Short Communication:

Causes of the triggering of Chamoli glacier burst of 7th February 2021 in Uttarakhand, India

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Abstract

The Himalaya, the youngest and the tallest folded mountain range of the world, is frequently affected by natural disasters.[18] In the form of flash floods, cloudbursts or glacial lake outburst floods, the entire Himalayan region is highly vulnerable to natural hazards[10].

In this context, the State of Uttarakhand of the Indian Himalayan Region has been the most vulnerable one among all the natural disaster-affected states in India.

Keywords: The Himalaya, Uttarakhand, Disasters.

Introduction

Indian Himalayan Region (IHR) is not an exception to disasters[1]. To name a few in the recent past are - cloud burst in Kullu district of Himachal Pradesh in August 2003; the earthquake of Jammu and Kashmir in October 2005; flood in Ladakh in August 2010; Sikkim earthquake in September 2011; floods in Jammu and Kashmir in September 2014 etc. All these disasters affected hundreds of lives and properties, causing havoc in the residing societies. Due to its geo-climatic, ecological and socioeconomic settings, Uttarakhand is one of the most disaster-prone States of the country.[17,23]

Consisting mostly of uplifted sedimentary and metamorphic rocks and tectonically very active, the region is very vulnerable to natural disasters. The tragedy of the Kedarnath cloud burst and a flash flood of 2013 has not been erased from our eyes, which took away thousands of lives and caused a huge monetary loss and now the Chamoli disaster of 7th February, 2021 shocked the whole country, putting everyone to think as to why such disasters have been happening in the Himalayas despite the development in the science and technology. The present study attempts to understand the Chamoli district's scenario where the glacier flood took place on 7th Feb. 2021. Some of the recent disasters in Uttarakhand in the past two decades are shown in table 1.

Table 1
Historical events of natural calamities in Uttarakhand[2,9-14]

Periods	District	River	Location	Event	Casualties
2001, 17 Aug.	Rudraprayag	Mandakini	Phata	Cloud burst	21
2002, 10 Aug.	Chamoli	Alaknanda	Budakedar	Landslide	28
2004, July	Chamoli	Alaknanda	Lambaghar	Landslide	16
2004, July	Uttarkashi	Yamuna	Kalandi	Landslide	6
2005, 30 June	Chamoli	Alaknanda	Govindghat	Cloud burst	11
2010, 12–13 August	Uttarkashi	Bhagirathi	Bhatawari	Landslide	167 house damage
2012, 3 August	Uttarkashi	Bhagirathi	Asi Ganga	Cloud burst	35
2012, 13 Sep.	Rudraprayag	Mandakini	Okhimath	Cloud burst	66
2013, 16–17 June	Chamoli	Alaknanda	Govindghat, Bhyundar	Heavy rain	106 casualties and more than 4,021 individuals got missing. 1,191 cattle and farm animals lost and more than 19,309 residential houses were damaged
	Rudraprayag	Mandakini	Shri Kedarnath, Rambara	Flash flood	
	Uttarkashi	Bhagirathi	Uttarkashi Dharali	Landslide	
2016, 28 May	Tehri Garhwal	Alaknanda, Bhagirathi	Kemra and Siliara, Kothiara, Tehri	Cloudbursts	100 animals were lost and 120 houses completely damaged
2016, 01 July	Pithoragarh	Ram Ganga	Didihat and Thal	Cloudbursts	In Bastari and Naulra villages, respectively, 19 and 3 persons were killed respectively
2017, 14 August	Pithoragarh	Kali	Mangti and Malpa, Dharachula	Cloudbursts	9 persons died while 18 persons went missing and 51 animals were lost
2019, 18 August	Uttarkashi	Bhagirathi	Mori tehsil	Cloudbursts	21 persons killed and 74 animals lost.

Study area

The present study area lies in the Chamoli district (Joshimath tehsil) along Rishi Ganga and Dhauli Ganga river basins located in the State of Uttarakhand, Central Himalaya (Figure 1). The basin is drained mostly by glacier-fed rivers, a premier being the Dhauli Ganga river, a major tributary of the Alaknanda river at Vishnuprayag. Rishi Ganga is the major sub-tributary of Dhauli Ganga which extends from longitude 79°45'24.037''E to 79°41'21.252''E and latitude 30°22'59.161''N to 30°29'14.85''N. The Dhauli Ganga river extends from longitude 79°46'46.697''E to 79°33'2.969''E and latitude 30°35'4.016''N to 30°33'58.096''N. The enduring flow of the river is attributable to its steep slopes, intensive monsoon precipitation and seasonal snowmelt, possessing great potential for hydropower generation. Major power stations lie in the study area i.e. National Thermal Power Corporation (NTPC), Tapovan on Dhauli Ganga river and Rishi Ganga Power Corporation Limited project on Rishi Ganga river.

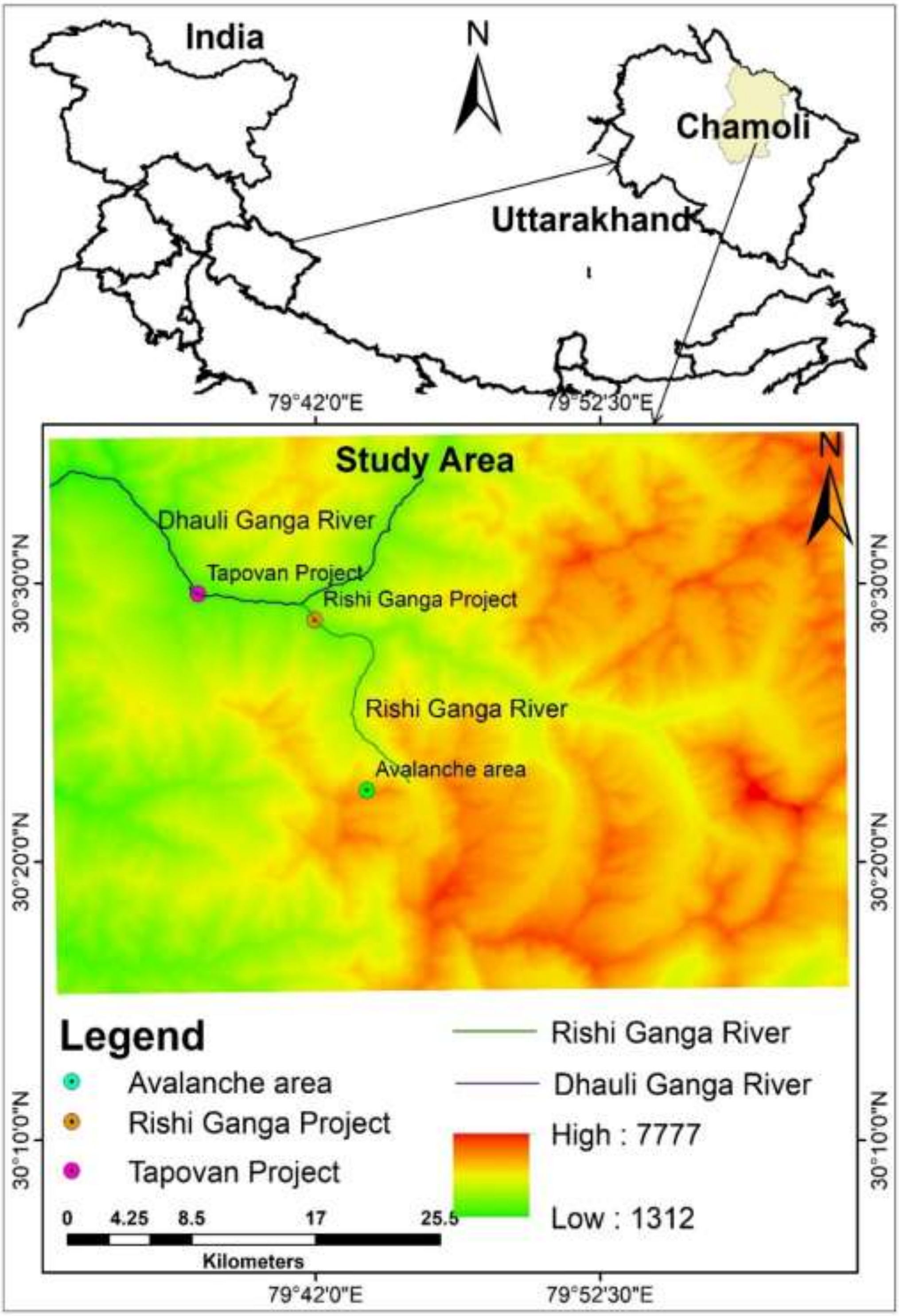

Figure 1: Map of the study area

Geological Setting of the Study Area: The present study area covers the Alaknanda watershed. Geologically the bedrocks are composed of Central Crystallines, consisting mainly of medium-to high-grade metamorphic sediments derived from pelitic, semi-pelitic and psammitic sediments which are sporadically interlaced with metabasic and to a lesser extent, calcareous rocks.[7,15] To the south-west of the study area lies the Lesser Himalayan Garhwal Group of rocks which comprises quartzites and slates with metavolcanics and carbonate rocks.

To the eastern side of the study area lies the Martoli and Sumna Group of rocks. Martoli group comprises slate, carbonate rocks, shale, quartzite, siltstone and phyllite etc. whereas Sumna group consists of limestone, siltstone, marl and shale etc. Some traces of alluvium are found amidst crystalline group which consist of gray sand, silt and clay[6]. The lithology map is shown in figure 2.

Crystalline rocks of the study area having shear zones show NNE dip direction, as they are visible along the road to Badrinath. These crystalline rocks are present close to the Main Central Thrust (MCT) plane distinguished by the presence of a combination of chlorite schists and quartzites. Around Joshimath area, the gneisses show aggregation of augen which is characterized by garnet, while the mica schist has abundant biotite, which sometimes includes amphibolite bands.[20] Virdi[24] has shown the lithotectonic framework of crystallized rocks near Joshimath. Gairola and Srivastava[5] have briefly explained the petrography and accumulation of minerals of the Joshimath region's metamorphic rocks. According to Virdi[24], crystallized rock masses in the Joshimath have been categorized into 3 litho-units - (A) Tapovan Formations (B) Joshimath Formations and (C) Pandukeshwar Formations.

Among the important tectonic setting, Main Central Thrust (MCT), Vaikrita Thrust, Tethyan Thrust and some fault lineament pass through the study area (Figure 3). The area where the avalanche took place is surrounded by all these lineament structures, that is why these disasters have become so vulnerable.

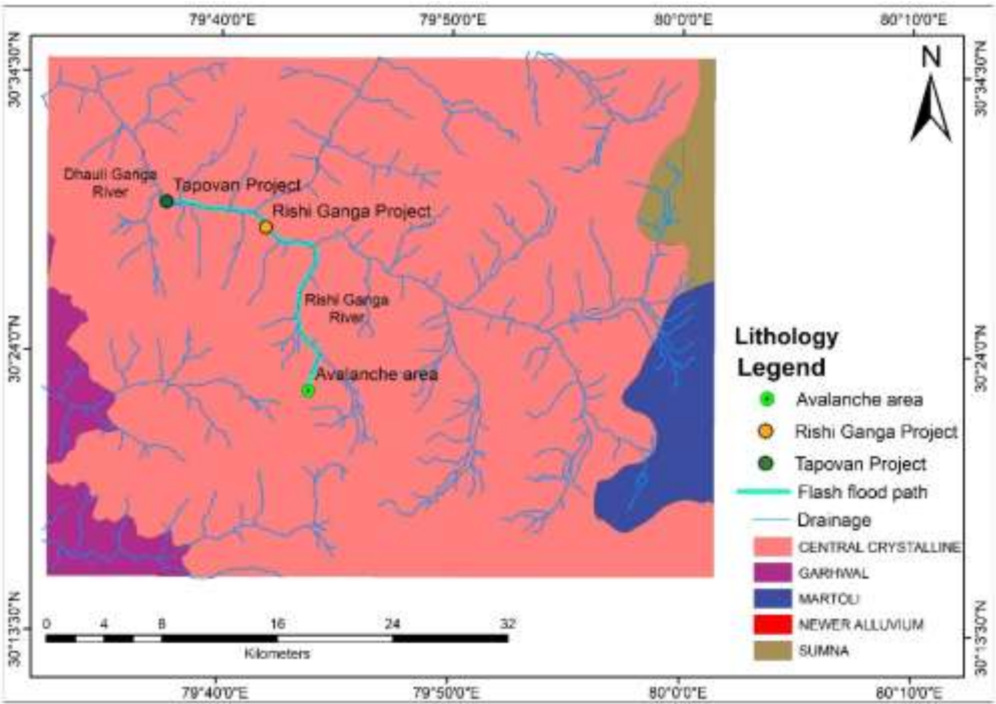

Figure 2: Lithology map of the study area (modified from GSI[6])

Table 2
Geology of the Study Area (GSI[6])

AGE	GROUP NAME	FORMATION	LITHOLOGY
Meghalayan	Newer Alluvium	Channel Alluvium	Grey Sand, Silt and Clay
Proterozoic (Undifferentiated)	Central Crystalline	Helang = Nyu = Wazri = Gangar	Quartzite and Quartz Mica Schist
Ordovician	Sumna	Garbyang	Limestone, Siltstone, Marl and Shale
Mesoproterozoic	Garhwal	Berinag = Chamoli = Nagnithank	Quartzite and Slate with Basic Metavolcanics
Neoproterozoic - Cambrian	Martoli	Milam	Slate, Carbonate rocks, Shale, Quartzite, Siltstone Phyllite

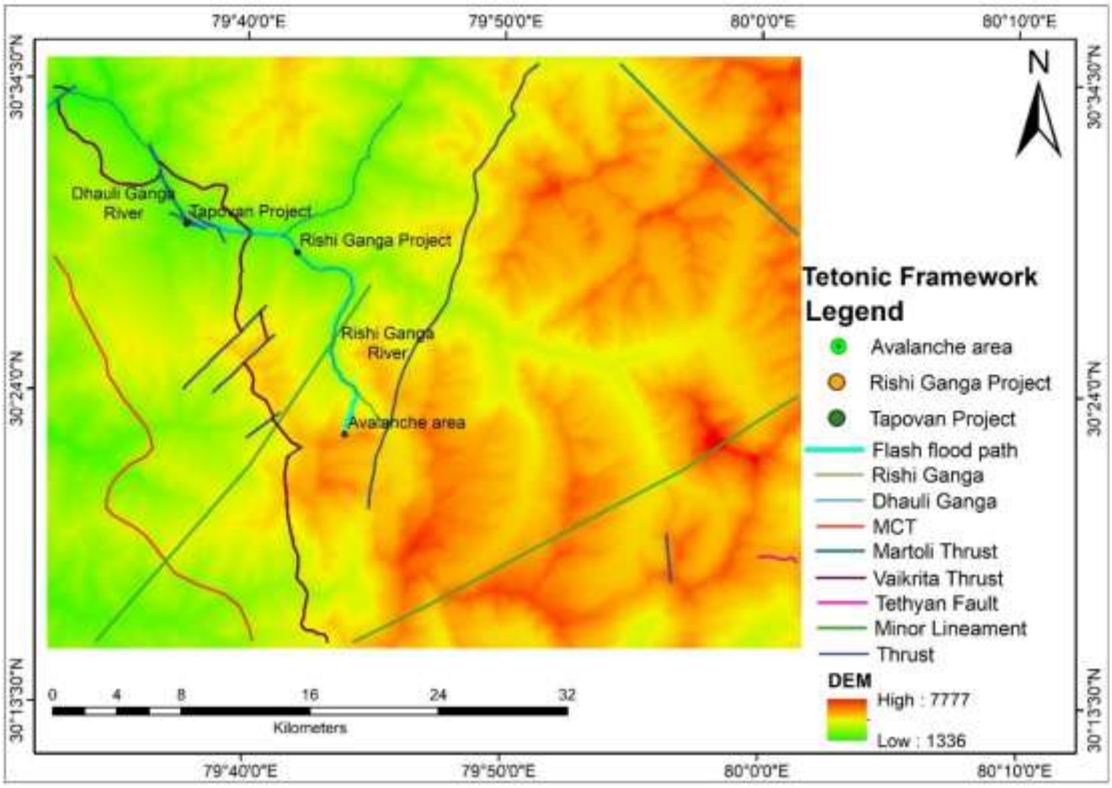

Figure 3: Tectonic framework of the study area (modified from GSI[6])

Disaster affected Hydel Projects

1. Tapovan Hydroelectric project: The Tapovan Vishnugad power plant is 520 MW run-of-river project installed in the Chamoli District of Uttarakhand, India, on the Dhauli Ganga River (79°37'30" E and 30°29'30" N) where the Central Crystallines are located. Crystallines are mainly composed of medium-to high-grade metamorphics represented by augen gneisses, metabasics, fine-grained Quartz-mica gneisses, micaschists, quartzites and coarse-grained garnet-biotite-cyanite gneisses[15].

While moving along the southern Himalayas, there are thrusts over those of the Lesser Himalayan rocks of the Garhwal Group along the Main Central Thrust. It is anticipated that the plant will produce approximately 2,558 GWh of electricity per year. The construction of hydroelectric power began in November 2006. The plant's power generation was scheduled to start in 2012, but slow tunnel excavation and flash floods in June 2013 delayed the work and the plant is yet to be fully operational to date. This power plant was one of the major damaged due to the Trishul glacier burst.

2. Rishi Ganga Power project: The power project located in 79°41'58" E 30°28'41"N at the Rishi Ganga river in the Alaknanda valley has only become operational in June 2020 that has been completely washed away by the flash flood. The capacity of the project was 13.2 MW and unfortunately, the power project was damaged in the 2016 floods, too, stopping electricity generation.[22] More than 30 workers involved in the project went missing in the flash flood.[21]

Event: Recent climate changes have impacted glacial systems in high mountains. This snowstorm has resulted in terrible flooding and melting glaciers created potential dangers in dammed lakes.[4] On 7th Feb. 2021 at around 10:30 am (IST), the whole country was in shock when they came to know about the glacier burst in Chamoli district. Among the most affected were the Raini village, Rishi Ganga Power project and the Tapovan Power project in Tapovan village causing a huge loss of life and property (Figure 4). As per the latest data, due to this disastrous incident, 58 lives were lost while about 148 people are still missing till date.

As per the Indian Space Research Organization (ISRO) weather forecast model, increase in snow precipitation was observed during 4-6 February, 2021, especially in Rishi Ganga and Dhauli Ganga areas and thereafter the snowfall gradually decreased. The low snowfall in a region is predicted by high surface temperature which goes beyond the amount of snowfall as reported by ISRO. As per their report, the surface temperature reached a maximum value of about 278 K on 7th Feb. 2021 compared to the average temperature of about 273 K in the February 2021. This is the reason which induced the avalanche to trigger.

In the pre-event (5th Feb. 2021) and post-event (10th Feb. 2021) satellite imagery of Sentinel 2, it is clearly visible that the snow cover has reduced to a larger extent (Figure 5), which also supports the weather forecast model of ISRO. Also, in the post event image, a lot of debris can be seen accumulated in the river bank.

Figure 4: Field photographs (A) Tapovan project after the disaster[19] (B) Dust plumes in the Dhauli Ganga river[3] (C) Rescue operation for the people stuck in the tunnel[19] and (D) Rescue operation of the injured people by the local authority[19]

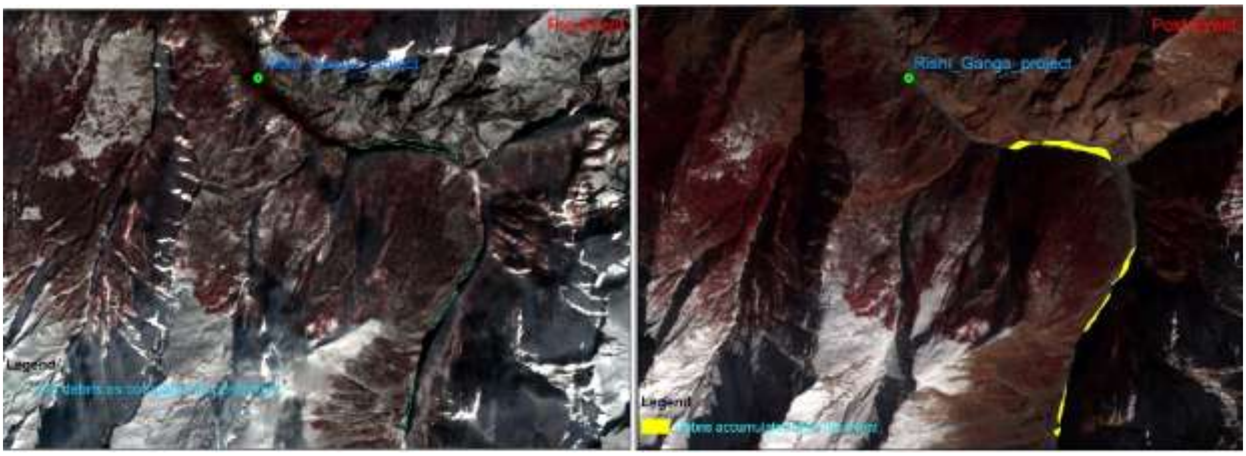

Figure 5: Pre (5th February, 2021) and Post (10th February, 2021) satellite image where the difference in snow cover and debris accumulation after the event is obvious

From the pre- and post-event satellite images of the affected area, a huge rock slide has taken place near the glacier. The huge cracks in the rock are observed in the pre-event satellite image, wherein the post-event data the block has already slides leaving behind a hollow structure (Figure 6). The ice melted quickly due to the landslide moving northwards along the Rishi Ganga valley, causing a massive surge of water which turned westward into the Dhauli Ganga valley.

Plausible causes

Cracks and fractures in Trishul glacier: The trapezedoil stretch of cracks (Figure 6) was observed before the initiation of the disaster. The vicinity of the spot where these cracks have developed and due to the freezing and thawing effect of glacier, the rapid slide of glacier volume occurred. Furthermore, the melted glacier's sudden movement along the downslope increased the spontaneous volume of water in Rishi Ganga River.

Geological and lithological criteria: The central crystalline group of Proterozoic age consists of schist, gneiss marble and basic intrusion. The marble lithology is more prone to chemical and deferential weathering, which may result to slope instability.

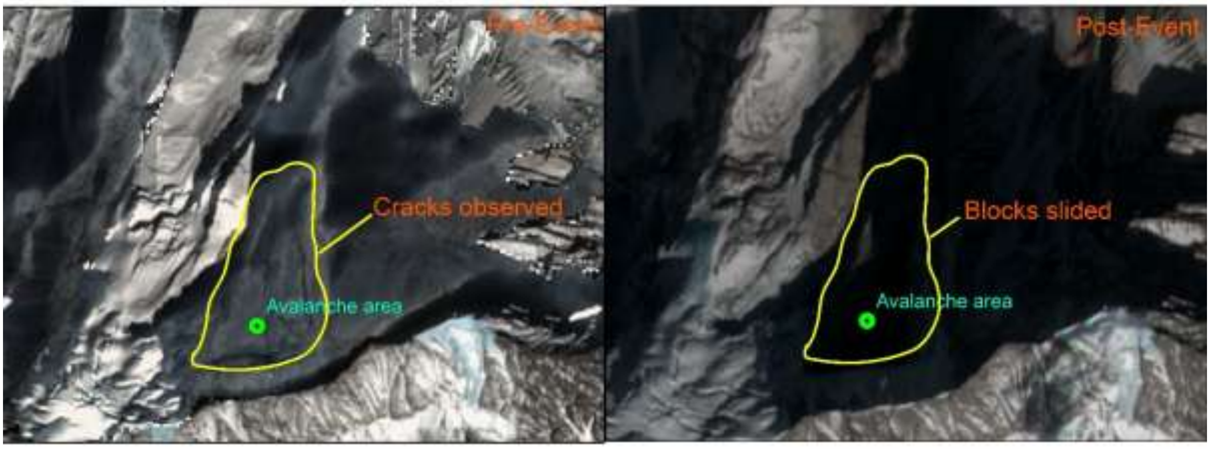

Figure 6: Pre (5th February, 2021) and Post image (10th February, 2021) where the cracks in the pre and the post avalanche in the Sentinel 2 image are obvious

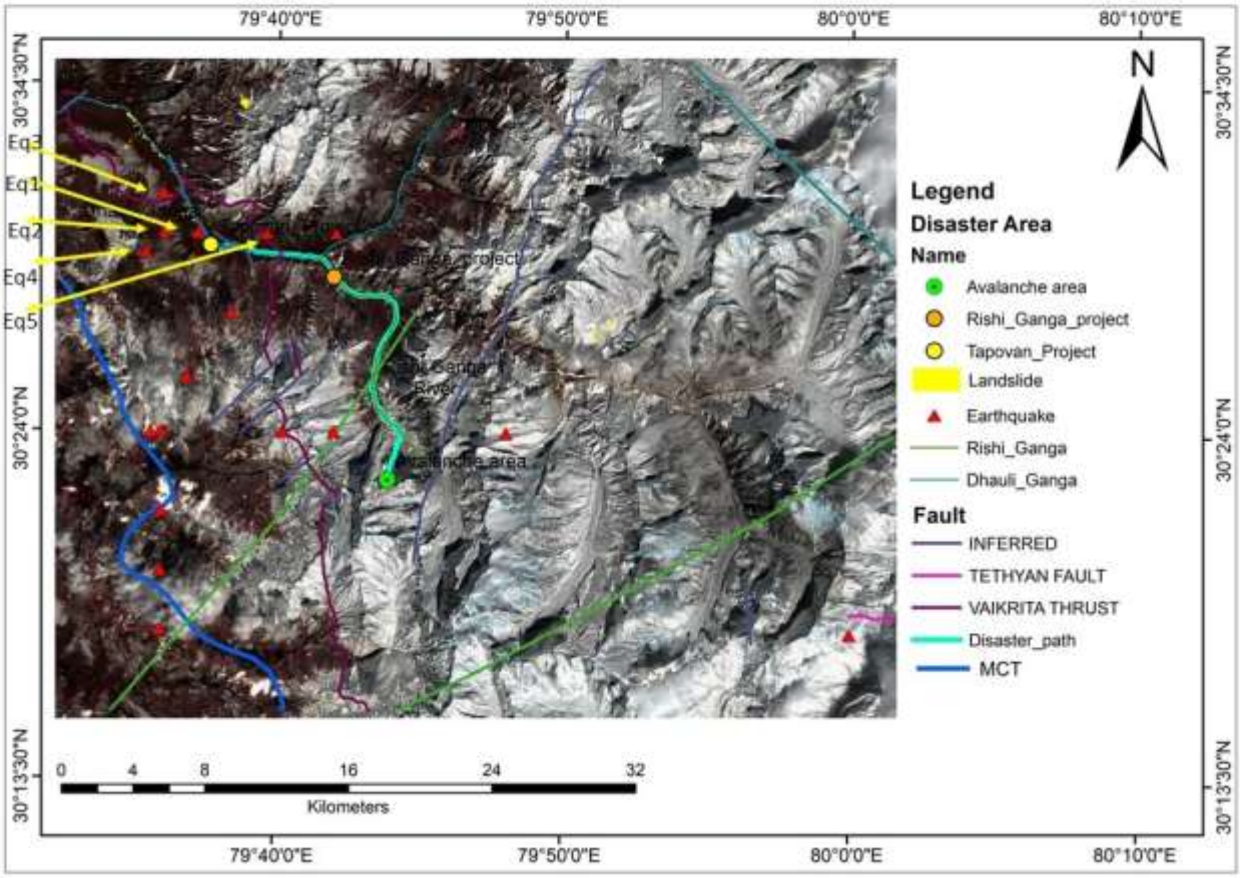

Figure 7: Holistic view of Paleo-seismicity, past landslide and tectonic settings of the area (modified from GSI[6])

Paleo- seismicity, paleo-landslide and active thrust/ tectonic lineament: Linear stretch of numerous paleo-landslides (Figure 7) as seen in North-West near Tapovan Dam Project. Even paleo-seismic earthquakes of year also made this zone high vulnerable to slope instability. The major earthquakes lying in the vicinity with their aerial distance are calculated in ArcGIS 10.7. Earthquake 1 (Eq1) at an aerial distance of 1 km North West (79.62003 E, 30.5 N), earthquake 2 (Eq2), 2.75 km West (79.5999 E, 30.5 N), earthquake 3 (Eq3), 3.2 km North West (79.660 E, 30.5 N), earthquake 4 (Eq4), 3.6 km South-West (79.5899 E, 30.49 N) and earthquake 5 (Eq5), 3.2 km North East (79.66 E, 30.5 N) of Tapovan dam project have triggered in the past. Two major faults namely Vikrita thrust and Main central thrust along with three inferred faults are present in the study as reported by GSI Bhukosh.[6]

Unfortunately, the Tapovan Dam project is also situated at the intersection of these three inferred faults[6] which consequently had magnified the damage and loss. The number of casualties and loss could have been reduced if the hydropower project's location would not be in the vicinity of these thrust, paleo landslides and paleo seismic center.

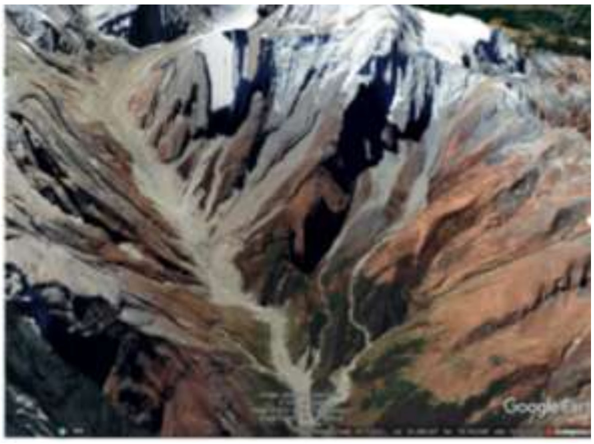

Figure 8: Change in hill slope observed in two different time period[16] (7th July, 2017 and 22nd November, 2020)

The Divecha Centre for Climate Change, IISc (Bengaluru) has estimated an underground glacial lake of 4.5 million cubic capacity and suggested that the outburst of beneath glacial lake has released the enormous water volume. They also suggested a depression upstream of 25ha after the release of underground glacial lake in the northern Nanda Devi glacier. These observations were also supplemented by Himalayan Glacier Thickness Mapper (HIGHTHIM) in which surface slope and laminar flow dimensions are used.[8]

Defence Geoinformatics Research Establishment (DGRE) of DRDO doubts the possibility of GLOF as in present atmospheric and climatic situation during the first week of February 2021 as there is no significant fluctuation in temperature in the particular snowcapped region. Defence scientists say that many military forces in the world use mountain tools as a way to reach enemy territories. According to an official, the Rishi Ganga hydropower project near Raini village in Uttarakhand was destroyed, as it was the under-construction project by NTPC on the Dhauli Ganga river near Tapovan.

While comparing hill slope from the satellite imagery of two different time period (7th July, 2017 and 22nd November, 2020) of pre disaster event, in the later picture, the large block that has failed is obviously seen, as it is the very steep slope down which the debris travelled. Before moving down the gorge, the debris seems to have travelled some distance up the opposite slope (Figure 8). The dust deposition region in the upper part of the direction of the flow is obvious. The flow appeared to have been gradually limited to the lower part of the valley, perhaps as it developed into a flow of rubble.[16]

Conclusion

The present study is a scientific approach to understand the scenario which led to the disaster in the Rishi Ganga and the Dhauli Ganga river on 7th February 2021.The plausible causes are the multi-factorial. The most appealing causes are the avalanches and abrupt average fluctuations of approximately 5K in temperature. Other triggering components include cracks, numerous old landslides, paleo-seismic events and presence of significant faults. Moreover, this kind of event is an eye-opener for all of us to rethink why such activities have been repeatedly happening in the hilly regions. Are we exploiting the nature in an unsustainable manner which has created an imbalance in the hilly eco-system?

Developmental activities in the hilly terrains should not come at the cost of innocent lives. It is true that technology had led us to mars and moon, but what is more important is to make the earth a safer place to live. The people living in the hills are so unpredictive about their lives. Technology should work for some model where the forecast in the flash flood, the avalanches etc. in the hilly terrains could be estimated. Furthermore, bio-engineering techniques with local remedial measures will definitely supplement the stability of vulnerable slopes. This could save at least the lives of people and minimize the economic/infrastructural losses in the hills.

Acknowledgement

The first and fourth author are very thankful to Guru Gobind Singh Indraprastha University, India for financial support through Indraprastha Research Fellowship, second author is thankful to CSIR for providing financial support through CSIR-Fellowship. The authors are thankful to the Dean, USEM, Guru Gobind Singh Indraprastha University, India, to provide the space and facility in carrying out the research work.

References

1. Dikshit A., Sarkar R., Pradhan B., Segoni S. and Alamri A.M., Rainfall induced landslide studies in Indian Himalayan region: A critical review, *Applied Sciences*, **10(7),** 2466 **(2020)**

2. Dimri A.P., Chevuturi A., Niyogi D., Thayyen R.J., Ray K., Tripathi S.N. and Mohanty U.C., Cloudbursts in Indian Himalayas: a review, *Earth-Science Reviews*, **168,** 1-23 **(2017)**

3. DNA India, https://www.dnaindia.com/india/photo-gallery-in-pics-glacier-breaks-in-uttarakhand-s-chamoli-evacuation-proceedings-underway-2873741 **(2021)**

4. Dobhal D.P., Gupta A.K., Manish M. and Khandelwal D.D., Kedarnath disaster: Facts and plausible causes, *Current Science*, **105(2),** 171-174 **(2013)**

5. Gairola V.K. and Srivastava H.B., Deformational and metamorphic studies in the Central Crystallines around Joshimath, district Chamoli, U.P. In ed., Gairola V.K., Proc. Nalional Seminar on Terliary Orogeny in Indian Subcontinenl, 49-63 **(1987)**

6. GSI, Bhukosh, https://bhukosh.gsi.gov.in/Bhukosh/Map Viewer.aspx **(2021)**

7. Heim A. and Gansser A., Central Himalaya, Geological Observation of the Swiss Expedition in 1936, *Mem. Soc. Helv. Sci. Nat*., **73,** 1–245 **(1939)**

8. Hindustan Times, https://www.hindustantimes.com/india-news/uttarakhand-underground-glacial-lake-led-to-flash-floods-says-iisc-analysis-101612842535639.html **(2021)**

9. Jain A.K., Stratigraphy and tectonics of Lesser Himalayan region of Uttarkashi region, Garhwal Himalaya, U.P., *Him. Geol*., **1,** 25-57 **(1971)**

10. Joshi V. and Kumar K., Extreme rainfall events and associated natural hazards in Alaknanda valley, Indian Himalayan region, *Journal of Mountain Science*, **3(3),** 228-236 **(2006)**

11. Khanduri S., Disaster hit Pithoragarh District of Uttarakhand Himalaya: causes and implications, *Journal of Geography and Natural Disasters*, **7(3),** 2-5 **(2017)**

12. Khanduri S., Natural hazards in the townships of Nainital, Uttarakhand in India, *International Journal of Engineering Applied Sciences and Technology*, **3(12),** 42-49 **(2019)**

13. Khanduri S., Sajwan K.S. and Rawat A., Disastrous Events on Kelash-Mansarowar Route, Dharchula Tehsil in Pithoragarh District, Uttarakhand in India, *Journal of Earth Science & Climatic Change*, **9(4),** 1-4 **(2018)**

14. Mehta M., Majeed Z., Dobhal D.P. and Srivastava P., Geomorphological evidences of post-LGM glacial advancements in the Himalaya: a study from Chorabari Glacier, Garhwal Himalaya, India, *Journal of Earth System Science*, **121(1),** 149-163 **(2012)**

15. Naithani A.K. and Murthy K.K., Geological and geotechnical investigations of Tapovan–Vishnugad Hydroelectric Project, Chamoli District, Uttarakhand, India, *J Nepal Geol Soc*, **34,** 1-16 **(2006)**

16. Petley D., https://blogs.agu.org/landslideblog/2021/02/15/perspectives-on-the-chamoli-debris-flow-disaster-in-uttarakhand **(2021)**

17. Sati V.P. and Litt D., Climate Disasters in the Himalaya, Risk and Vulnerability. In International Conference on Climate Change and Natural Hazards in Mountain Areas, Dushanbe Sept, 19-21 **(2011)**

18. Sati V.P., Increasing Events of Disasters, In Himalaya on the Threshold of Change, Springer, Cham., 79-99 **(2020)**

19. Source, The New York Times, https://www.nytimes.com/2021/02/08/world/asia/india-flood-ignored-warnings.html#:~:text=the%20main%20story,Before%20Himalayan%20Flood%2C%20India%20Ignored%20Warnings%20of%20Development%20Risks,more%20so%20by%20global%20warming **(2021)**

20. Srivastava H.B. and Tripathy N.R., Shear Zones structures from the Main Central Thrust Zone of the Joshimath area, Garhwal Himalaya, *Spec. Publ. Paleont. Soc. India*, **2,** 53-64 **(2005)**

21. Tapovan project, https://www.power-technology.com/projects/tapovan-vishnugad-hydroelectric-power-plant-uttarakhand **(2021)**

22. The Hindu Businessline, https://www.thehindubusinessline.com/companies/ntpc-rishi-ganga-power-projects-nearly-washed-away/article33776257.ece **(2021)**

23. Tripathi S., Areendran G., Gupta N.C., Raj K. and Sahana M., Environmental and Livelihood Impact Assessment of 2013 Flash Flood in Alakananda and Mandakini River Valley, Uttarakhand (India), Using Environmental Evaluation System and Geospatial Techniques, In Remote Sensing and GIS, Springer, Cham., 11-34 **(2021)**

24. Virdi N.S., Litho-stratig raphy and structure of Central Crystallines in the Alaknanda and Dhauli Ganga vallies in Garhwal Himalaya, U.P., Himalayan Thrusts and Associated Rocks, 155-166 **(1986)**.

(Received 22nd March 2021, accepted 20th May 2021)

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