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REVIEW

Sequential Damming Induced Winter Season Flash Flood in Uttarakhand Province of India

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ABSTRACT

204 persons were killed while two hydropower projects located in close proximity at Rishiganga (13.2 MW), and Tapoban (520 MW) were damaged in Dhauliganga flood of February 7, 2021 in the Indian Himalaya. This incidence occurred during the winter season when the discharge of the glacier fed rivers is minimal, and no rain was experienced in the region around the time of the flood. Despite discharge of the main river, Rishiganga, not involved in the flood due to damming upstream of its confluence with Raunthi Gadhera, based on field evidences massive volume of around 6 million cu m water involved in this flood is attributed to sequential intermittent damming at three different places; (i) Raunthi Gadhera was dammed first in its upper reaches, (ii) Rishiganga river was then dammed to the north of Murunna, and (iii) finally Dhauliganga river was dammed around Rini village to the upstream of its confluence with Rishiganga river. Lacking warning system only enhanced the flood-induced devastation. Legally binding disaster risk assessment regime, together with robust warning generation, and dissemination infrastructure are therefore recommended for all major infrastructure projects.

1. Introduction

Continuity of tectonic movements, evolutionary history, and geomorphic setup of the terrain, together with peculiar meteorological conditions make the Himalayan region vulnerable to a number of hazards.

Located in the central sector of the Himalaya to the west of Nepal (Figure 1), Uttarakhand province in India is routinely devastated by flash flood, flood, landslide, and cloudburst incidences (Table 1), particularly during the monsoon period (mid-June to mid-September) when the region experiences heavy precipitation due to SW monsoon.

These losses are often associated with localised heavy rainfall events, referred as cloudburst, that have registered a marked increase in the Himalayan region during the previous decade, and are often attributed to climate change [1-3]. Ensuing sudden increase in the discharge of streams sometimes results in flash flood conditions, and during the monsoon period of 2010, 2012, and 2013 Uttarakhand witnessed major devastation due to these [4]. Cloudburst is however not the only cause of flash floods, and the region has witnessed incidences wherein streams have been blocked by landslides, and subsequent release

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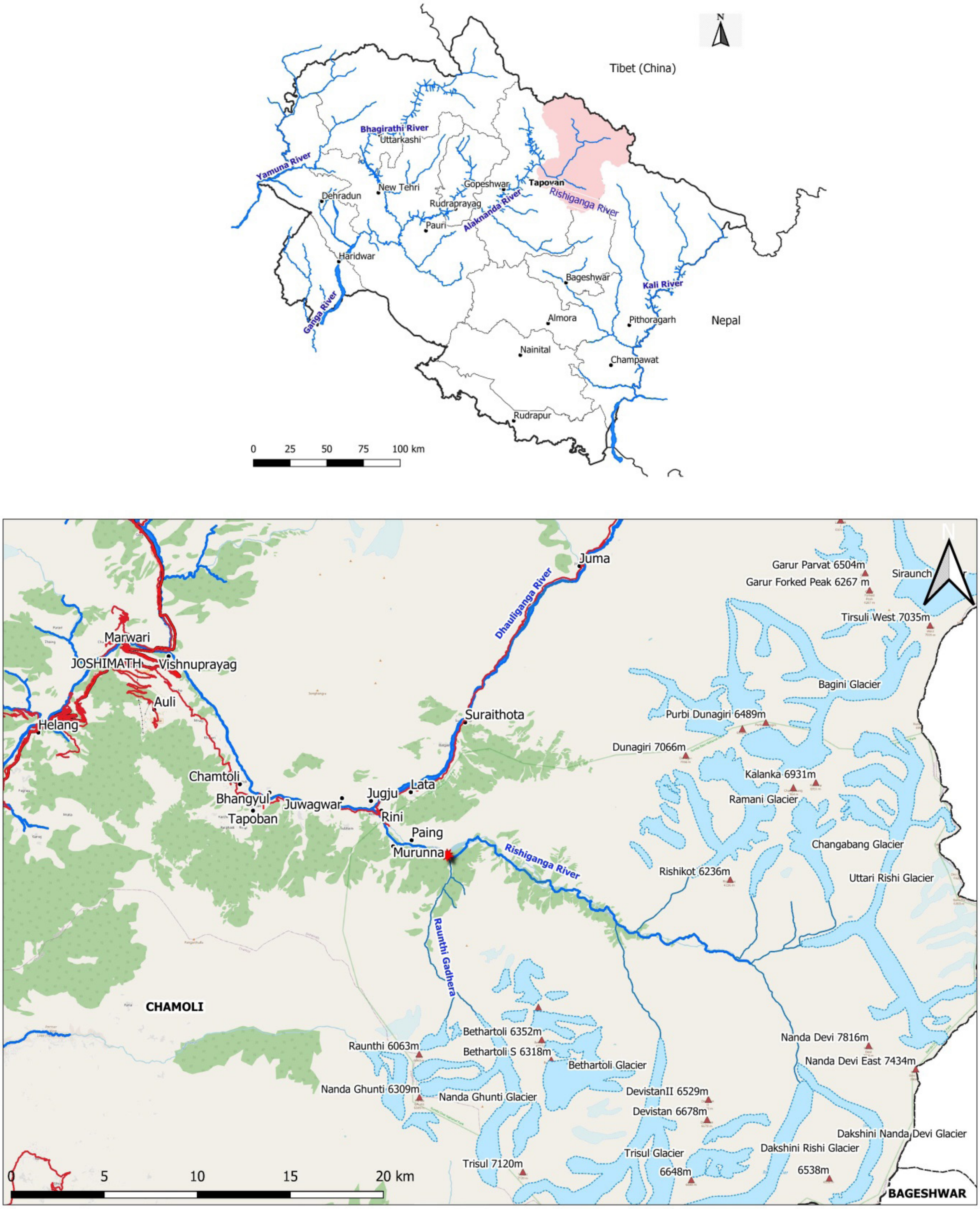

Figure 1. Map of Uttarakhand with Dhauliganga valley highlighted (above), and map of Dhauliganga valley (below).

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Table 1. Disaster induced losses in the Uttarakhand province in the period 2010-21.

Year	Human loss			Number of farm animals lost	Number of houses damaged / destroyed			Loss of Agriculture land (in ha)
	Dead	Missing	Injured		Partially	Severely	Fully	
2010	220	-	139	1,798	10,672	-	1,215	240.9
2011	83	-	71	876	5,814	-	514	806.4
2012	176	-	96	997	743	-	285	40.3
2013	225	4,021	238	11,268	11,938	3,001	2,295	1309.0
2014	66	-	66	371	1,260	278	342	1285.5
2015	55	-	64	3,717	1,313	125	81	15.5
2016	119	05	102	1,391	2,684	839	252	112.3
2017	84	27	66	1,020	1,067	434	101	21.0
2018	100	09	48	764	2,042	433	122	295.4
2019	102	02	78	1,323	571	64	300	238.8
2020	82	03	45	718	448	442	135	1087.1
2021	308	61	105	1,048	715	395	87	18.7
Total	1,620	4,123	1,118	25,291	39,267	6,011	5,729	5,470.9
Average	135	344	93	2,108	3,272	501	477	455.9

Data source: State Emergency Operations Centre (SEOC), Uttarakhand.

of impounded water has caused devastating flash floods (Table 2) [5]. These incidences are generally referred to as landslide lake outburst floods (LLOF).

Alaknanda river valley of Garhwal Himalaya has been particularly vulnerable to LLOFs, and 33% of the reported incidences are associated with Dhauliganga valley (Table 2).

2. Dhauliganga Flood of 2021

The discharge of Rishiganga, and Dhauliganga rivers in Chamoli district of Uttarakhand increased suddenly in the forenoon of February 7, 2021 and the floodwaters washed off a hydropower project of 13.2 MW capacity on Rishiganga river upstream of Rini while to the downstream, dam axis and other structures of an under construction hydropower project of 520 MW on Dhauliganga river at Tapoban were severely damaged (Figure 2). Persons working in these projects were washed off or buried in the debris. At the time of the incidence 30-35 persons were working in a tunnel at Tapoban that was chocked with debris, and these persons could not be rescued.

Even though agriculture is practiced over alluvial, and colluvial terraces on middle, and lower slopes of the valley, habitations in the region are traditionally located at higher elevations and these did not witness direct flood impact. Connectivity of surrounding 13 villages was however disrupted as six bridges were damaged by the floodwaters. Low lying agricultural fields were also damaged while 360 farm animals were lost in this incidence. 09 persons of the surrounding villages (05 of Rini, 02 of Tapoban, and 02 of Ringi) together with 02 personnel of state Police were amongst 204 persons that went missing.

There being no discharge measurement station in the catchment of Dhauliganga river, exact estimates of the flood volume are not available. A gauging station of Central Water Commission (CWC), 18 km downstream of Tapoban on the Alaknanda river at Marwari however recorded discharge of 1670 cumecs at 1100 hrs on February 7, 2021 as against normal discharge of around 41 cumecs. Around 6 million cu m water estimatedly passed through this gauging station in one hour. There being no rainfall, or accompanying flood incidence in the region entire excess discharge of the Alaknanda river at Marwari on February 7, 2021 is attributed to the flood incidence in Dhauliganga river valley.

Thick pile of fluvio-glacial sediments brought down by the floodwaters, were deposited all along the valley. According to the cross section measurements of the Alaknanda river by CWC at Marwari on February 10, 2021 the river bed was risen by 3.09 m. Thickness of the deposited sediments was observed to be more than 12 m at the dam site at Tapoban.

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Table 2. Landslide lake outburst flood incidences in Alaknanda river valley of Garhwal Himalaya.

Sl. No.	Date / year of blockade	Place of damming	Date of breach	Remarks
1.	1868	Alaknanda river blocked by landslide upstream of Chamoli [6]	1868 (Duration of impoundment not clear)	2 villages devastated. 70 persons killed
2.	1893	Birahiganga near its confluence with Alaknanda [7]	1893 (Duration of impoundment not clear)	Water impounded to 10-13 m above normal. 2 bridges damaged.
3.	September 6, 1893	Birahiganga river blocked by landslide forming Gohna Tal [8]	August 25, 1894 (Partial breach)	Landslide dam was 350 m high. Life loss averted by regular monitoring, warning Massive loss of property, and infrastructure
4.			July 12, 1970 (Final breach)	Massive loss of infrastructure, particularly at Srinagar
5.	1930	Alaknanda river blocked near Badrinath [9]	1930 (Duration of impoundment not clear)	Water impounded to 9 m above the normal water level Some houses damaged
6.	1957	Dhauligana river blocked near Bhapkund by an avalanche along Dronagiri river [9]	1957 (Duration of impoundment not clear)	The lake was later filled with debris
7.	February 4, 1968	Rishiganga river blocked by landslide near Rini [10,11]	July 20, 1970	Water impounded to 40 m above the normal water level Extensive damage in downstream areas
8.	September, 1969	Alaknanda river blocked partially upstream of Kaliasaur [11]	1969 (Duration of impoundment not clear)	
9.	July 20, 1970	Dhauliganga river blocked near Tapoban by the debris brought down by Dhak Nala [11]	July 20, 1970	Water impounded to 15-20 m above normal water level
10.	July 20, 1970	Alaknanda river blocked near Helang by the debris brought down by Karmanasa Nadi [11]	July 20, 1970	
11.	July 20, 1970	Alaknanda river blocked by landslide near Hanuman Chatti at Badrinath [10,11]	July 20, 1970	Water impounded to 30-60 m above the normal water level Breach caused considerable loss of life
12.	July 20, 1970	Patalganga river blocked by landslide [7,12]	July 20, 1970	Water impounded to 60 m above the normal water level Major flooding in Alaknanda river Belakuchi village washed off
13.	April, 1979	Alaknanda river blocked by avalanche near Bamni village in the proximity of Badrinath [13]	1979 (Duration of impoundment not clear)	The blockade was in the proximity of Badrinath and triggered by avalanche action
14.	2002	Gandhwi river blocked by landslide near Saigari village [14]	2002 (Duration of impoundment not clear)	Dhauliganga river was flooded by the breach, and Saigari village devastated
15.	February 7, 2021	Course of Raunthi Gadhera, Rishiganga and Dhauliganga blocked	February 7, 2021 (Impoundment was for short duration)	204 persons dead Major devastation to two hydropower projects at Rini, and Tapoban

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Figure 2. Devastation at the dam site of Dhauliganga hydropower project.

3. Initial Suggestions on the Cause of Flash Flood

According to an online report based on satellite imageries of Planet Lab, rock mass together with some ice got detached along a crack on the flank of Nanda Ghunti at an elevation of 5,600 m asl, and fell to 3,800 m asl initiating a rock and ice avalanche that travelled down the glacier generating vast quantity of dust, which was observed to be smeared to the west of the valley [15]. Energy generated by the impact of the free fall of huge rock mass and ice over almost 1,800 m was held responsible for quickly melting the snow and ice available in the area, and initiating a debris flow that rushed downslope to cause the devastation [15].

Based on the analysis of LISS-IV satellite data Uttarakhand Space Application Centre (USAC), Dehradun informed the provincial government on February 9, 2021 that a lake has come into existence along the course of the Rishiganaga river at a distance of around 06 km upstream of Rini due to the mass movement along Raunthi Gadhera. This report expressed possibility of breach of this lake that could jeopardize safety and security of the persons engaged in rescue work at Tapoban. Efforts were therefore made to assess the threat posed by the lake that breached naturally on February 12, 2021.

On February 10, 2021 Indian Institute of Remote Sensing (IIRS), Dehradun reported sudden disappearance of snow over almost 14 sq km area (Figures 3 and 4), and added that the avalanche triggering the event also involved melting of fresh snow over this area. Apart from the energy generated by the impact of the rock fall [15], presence of water was attributed to abnormal rise in temperature that was ascertained from the WRF model. Volume of water generated in this process was estimated as 2-3 million cu m.

Figure 3. Planet Lab satellite data of the area of February 7, 2021.

Source: Courtesy Dr. Prakash Chauhan, Director, IIRS.

Based on the analysis of Sentinel-2 satellite imageries of February 5 and 8, 2021 IIRS, Dehradun later assessed the volume of rock mass dislodged along a pre-existing crack on the flank of the western peak adjacent to Trishul glacier as 39.67 million cu m. This rock mass reportedly impacted the valley floor 1,456 m below, near the snout of Trishul glacier generating 1.51 X 10^{12} J energy that was assessed to have melted 4.5 million ton ice in 1.5 hours to initiate the flood event.

Figure 4. Planet Lab satellite data of the area of February 6, 2021.

Source: Courtesy Dr. Prakash Chauhan, Director, IIRS.

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Wadia Institute of Himalayan Geology (WIHG), Dehradun on February 10, 2021 expressed possibility of temporary blockade of the Raunthi Gadhera due to avalanche debris at an elevation of 3600 m asl for a few hours in the morning hours of February 7, 2021. Breach of this impoundment was put forth as being the cause of the flash flood.

Figure 5. View of the lake formed in Rishiganga river on February 11, 2021.

Source: Courtesy Dr. M.P.S. Bisht, Director, USAC.

International Centre for Integrated Mountain Development (ICIMOD), Kathmandu[16] as also unpublished report of the Glacier and Permafrost Hazards in Mountains (GAPHAZ), based on the analysis of satellite imageries brought forth evidence of an ice or rock/ice avalanche in the same area between September 19 and 26, 2016. Besides frictional melting and liquification of ice, these reports suggested possibility of reactivation of buried ice together with water trapped under and within the 2016 avalanche debris.

4. Methodology

The flood in the Dhauliganga river valley took place during the winter season when the discharge of glacier fed Himalayan streams and rivers is minimum. At the same time this incidence was not accompanied by major rainfall event. In such a situation pinpointing the source of the floodwaters was a major challenge and different reasons were thus put forward for explaining the flood incidence.

None of these reports convincingly explain the source of huge quantity of water required to initiate the flash flood. Moreover, Rishiganga river, with a catchment area of 664 sq km, being the main tributary of Dhauliganga river, was blocked by the debris brought down by the rock fall-avalanche along the Raunthi Gadhera (Figure 5). This implies that the flood resulting in additional discharge of 1,629 cumecs in the Alaknanda river was caused by the Raunthi Gadhera alone. It is not convincing if a small rivulet with catchment area of only 83 sq km could generate enough water to cause this massive flood.

As observed in different satellite imageries rock mass which is estimated as being 39.67 million cu m by IIRS, Dehradun got detached from a higher elevation with some ice mass. No report convincingly puts forth the proportion of ice in this rock mass. Moreover, for initiating a flash flood, melting has to be instantaneous. It is not convincing that frictional forces, and energy generated in the impact could instantaneously melt huge volume of ice to initiate this flood.

All available reports on this event are primarily based on satellite data and have no field evidences to supplement their assertions. Detailed fieldwork was therefore undertaken in the affected area to understand the mechanism of this flood event and convincingly reconstruct the sequence of events resulting in this massive flood incidence so as to suggest a strategy for minimising possibility of similar incidences in future.

Moreover, to validate the assertion of abnormal temperature increase rainfall and temperature data of various observation stations of India Meteorological Department (IMD) and Uttarakhand State Disaster Management Authority (USDMA) was assessed and analysed.

5. Field Observations

Dhauliganga river originates in the proximity of Niti pass, and flows SW till Rini where it has confluence with Rishiganga river which originates from the glaciers of Nanda Devi massif with Nanda Devi (7,817 m) being the highest peak, and flows NW. Originating from around Nanda Ghungti (6,309 m) and flowing N, Raunthi Gadhera is a major tributary of Rishiganga river. From Rini to Chamtoli (1.0 km downstream of Tapoban) Dhauliganga river maintains a tectonically controlled E-W course, and thereafter flows SE to meet the Alaknanda river at Vishnuprayag (Figure 1).

Dhauliganga valley has rugged mountainous topography with high relative relief, and the altitudes vary between 1,450 and 7,817 m asl. Geo-tectonically aligned narrow valleys and gorges are prominent geomorphic features of this area. In the upper stretches of the valley up to Bhapkund, where a hot spring is located, distinct

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glacial landforms with characteristic 'U' shaped valleys, outwash deposits, hanging valleys, moraines and cirques are observed. To the downstream, between Jelam and Juma the landforms are observed to be modified by fluvial action with distinct "V" shaped incised valleys and deep gorges. Thick pile of overburden, steep slopes and high precipitation make this stretch prone to mass wastage. Thereafter, Dhauliganga river is observed to flow through a wide valley till Rini, and the valley becomes relatively narrow to the downstream till Tapoban where another hot spring is located. Narrow valley is observed thereafter till Vishnuprayag.

Evidences of previous damming are observed on the left bank of Dhauliganga river on road section close to hot spring at Tapoban. These lacustrine deposits consist of an inter-bedded sequence of sand, silt, and pebbles (Figure 6).

Figure 6. Evidence of ponding on the left bank of Dhauliganga river in the proximity of hot water spring near Tapoban.

Distinct marks of inundation and fresh erosion are observed on both the valley walls of Dhauliganga river upstream of its confluence with Rishiganga river near Rini village at an altitude of 1,960 m asl, for about 1 km. From the impressions on the valley walls the level of the impounded water is assessed as being 3-4 m above the normal river level (Figure 7).

To the N of Murunna (Figure 1), Rishiganga river is observed to have constricted valley configuration. Fresh deposits of debris are observed at this site on both the banks. The inundation and erosion marks observed on the valley walls at this site suggest the floodwaters to have reached 40-50 m above the riverbed (Figure 8).

Upper catchment of Raunthi Gadhera, the source of the floodwaters, could not be approached. Rocky cliff is however observed along the right bank of Raunthi Gadhera while the left bank is covered with thick pile of overburden material. Huge volume of debris comprising of a mixture of ice blocks, rock fragments and morainic material consisting mainly of pebbles, cobbles, and boulders of quartzite, granitic gneiss and mica schist with silty-clayey matrix are observed in the lower slopes in the proximity of Rishiganga river. Fine dust is also observed on the valley walls as also over vegetation.

Figure 7. Erosion marks on the valley walls of Dhauliganga river near its confluence with Rishiganga river (above), and 1 km upstream along Dhauliganga river (below).

Figure 8. Erosion marks on the valley walls of Rishiganga river to the N of Murunna.

Evidences of previous damming are also observed on the right bank of Raunthi Gadhera upstream of its confluence with Rishiganga river. These lacustrine deposits are observed to consist of an inter-bedded sequence of sand, and pebbles (Figure 9).

Figure 9. Evidence of ponding on the right bank of Raunthi Gadhera near its confluence with Rishiganga river.

Around 500-700 meters upstream of the confluence of Rishiganga and Raunthi Gadhera blockade is observed on Rishiganga river. Huge volume of rock and debris material (Figure 5) dumped there is observed to be around 50 m high and 100 m wide. Presence of embedded ice blocks is also observed in this barrier. Upstream of this barrier a lake is observed on Rishiganga river along a deep gorge carved in very hard quartzitic rocks that have three sets of consistent joints.

6. Meteorological Parameters Preceding the Disaster

Flash flood requires large volume of water to overwhelm the downstream areas, and apart from breach of a lake, presence of water can generally be explained either by rainfall or melting of snow/ice. Meteorological parameters, particularly rainfall, and temperature, in the surrounding area in the period preceding the flash flood incidence are therefore reviewed.

Average precipitation in Uttarakhand during the winter season of 2020-21 was below normal, and except for November 2020 deficiency in average monthly rainfall in all the districts between September 2020, and February 2021 was between 34 and 99%. The precipitation in Chamoli district that houses Dhauliganga valley, as also around the affected area at Tapoban, and Auli (AWS sites of Uttarakhand State Disaster Management Authority) was also much less than normal for the district between September 2020, and February 2021. The affected area however received some precipitation on February 4 and 5, 2021 and higher reaches experienced snowfall that is observed in the satellite imagery of the area (Figure 4).

As inferred by IIRS, Dehradun from WRF model the area did actually witness sharp rise in the temperature on the very day of this incidence; between February 6 and 7, 2021 Tapoban at an altitude of 2,000 m asl experienced rise of 2.8^{o}C and 5.4^{o}C respectively in minimum, and maximum temperature while the rise at Auli (2,600 m asl) was observed to be 6.0^{o}C and 9.6 ^{o}C respectively.

7. Scenario Reconstruction

Geomorphic conditions in the Dhauliganga valley provide suitable conditions for river blockade and the same is testified by field evidences of damming at two places (Figures 6 and 9). Field evidences further reveal that the flash flood event of February 7, 2021 was accompanied by damming at three different places, besides the one upstream of the confluence of Raunthi Gadhera and Rishiganga river. This facilitated accumulation of enough water, despite discharge of Rishiganga river being cut off, and explains devastating flood during the lean flow season.

7.1 Damming of Raunthi Gadhera

The upper reaches of Raunthi Gadhera being snowbound could not be assessed during the fieldwork. However, authors in line with WIHG, Dehradun assert preliminary blockade in the upper catchment of Raunthi Gadhera by the rock and ice mass detached from a higher elevation, as also morainic deposits mobilized by the impact from the valley floor. The people of the surrounding villages reportedly heard sound of falling rocks around 0200 hrs on February 7, 2021. This is taken as the timing of the initial rock fall and creation of a rock fall-avalanche barrier along the course of Raunthi Gadhera at an altitude of around 3,600 m asl.

Moreover, the region witnessed precipitation on February 4 and 5, 2021 and fresh snow was present in the upper reaches of the catchment on February 6, 2021 (Figure 4). Sharp rise in temperature on the very day of this incidence facilitated fast melting of freshly accumulated snow as also detached ice mass (Figure 3), and this water accumulated upstream of the avalanche debris. As put forth by an unpublished report of GAPHAZ, buried ice and water trapped under and within the 2016 avalanche debris would have also added to this water.

As put forth by various reports another avalanche activity in the upper reaches of Raunthi Gadhera around 1015 hrs on February 7, 2021 resulted in breach of this impoundment. The water generated by frictional forces

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and impact of rock fall as suggested by various reports only added to the volume of the flood waters.

7.2 Lake on Rishiganga River

Breach of the avalanche dam in the upper reaches of Raunthi Gadhera resulted in sudden downslope gush of water along steep slope that transported huge volume of glacial material, ice and rock mass. This movement generated a plume of dust that is observed on the valley walls as also over vegetation.

This fast moving debris laden water eroded the valley slope on the left bank of Raunthi Gadhera and the eroded mass added to the debris material transported downstream. Large rounded chunks of ice transported by floodwaters were observed all along the valley slope after many days of the incidence which refute the hypothesis of instant melting of ice resulting in flash flood.

The fast moving and debris, ice and rock mass laden flow of Raunthi Gadhera smashed against the valley wall on the right bank of Rishiganga river (2315 m asl). High angular relationship of these streams caused flow deflection, which facilitated backflow along Rishiganga river and large volume of rock and debris material was transported upstream along Rishiganga river for about 500 - 700 m and dumped there (Figure 5). This barrier cut off discharge of Rishiganga river and the water draining down from Raunthi Gadhera alone flowed downstream along the course of Rishiganga river till February 12, 2021.

7.3 Intermittent Damming N of Murunna

Though the discharge of Rishiganga river was blocked by the debris barrier, the floodwaters of Raunthi Gadhera travelled downstream along the course of Rishiganga river. Field evidences suggest that the course of Rishiganga river was blocked again intermittently to the N of Murunna (Figure 1) by the debris being carried by the floodwaters. Constricted valley configuration at this site facilitated the damming (Figure 8). Deposits of debris are observed at this site on both the banks and evidences on the valley walls suggest that the impoundment was up to 40-50 m above the riverbed.

With discharge of Rishiganga river cut off, but for this impoundment the flood would not have been particularly devastating. It is this damming that ensured accumulation of enough water to devastate the downstream areas. With the breach of this barrier floodwaters rushed downstream washing away Rishiganga hydropower project upstream of Rini.

7.4 Intermittent Damming around Rini

Rishiganga river meets Dhauliganga river at almost right angles near Rini village at an altitude of 1,960 m asl. The floodwaters of Raunthi Gadhera travelling down the course of Rishiganga river along with huge amount of debris and rock mass hit the valley wall on the right bank of Dhauliganga river deflecting its flow, and causing deposition of debris to block the course of Dhauliganga river for a short duration. The evidences of impoundment of water are observed on the valley walls along the course of Dhauliganga river upto 1 km upstream of its confluence with Rishiganga river, and the level of the impounded water is assessed as being 3-4 m above the normal river level (Figure 7). It is this blockade that added huge volume of water, and its breach resulted in the devastation of downstream areas including the hydropower project at Tapoban.

8. Discussion and Way Forward

The frictional forces and impact of the rock avalanche facilitated melting of ice but it could not have instantaneously produced around 6 million cu m water. The assertion of instantaneous melting of ice is at the same time refuted by large chunks of ice observed in the debris material along the lower slopes of Raunthi Gadhera as also those enbedded in the debris barrier damming the Rishiganga river. Therefore, based on field evidences, the flood event of February 7, 2021 is attributed to sequential intermittent damming along the course of Raunthi Gadhera, Rishiganga, and Dhauliganga rivers.

Absence of warning infrastructure in the catchment resulted in massive loss of human lives as a simple water level recorder based warning system around the hydropower project on Rishiganga river would have averted loss of human lives at Tapoban. The following measures are therefore recommended to avert similar incidences in future.

8.1 Disaster Risk Assessment

It seems that the flood history of Dhauliganga river (Table 2) and evidences of previous damming (Figure 6, and 9) were ignored while planning the hydropower projects. Comprehensive inventory of previous disaster incidences is therefore recommended to establish the hazard profile of the area. Risk assessment should accordingly be undertaken and account for extreme events with long recurrence period. This should be a mandatory legal requirement for all major developmental projects in the Himalayan region. Putting these reports in public domain would either discourage the insurance companies from extending safety cover to the unsafe projects or force them to make premiums economically unviable. This in turn would ensure that only disaster safe projects are implemented in this hazard prone terrain.

8.2 Warning Generation and Dissemination

With present level of technical knowledge, instrumentation, and communication facilities warnings, particularly of hydro-meteorological events, can be easily generated and disseminated. A network of hydro-meteorological observatories with real time data transmission capability should thus be calibrated for this purpose to provide rainfall threshold based flood / flash flood and landslide warnings. Hydropower projects should be mandated to contribute data and resources towards this network.

Streams and rivers are generally dammed at places with favourable geomorphic configuration and these areas can be identified through dedicated geomorphic mapping. Appropriate monitoring infrastructure should be resorted to around these places for prompt mitigation measures in case of damming.

8.3 Diversification

Diversification of assets, though a risk reduction strategy, ensures equitable development of the region. In the present context two hydropower projects were located in close proximity, and both were damaged in the incidence. It is therefore suggested that as a policy measure, major infrastructure not be allowed to be concentrated in a particular area.

At present most investors desist from venturing into remote areas of the province, and are keen to invest in areas that are relatively developed in terms of basic infrastructure and facilities. To start with the state could create basic facilities and infrastructure in identified suitable parts of the state and the same could be an incentive for the investors to explore possibilities of setting up their venture in other areas. As a by-product, this exercise would ensure balanced development of the province.

8.4 Abnormal Meteorological Observations

The present incidence was accompanied by abnormal rise in temperature. It is therefore suggested that abnormal changes in meteorological parameters be taken note of seriously and correlated with possible triggering of some hazard prevalent in the proximity. Precautionary actions can also be initiated based on such observations. This exercise is sure to be futile in most instances but is certainly worth trying, as it could sometimes save human lives.

9. Conclusions

Though not conclusively attributed to climate change abnormal temperature rise contributed to this disaster in one way or the other, while sequential intermittent damming increased the devastating potential of the floodwaters. The possibility of recurrence of similar incidences gaining ground with climate change impacts becoming increasingly prominent, the region is to face scarcity of capital investment which in turn is to have adverse impact on the pace of growth and socio-economic development. With environmental groups already lined up to hold hydropower projects responsible for this disaster, the fate of hydropower as also other major infrastructure projects in the Himalayan region is sure to have long-term adverse implications.

In order to ensure disaster resilient, environment friendly, and holistic development of the region authors recommend (i) scientific documentation of previous catastrophic events, (ii) detailed, focused, and long-term studies for in depth assessment of risk posed by various hazards, with incorporation of climate change driven extreme events, (iii) implementation of a legally binding disaster risk assessment, and reduction regime, (iii) robust, reliable, and redundant warning generation, and dissemination infrastructure, and (v) policy for the diversification of assets.

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