rockfall had happened approximately 22 km upstream of the hydropower site, just below Ronti peak in the Nanda Devi massif. The location of the source was clearly identifiable from the imagery (Figure 4) while no other source (flood paths, emptied lake, or avalanche scour) could be identified.

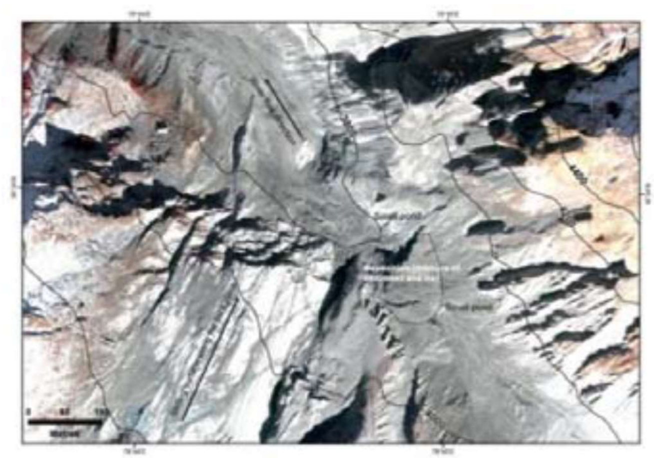
3. ANALYSIS OF ROCKFALL /HEAT GENERATION AND SNOWMELT

Figure 7 gives a 3D view of the origin of the rockslide and the debris flow captured on a satellite image at 10:30 IST,on Feb.7th just before it reached the Tapovan Hydropower Project site. Ash color area in Fig.6 (a) shows the sediment deposited in the valley and adjacent slopes of the river valley. The released zone of the rockslide is marked in red.Fig.6(b) indicates damaged Tapovan barrage in the valley overtopped by water and incoming sediments.

Based on available imagery and relying on published data, an approximate calculation of the mass movements was made. It was found that a crack had formed prior to the event at the site where the rock detachment took place followed by a rockslide. This failure eventually propagated along a 550 m wide crest starting at an elevation of 5500 masl reaching down to nearly 3900 masl.). Pre- and post-event models suggests that the scarp left by the rockslide is 150 m deep, 100 m wide on an average and consists largely of rock and relatively little ice. It is 39° steep, 1060 m long and has an area of ~3,50,000 m2 resulting in an approximate volume of 22 M m3, which corresponds with the DEM differencing that puts it at 25 mio m. Relying on modeled glacier thickness (21 to 25 m) for the three glacierettes in the inventory, which corresponds to typical heights of such hanging glaciers (Farinotti et al. 2019), it is estimated that the rock fraction is 85% and ice 15% with a total mass of ~52 * 109 kg. With a straight slide line of 1.6 km (5500 to 3900 masl), this results in total potential energy of 8.24 * 1014 J. The potential energy (due to fall) is converted to kinetic energy during the fall and dissipatedenough heat (due to friction) to melt 2.7 * 106 m3 of ice (with 335 kJ per kg of ice necessary at 0 °C). Considering that not all the mass was converted into energy during the fall, this number is likely on lower side (Huggel et al. 2005) As Huggel argues and conclusively shown in experiments (Arakawa 1999) and for a large co-seismic event (Eberhart-Phillips et al. 2003) fluidization can also happen simply from a very

(a)

Fig. 7(a) : Three Dimentional View of (a) Rock Slide Near Tapovan H.E. Project



(b)

Fig. 7(b) : Damage to Barrage due to overtopping water and debris flowing in valley large impact on present ice, which might possibly took place in the present case.

During an ice avalanche in 2016, a volume of ~7.2 * 10^6 m^3 of ice was dislodged to the west of the current rockslide in 2021, taking bed rock with it along the way, resulting in a mixed ice-debris deposit of ~1.5 * 10^7 m^3. Sentinel-2 Imagery from 2 December 2020, when the area was not snow covered yet, shows that a large part of this deposit was still present in the valley below where the event took place on 7 February 2021 . In a similar case in Langtang Valley in Nepal, a co-seismic avalanche resulted in a large compound deposit of ice, snow, and debris. As debris settles on top during the fall, ice was protected from melt by a debris layer of several metres thickness (Fujita et al. 2017), Kargel et al. 2016). A big part of the ice body is still present in Langtang in Nepl even today, nearly 6 years later.

As some of this ice body was still present just after the event below Ronti peak in 2021, it may be concluded that a fraction of this previous deposit (< 7.2 * 106 m3), was fluidized by the available energy. There are also reports from observers of the event of a pungent smell, suggesting water-saturated sediments were mobilised and added to the fluid content of the debris flow. Locations of 2016 and 2021 events are shown in Fig.7.

4. IMPACT OF CHAMOLI FLOOD

Chamoli flood on Feb.7-8 had several impacts as mentioned below. Its highest impact, however, was on the several hydro projects under construction as well as the future projects planned in the area.

4.1 Impact on Delhi

Flash floods in Chamoli increased turbidity of raw water fetched by Delhi from Upper Ganga Canal to "unprecedented levels", which affected water supply in many parts of the national capital as reported by sh. Raghav Chadha , vice chairman, Delhi Jal board..

4.2 Flood impact on Chardham road project

The deluge of pictures of the glacier burst in Chamoli raised fresh troubles for the ongoing Char Dham road project for easy access to Hindu shrines at Kedarnath, Badrinath, Gangotri and Yamunotri. The project is interlinked with 53 road projects in Uttarakhand at a cost of Rs. 12,072 crore meant for improving connectivity, pilgrimage and tourism in the state of Uttarakhand. While about 50 per cent of the project has been completed, the difficult part demanding most of the money for new roads and widening of roads adjoining glaciers and landslide-prone zones up in the hills are yet to be constructed. In 2013 flash flood in Kedarnath valley,Kedarnath Shrine was damaged. Sri Sri Shankaracharya who saved Hinduism from spread of Buddhism in India, breathed his last at Kedarnath. Every year large numbers of Hindu devotees congregate and visit Chardham . A temple built in memory of Sri Sri Shankaracharya (adjoining Kedarnath shrine), was washed out in 2013 flood.

4.3 Hydropower Projects Face Public Anger after Uttarakhand Flood Tragedy

The flash flood has raised public anger over hydropower projects that the government considers essential to decarbonize the nation's electricity generation. Experts say the event, induced by the effect of global warming on melting glaciers, was made worse by construction of infrastructures like roads and hydro-power plants.

´Hydropower projects, which use large-scale blasting, tree felling and tunneling, most certainly added to the proportion of the impact. They are a force multiplier in the destruction." said Himanshu Thakkar, coordinator of the New Delhi-based South Asia Network on Dams, Rivers and People (Anon n.d. 2021), which studies the social and environmental impact of water-related projects in India.

4.3.1 *Fate of NTPC's Tapovan Hydro-Power Project Hangs in Balance*

Details of Hydro-power projects damaged due to Chamoli flood are given in Table 1

Table 1 : Hydr-Power Projects Damaged in Chamoli Flood

S N	Name	(Latitude/ longitude)	Capacity (status)
1	Rishi Ganga Hydropower Project	30.478 / 79.699	13.2 MW (Operational)
2	Tapovan Vishnugad Hydropower Project	30.493 /79.628	520 MW (Under construction)
3	Vishnuprayag Hydro Electric Project (Jaypee Group)	30.566 /79.547	400 MW (Operational)
4	Vishnugad Pipalkoti Hydro Electric Project	30.433 /79.424	444 MW (Under construction)

The fate of NTPC's 520-MW Tapovan-Vishnugad hydel project hangs in balance as India's largest power company is estimated to have suffered a loss of Rs 1,500 crore due to damage to their construction caused by the flash flood. The event and related avalanche made of debris flow/flood caused damage to four hydropower projects along the Rishi Ganga, Dhauliganga and Alaknanda river path. The Rishi Ganga Hydropower Project (13.2 MW) near Raini village, located 14 km downstream from the impact site, was the first to be hit by the debris after the rockslide. The unfinished Tapovan Vishnugad Hydropower Project (520 MW) , 8 km downsteam from Rishi Ganga Hydropower Project, was the second hydropower plant hit by the flood. The diversion dam of this run-of-the river type project faced massive damage from sedimentation and the dam was filled with debris, which can be seen in the remote sensing images taken before and after the event. Two power projects — NTPC's Tapovan-Vishnugad hydel project and the Rishi Ganga Hydel Project — were extensively damaged with scores of laborers trapped in tunnels as the waters came rushing in. At least 32 people were dead and over 190 missing. And the trail of destruction can be seen in Figs. 8, 9 and 10.

Fig. 8 : A view of the portion of the Rishi Ganga river ravaged by floods on February 7, 2021 (Photo: Reuters/Anushree Fadnavis)

Fig.10 : National Disaster Response Force (NDRF) and Indo Tibetan Border Police (ITBP) search for workers trapped in a tunnel in Tapovan area on February7- 8, 2021.

5. CONCLUSIONS

- Chamoli Floods occurred on 7-8 Feb. due to landslide triggered by detachment of massive rock from Nandadevi glacier from an elevation of 5600 to 3800 masl.
- Large amount of snow/mud/sediment/boulder/debris brought by the landslide caused aggradation of river bed and consequent rise in flood levels in the rivers Rishiganga and Dhauliganga and Alkananda-all tributaries of river Ganga.
- Due to steep slope of the terrain (S), heat generated in friction caused melting of snow and sudden increase in flow magnitude (Q), flow velocity (V) and stream power ($P = \gamma QS$) resulting in wash out of several bridges and barrages and damage to several hydel projects under operation/ construction in the valley.

Fig. 9 : Land Slides with Flood Water, Muds and Debris Flowing at Chamoli District in Uttarakhand, India on 7-8 Feb. 2021 (Pic: AP)

- The event had several impacts and will affect development projects e.g. Chardham road project and large numbers of hydro project planned for the development of tourism and connectivity.
- In the design of hydraulic structures e.g. bridge, barrages etc., planned in the slide prone areas like Uttarakhand, it is essential to take into account such extra ordinary rise in water level (like water hammer in closed conduit flow) due to impact of landslides and consequent aggradation and sudden rise in flood level (HFL) much higher than the normal design HFL corresponding to design HFL of a given return period.

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