JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.97, April 2021, pp.335-338

A Perspective on Rishiganga-Dhauliganga Flash Flood in the Nanda Devi Biosphere Reserve, Garhwal Himalaya, India

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ABSTRACT

A ground-based and heliborne survey was conducted immediately after the disaster that took place on 7th February, 2021 in the Chamoli district of Uttarakhand. Based on these observations and freely available Google Earth imagery, we have arrived at plausible causes of this catastrophe as detachment of a sizeable rock mass and overlying hanging glacier in the Raunthi catchment that dammed the Rishiganga River and led to the devastation of roads, bridges and hydropower projects in downstream.

INTRODUCTION

The Hindu Kush Himalayan region consists of largest number of glaciers outside the polar region and is often termed as the "Third Pole". The number of glaciers in the Indian Himalayan Region (IHR) have been estimated by several organisations at different scales and with varying attributes of a glacier. These glaciers are the perennial source of the major rivers like the Indus, the Ganga and the Brahmaputra, which are lifeline to millions of people in the downstream (Immerzeel et al., 2010). Glaciers and related processes have both long-term (indirect) and short-term (direct) impacts on the society. The long-term impacts include fluctuations in glacier length, area and volume; changes in temperature and precipitation (rainfall and snowfall), water availability. Further, these glaciers can also lead to potential hazards in the Himalaya, which include avalanche, glacial lake outburst floods (GLOFs), flash floods, debris flow, etc. which significantly impact the society in short-term. These are paid attention only when humans and their activities become vulnerable. The frequency of such events may increase, as the glaciers recede in response to climatic variability (Kääb et al., 2020; Chen et al., 2021; Shugar et al., 2021).

In recent times, Uttarakhand has witnessed several disasters such as GLOFs, debris flows and flash floods which include Kedarnath, 2013 (Bhambri et al., 2016), Gangotri, 2017 (Kumar et al., 2018) and Rishiganga-Dhauliganga, 2021 (this study), respectively. The Kedarnath and Gangotri events took place during the peak ablation/ summer season (June and July), while the Rishiganga-Dhauliganga flash flood took place during the peak winters (February) in the morning hours of 7th February, 2021. Uttarakhand has a total of 1573 glaciers with a total glacier area of 2258 km^2 which has been estimated using the glacier outlines from Randolph Glacier Inventory (RGI) version 6.0 (RGI Consortium, 2017), which includes glaciers and ice masses up to 0.01 km^2. The Dhauliganga basin has an area of ~3030 km^2 up to the confluence with Alaknanda at Vishnuprayag, which encompasses 245 glaciers with a total glacier area of ~436 km^2 (Fig. 1). While, the Rishiganga catchment has a total area of ~691 km^2 up to the confluence with Dhauliganga near Raini village, which has a total of 70 glaciers and a total glacier area of ~175 km^2 (Fig. 1). Similarly, the Raunthi sub-basin has a total area of ~95 km^2, and has 12 glaciers with a total glacier area of ~16 km^2. Raunthi Glacier is the major glacier in this valley and Raunthi stream originates from it at an altitude of ~4250 m asl. The Rishiganga-Dhauliganga catchments have a high potential for generation of hydropower due to the availability of snow and glacier melt. Therefore, a number of hydroelectric projects (HEP) are proposed, some of which have been commissioned, while others are under various levels of construction. The HEP at Raini and Tapovan over the Rishiganga and Dhauliganga rivers respectively, were nearing the completion of work.

RISHIGANGA-DHAULIGANGA FLASH FLOOD (7th February, 2021)

A team of scientists from Wadia Institute of Himalayan Geology (WIHG) responded and moved to the Rishiganga-Dhauliganga catchments (Fig. 1) on 8th February, 2021 to make a reconnaissance of the event and understand the reasons behind the disaster. The event was witnessed in the form of unusually high suspended sediment concentration (SSC) in the reservoir of the Srinagar HEP over Alaknanda River during peak winter season (February). This sediment laden water was visible throughout the Alaknanda and Dhauliganga rivers in the upstream. The high SSC was unexpected as February is peak month of the lean season as per the annual hydrograph characteristics of Dhauliganga River (NTPC, 2007). The WIHG team visited the damaged HEP sites at Raini and Tapovan for assessing the impact of the flash flood. The team also carried out a heliborne survey of the inaccessible Rishiganga and Raunthi catchments to obtain aerial photographs to comprehend with the sequence of events.

It was observed that a hanging glacier along with rock mass broke off in the Raunthi Glacier catchment below Raunthi Peak (Fig. 1 and 2a) from an altitude of 5600 m asl (30.375713° N, 79.726631° E). The ice and rock mass moved downward for a stretch of ~3 km over a steep slope before reaching to the Raunthi stream at an altitude of ~3600 m asl. The distance of this impact is about 1.6 km downstream from the snout of the Raunthi Glacier. Fresh snowfall was observed on 4th-5th February (Monthly Weather Review, India Meteorological Department), which was visible in the higher reaches, while most of it in the lower elevations had melted. The snowfall during winters and other meteorological data at high altitude regions is rarely available (Kumar et al., 2018). The development of cracks in the broken ice mass are visible in the temporal Google Earth images. The

0016-7622/2021-97-4-335/$ 1.00 © GEOL. SOC. INDIA | DOI: 10.1007/s12594-021-1691-5

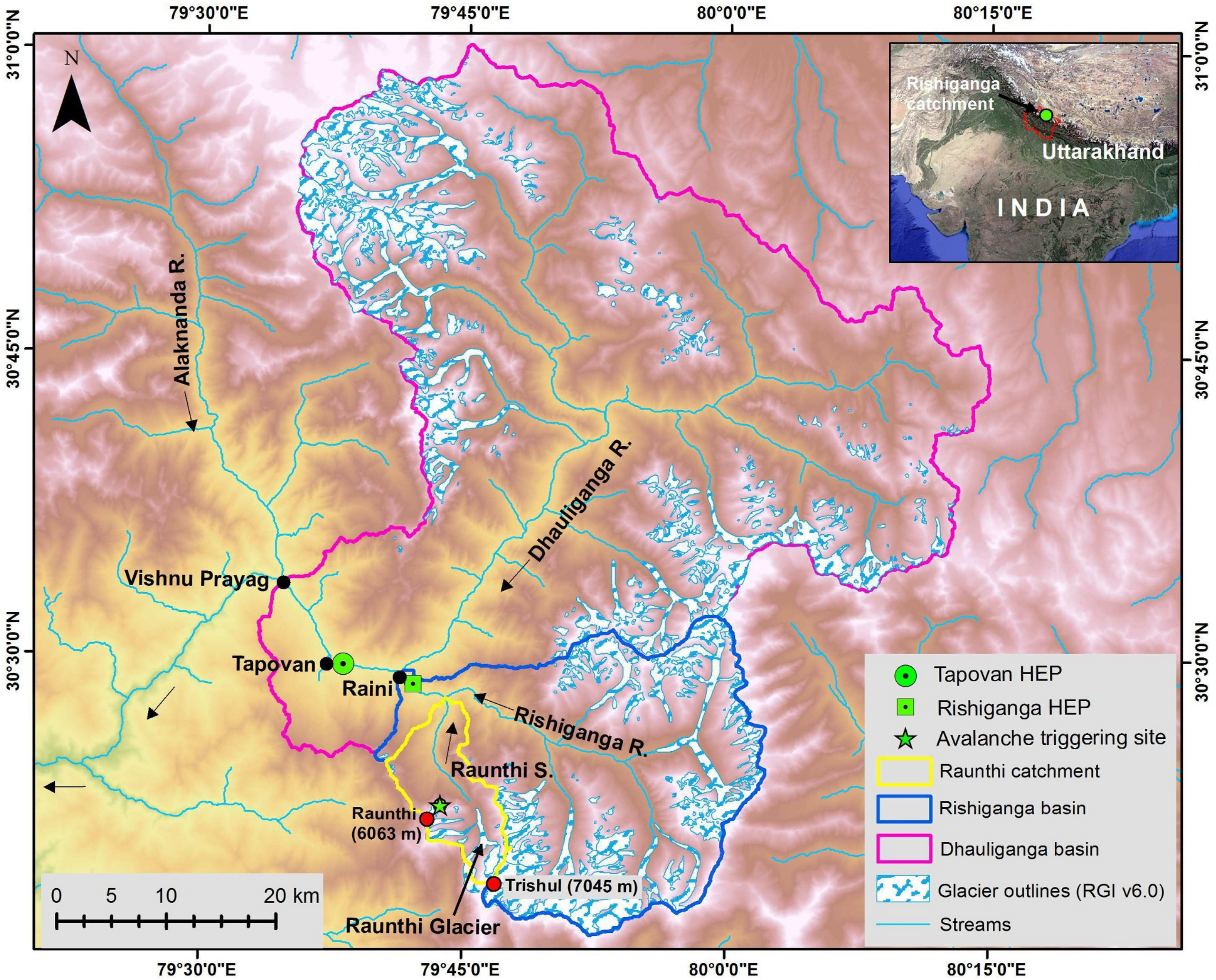

Fig. 1. Location of the initiation zone of avalanche in the Raunthi (bank) glacier and hydroelectric projects in Rishiganga-Dhauliganga basins. Arrows show the direction of river flow and solid black circles represent important towns/villages.

interpretation of these temporal images indicate that the Raunthi catchment observed snow avalanche, ice avalanche and debris flow event between the years 2015-2017. These events did not make any major disaster in the downstream, however they caused major morphological changes in the catchment and led to the accumulation of loose morainic debris and sediments in the pro-glacial region of Raunthi stream. There are evidences of the Raunthi stream flowing under the debris and sediments making them saturated.

The energy generated by the momentum of the ice and rock mass and its impact over the remnant saturated debris and sediments formed a complex admixture of snow, glacier ice, rock fragments, morainic debris and sediments (slurry). This slurry moved downstream along the Raunthi stream for ~8.5 km and blocked the Rishiganga River at an altitude of ~2300 m asl on the confluence leading to the formation of a fresh water lake (Fig. 2b). The Uttarakhand State Disaster Management Authority (USDMA) was immediately informed about the formation of a lake over the Rishiganga River due to damming by the debris and glacier ice from the Raunthi stream. The slurry material at this point gained water from the Rishiganga and entrained sediments, wood debris, ice blocks causing large scale devastation to the run-of-river HEP (~13.2 MW) located over the Rishiganga River (Fig. 2c). Simultaneously, a major bridge ~70 m above the river bed over Rishiganga River near Raini village was completely washed out (10:21 AM, 7th Feb 2021), thereby disrupting the supply to the villages and border areas in the upstream (Fig. 2d).

At the confluence of Rishiganga and Dhauliganga rivers, the latter experienced back thrust of water and slurry in the upstream, as evident from signatures of the slurry material on both banks (Fig 2e). Also, wood debris is visible in the upstream of Dhauliganga, confirming the back thrusting. This amplified the slurry that moved downstream and damaged the Tapovan run-of-river HEP (Fig. 2f, 10:37 AM). This was the highest capacity (520 MW) project over the Dhauliganga River. The slurry material at the Tapovan HEP is ~20m thick and also deposited large boulders near the barrage gates (~12 m high). The head-race tunnel built by the HEP is ~7 m in diameter and was flooded. The slurry material included large ice blocks that were recovered from the tunnel (Fig. 2g). The presence of solid blocks of ice within the slurry material near the tunnel of Tapovan HEP, which is ~22 km downstream from the source, is an indication to the scale and magnitude of this event. This catastrophic event engulfed several lives and obliterated infrastructure on its way. It is feared that ~ 72 people died and ~205 people were missing in this disaster (The Hindu, 27th February, 2021). The initial estimated damage to the infrastructure is to the order of ~1500 crore rupees (PTI, 8th February, 2021).

The event is unprecedented as it happened during the peak winter season, when the 0°C isotherm is at an altitude of ~3000 m asl during February, while it is at an altitude of ~5400 m asl during July and August for Garhwal Himalaya (Misra et al., 2020; Yadav et al., 2020). Therefore, linking this event to climate change is too early to opine. Other factors such as the topography (aspect, elevation,

Fig. 2. View of the triggering site of the ice-rock avalanche **(a)**, lake formation at the confluence of Raunthi stream with Rishiganga River **(b)**, damaged site of Rishiganga HEP **(c)**, washed out bridge near Raini village **(d)**, signature of back thrusting at the confluence of Rishiganga and Dhauliganga rivers **(e)**, deposition of slurry material at Tapovan HEP barrage **(f)**, tunnel **(g)**, and high SSC in downstream **(h)**.

slope), geological and tectonic settings may play important role (Kargel et al., 2016). The USDMA has recently established a network of meteorological stations across the state, which would be beneficial by enhancing the network at altitudes above 3000 m asl. Similarly, real-time hydrological observations to monitor the discharge and sediment flux in the high altitude regions are important as they can provide precursory information on unusual activities in the upstream. For e.g. formation of a lake/ damming due to landslide, debris flow, avalanche would decrease the discharge, while if any lake is breached, it would increase the discharge and sediment flux (Fig. 2h). Therefore, continuous long-term monitoring of glaciers and glaciated regions in the Himalaya is of utmost importance for generating data and developing early warning systems. Further, the local communities must be educated and sensitized to such hazards in the Himalaya, to reduce the risk involved. The awareness in the local people could have saved some lives during this event, as the time lag between the arrival of flash flood at Rishiganga and Tapovan HEP was ~16 minutes.

The entire event of disaster is summarized below:

- Breaking of rock mass and overlying hanging glacier from Raunthi peak (5600 m asl) to Raunthi stream (3600 m asl).
- This created slurry materials that dammed the Rishiganga River at ~2300 m asl.
- The slurry further entrained a large quantity of sediment, wood debris, ice block and water, and caused devastation to Rishiganga and Tapovan HEP along with roads and bridges in downstream.

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(Received: 8 March 2021; Revised form accepted: 12 March 2021)