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Disaster Risk Reduction Lessons from February 7, 2021 Flash Flood in Uttarakhand Province of India

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ABSTRACT

204 people were killed, while two hydropower projects located in close proximity to Rini (13.2 MW) and Tapoban (520 MW) were severely damaged in Dhauliganga flood of February 7, 2021, in the Indian Himalaya. In addition, it caused massive loss of farm animals, agricultural land, property and infrastructure. This incidence occurred during the winter season when the discharge of glacier fed rivers is minimal, and the region did not experience rains around the time of the flood. Based on a detailed review of post-disaster search and rescue efforts, and bottlenecks faced by disaster managers, authors recommend (i) scientific documentation of past catastrophic events, (ii) detailed assessment of the risk posed by various hazards, (iii) legally binding disaster risk assessment, and a reduction mandate for major infrastructure projects, (iv) robust, reliable and redundant warning generation and dissemination infrastructure, (v) diversification of assets, and (vi) creating a dedicated cadre of Disaster Risk Reduction (DRR) professions.

Key words: Himalaya, Flash Flood, Landslide Dam, Landslide Lake Outburst Flood (LLOF), Dam Breach.

Introduction

Himalaya is an evolving mountain range which is vulnerable to a number of hazards due to the continuity of tectonic movements and peculiar meteorological conditions, in addition to the evolutionary history and geomorphic setup of the terrain. Located to the west of Nepal, Uttarakhand province of India (Fig. 1) is regularly devastated by flash flood, flood, landslide and cloudburst. (Table 1), particularly during the monsoon period (mid-June to mid-September) when the region experiences heavy precipitation due to southwest monsoon.

Local heavy rainfall events, often referred as cloudburst and attributed to climate change, have registered a marked increase in the Himalayan region during the previous decade (1, 2, 3). The consequent sudden increased discharge of streams sometimes results in flash flood in the downstream areas, because of which, during the monsoon period of 2010, 2012 and 2013, Uttarakhand witnessed major devastation (4). Cloudburst is, however, not the only cause of flash flood, and the region has also witnessed flash floods due to the breach of landslide dammed lakes (5), which are referred to as landslide lake outburst flood (LLOF).

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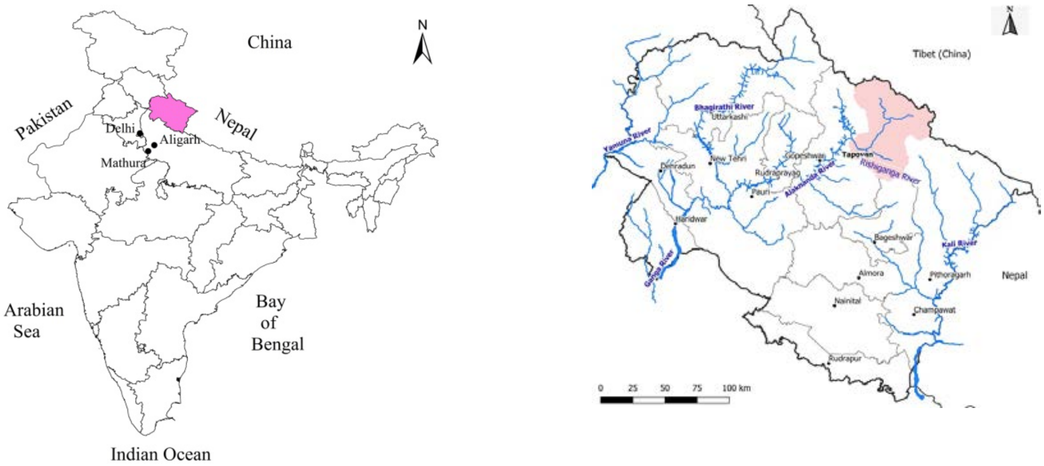

Figure 1. Location of Uttarakhand Province in the Map of India (Left), and the Catchment Area of Dhauliganga River in the Map of Uttarakhand, Depicting Drainage Network and District Boundaries (right).

Table 1. Disaster Induced Losses in the Uttarakhand Province in the Period 2010-21.
Data Source: State Emergency Operations Centre (SEOC), Uttarakhand.

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 (up to August 31)	135	121	81	678	289	52	201	118.2
Total	1,447	4,188	1,094	24,930	38,841	5,668	5,843	5,570.4
Average	121	349	91	2,078	3,237	472	487	464.2

Table 2. LLOF in Alaknanda River Valley of Garhwal Himalaya.

Sl. No.	Date / year of blockage	Place of damming	Date / year of breach	Remarks
1.	1868	Alaknanda River blocked by landslide upstream of Chamoli (6)	1868 (Period of impoundment was not clear)	2 villages were devastated 70 people were killed
2.	1893	Birahiganga River near its confluence with Alaknanda river (7)	1893 (Period of impoundment was not clear)	Water impounding to 10-13 m above normal 2 bridges were damaged
3.	September 6, 1893	Birahiganga River was blocked by landslide, forming Gohna Tal (8)	August 25, 1894 (partial breach)	Landslide dam was 350 m high Loss of life was averted by regular monitoring and warning Massive loss of property and infrastructure

Sl. No.	Date / year of blockage	Place of damming	Date / year of breach	Remarks
4.			July 12, 1970 (final breach)	Massive loss of infrastructure, particularly at Srinagar
5.	1930	Alaknanda River blocked near Badrinath (9)	1930 (Period of impoundment was not clear)	Water impounding to 9 m above the normal water level Some houses were damaged
6.	1957	Dhauligana River was blocked near Bhapkund by an avalanche along Dronagiri River (9)	1957 (Period of impoundment was not clear)	The lake was later filled with debris
7.	February 4, 1968	Rishiganga River was blocked by landslide near Rini (10,11)	July 20, 1970	Water impounding to 40 m above the normal water level Extensive damage in downstream areas
8.	September 1969	Alaknanda River was partially blocked upstream of Kaliasaur (11)	1969 (Period of impoundment was not clear.)	
9.	July 20, 1970	Dhauliganga River was blocked near Tapoban by the debris brought down by Dhak Nala (11)	July 20, 1970	Water impounding to 15-20 m above normal water level
10.	July 20, 1970	Alaknanda River was blocked near Helang by the debris brought down by Karmanasa Nadi (11)	July 20, 1970	
11.	July 20, 1970	Alaknanda River was blocked by landslide near Hanuman Chatti at Badrinath (10,11)	July 20, 1970	Water impounding to 30-60 m above the normal water level Breach caused considerable loss of life

Table 2. (Contd.) LLOF in Alaknanda River Valley of Garhwal Himalaya.

12.	July 20, 1970	Patalganga River was blocked by landslide (7,12)	July 20, 1970	Water impounding to 60 m above the normal water level Major flooding in Alaknanda River Belakuchi village was washed off.
13.	April 1979	Alaknanda River was blocked by avalanche near Bamni village in proximity of Badrinath (13)	1979 (Period of impoundment was not clear.)	The blockage was in proximity of Badrinath and triggered by avalanche.
14.	2002	Gandhwi River was blocked by landslide near Saigari village (14)	2002 (Period of impoundment was not clear)	Dhauliganga River was flooded by the breach and Saigari village was devastated.
15.	February 7, 2021	Lake formed on Rishiganga River Course of Raunthi Gadhera, Rishiganga and Dhauliganga were blocked intermittently	February 7, 2021	204 people were dead There was major devastation to two hydropower projects at Rini and Tapoban

Alaknanda Valley of Garhwal Himalaya has been particularly vulnerable to LLOF (Table 2), and 5 out of 15 (33%) reported incidences of river blockage in this valley, have been associated with Dhauliganga River (Figure. 2). Field evidences of damming in the form of interbedded sequence of sand and pebbles have also been observed in this valley at two different places (Figure. 3). Dhauliganga valley is, thus, particularly vulnerable to flash floods.

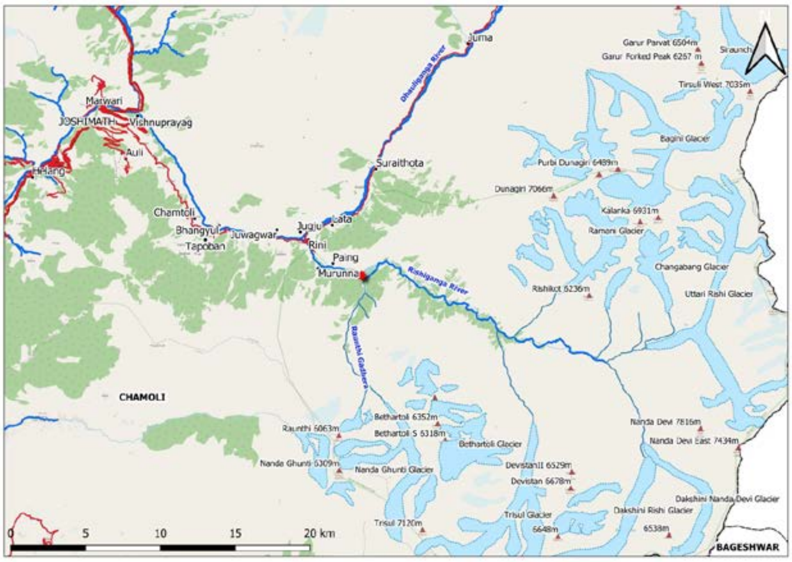

Figure 2. Map of Dhauliganga – Rishiganga Valleys

Dhauliganga River originates in the proximity of Niti Pass and flows southwest towards Rini, where it has its confluence with Rishiganga River which originates from the glaciers of Nanda Devi Massif and flows northwest. From Rini to Chamtoli (1.0 km downstream of Tapoban), Dhauliganga River maintains a tectonically controlled east-west course, and thereafter, flows southeast to meet Alaknanda River at Vishnuprayag (Fig. 1). Dhauliganga valley exhibits rugged mountainous topography with high relative relief, and the altitudes range from 1450 to 7817 m (Mt. Nanda Devi). Geo-tectonically aligned narrow valleys and gorges are prominent geomorphic features of this valley that can be approached by Joshimath – Malari state highway.

Figure 3. Lacustrine deposits on the right bank of Raunthi Gadhera near its confluence with Rishiganga River (left), and on the road close to hot water spring at Tapoban (right).

Flash flood of February 7, 2021

Sudden increase in the discharge of Rishiganga and Dhauliganga rivers in the forenoon of February 7, 2021 left behind a trail of death and destruction. Most dwellings in the affected area, located at higher elevations, were spared from direct impact of the floodwaters. Low lying agricultural fields, together with 360 farm animals, were however lost in this incidence. 9 people from surrounding villages (5 from Rini, 2 from Tapoban, and 2 from Ringi), and 2 police personnel were amongst 204 people who went missing in this incidence.

Figure 4. Devastation at the dam site of Dhauliganga hydropower project at Tapoban.

Figure 5. Debris removal operations in the tunnel of the hydropower project at Tapoban.

6 bridges were washed off or damaged by the floodwaters disrupting connectivity of 13 villages. The flash flood, also, washed away a hydropower project of 13.2 MW capacity on Rishiganga River, upstream of Rini. To the downstream of this severe damage was inflicted to the dam axis and other structures of an under construction hydropower project of 520 MW capacity on Dhauliganga River at Tapoban (Figure. 4). People working at these hydropower projects were washed off or buried in the debris. 30-35 people were trapped in a tunnel at Tapoban which was chocked with debris (Figure. 5).

There exists no discharge measurement facility in the catchment area of Dhauliganga River. However, the discharge of Alaknanda River at Marwari, 18 km downstream of Tapoban, was observed by Central Water Commission (CWC), to be 1670 cumecs at 1100 hrs on February 7, 2021, against normal discharge of around 41 cumecs during this season. It is estimated that about 6 million cumecs of water passed through this gauging station in one hour, and the Alaknanda River crossed both danger level (1383.00 m) and the highest flood level (HFL) (1385.54 m) of June 28, 2013.

Fluvio-glacial sediments mobilized by floodwaters were observed to be deposited all along the valley. This resulted in 3.09 m rise in the bed of Alaknanda River at Marwari, as observed in cross section measurements carried out by CWC on February 10, 2021. The thickness of deposited sediments was observed to increase gradually towards the upstream with the sediment thickness reaching more than 12 m at the dam site at Tapoban.

Figure 6. View of the Lake Formed in Rishiganga River on February 11, 2021.

Geomorphic changes brought forth by flood created a lake on Rishiganga River, close to its confluence with Raunthi Gadhera (Figure. 6). Having potential of LLOF, this lake was a major cause of concern after the flood, as it could jeopardize the safety of rescue workers at Tapoban. The debris barrier, however, breached naturally on February 12, 2021, and the threat was averted.

The present study reviews the post-disaster initiatives of various response agencies with particular focus on the challenges faced, with the goal of putting forth recommendations for averting and better managing such incidences in future.

Objectives and methodology

Despite emphasizing the importance of incorporating disaster resilience during post-disaster reconstruction, classical disaster management cycle (15) does not specifically include post-disaster review in the response phase. Post-disaster review is, however, an important ingredient of the risk reduction strategy, providing an opportunity for reflecting upon shortfalls, and accordingly undertaking necessary improvements in the procedures and protocols. This at the same time ensures routine identification of vulnerabilities, and facilitates incorporation of resilience by vulnerability reduction and building upon the strengths.

Disaster resilience warrants that the shortcomings resulting in a disaster are not repeated in future, and it is for this reason that priority 1 and 4 of the Sendai Framework of Disaster Risk Reduction emphasize upon post-disaster reviews, as well as sharing of experiences and lessons learnt (16). The practice of documenting the lessons learnt is, thus, gaining ground (17, 18).

Except for uniformed forces, other agencies involved at various stages of post-disaster operations in India, do not generally have a culture of routine briefing and debriefing, which has adverse impact on the continuity of operations. It is a reason for lacking formal account of challenges faced and lessons learnt from disasters. Rather than getting imbibed in organizational memory, the lessons, therefore, remain confined to individuals. This often results in operations becoming individual driven, rather than system or organization driven.

The present study was undertaken with the objective of documenting the challenges faced by the response agencies, while managing the Dhauliganga flood of February 7, 2021, and to document the lessons learnt. For this, the disaster scenario highlighting various landmarks was reconstructed from the records of both District and State Emergency Operations Centre. At the same time, in-depth interactions were carried out with the officials of various response agencies, to document the challenges faced by them, and the lessons learnt. This study is, thus, an attempt to ensure that these lessons are imbibed in the institutional memory, and result in more effective and professional response in future by eliminating the shortfalls, and at the same time, improving procedures and protocols.

Post-disaster response

After receiving information from the disaster site, the provincial government immediately initiated relief and rescue operations, details of which are summarized in the sections below.

Mitigation measures

CWC, the federal government agency responsible for monitoring river discharge and issuing flood related warnings in India, was requested to monitor the level and discharge of Alaknanda River, and provide necessary inputs. Contemplating flood situation, high alert was, at the same time, sounded in the downstream dwellings.

Reservoir of GVK hydropower project on Alaknanda River at Srinagar, at a distance of around 160 km from Tapoban, was vacated to accommodate the floodwaters and avert flooding in the densely populated and low lying downstream dwellings, particularly, Rishikesh and Haridwar. The turbines of hydropower projects at Tehri and Koteshwar were shut down, so as to minimize the discharge of Bhagirathi River, which joins Alaknanda River at Devprayag to form Ganga River. Being one time catastrophic release, water level in Alaknanda River, however, normalized with valley widening and the floodwaters did not cause devastation in the downstream areas.

Flood modelling undertaken previously by Uttarakhand State Disaster Management Authority (USDMA) for Alaknanda River, was also utilised for assessing the flood situation. The models depicted water to reach the HFL mark around Marwari, and the same was verified by site observation data of CWC. With downstream propagation, the models depicted gradual decrease in flood level, and the level was assessed to become normal downstream of Rudraprayag.

Being a low discharge month, and the flood restricted to only one tributary of the Alaknanda River, the floodwater was self-routed, and thus, the effect of the event was assessed to remain restricted only to the upper reaches. This input helped in avoiding unnecessary panic in the dwellings along the Alaknanda River.

Initial actions after the disaster

Provincial government immediately took stock of the situation, assessed the requirements, and accordingly, started resource mobilization. Help of Army, Indo-Tibetan Border Police (ITBP), and National Disaster Response Force (NDRF), was sought together with Indian Air Force (IAF) and Indian Navy, while personnel of State Disaster Response Force (SDRF), along with the required search and rescue equipment, were airlifted to the disaster site to assist the local administration and police in search and rescue operations.

Officers of various departments, together with those of the response agencies (Army, NDRF, SDRF and ITBP), were put on duty at the State Emergency Operations Centre (SEOC) at Dehradun, to coordinate rescue, relief, and restoration activities concerning their department.

Though safe from floodwaters, the residents of the Dhauliganga valley were highly traumatised, and disrupted surface connectivity added to their misery. Support of Non-Governmental Organisations and Civil Society Groups was, therefore, organised for psychosocial care and needs assessment. Civil Supplies Department was directed to ensure that there is no shortage of food grain, and other essential supplies in the affected villages. Health check-up and medical camps were, also, regularly organised in the affected villages.

Trollies were quickly installed at the site of disrupted pedestrian bridges, while alternative connectivity was provided at the site of damaged vehicular bridge. Process was at the same time initiated for mobilising Bailey bridge, and the same was opened for traffic on March 4, 2021.

Disrupted drinking water and electricity supply in the affected villages was restored within two days.

Coordination and information exchange

A control room was set up at Tapoban, to supervise and ensure coordination in the search and rescue operations being carried out by different agencies. Senior officials of the provincial government, including Commissioner and Deputy Inspector General of Police of Garhwal Range, together with District Magistrate and Superintendent of Police of Chamoli, camped at Tapoban to oversee and report the progress of the search and rescue operations.

As the workers of the two affected hydropower projects were from all parts of the country, local control room was flooded with queries from both next of kin of the workers and concerned state government officials. A dedicated helpline was, therefore, set up for proactively responding to the queries related to the incidence.

Most of the missing people in the incidence were from neighbouring province of Uttar Pradesh, from which a team of four senior officials was deputed for taking care of various medico-legal formalities, arranging transport of identified bodies to their hometowns, supporting next of kin of the missing people visiting the affected area, and facilitating early release of ex gratia relief. Required logistics and other support were arranged for the visiting officials, both by the district and state administration.

Updates on the incidence were provided three times every day to all the entities concerned, including media. Necessary infrastructure was mobilised and put in place for providing real time video feed from the disaster site at Tapoban. This was helpful for information exchange, and regular review and supervision of the relief and rescue operations by senior officials from the state capital.

With photographs of the lake formed on Rishiganga River becoming public, speculations started to crop up in social media on possible breach and ensuing devastation in the downstream areas. In order to avoid panic and gather regular updates concerning the lake, necessary infrastructure was put in place on February 23, 2021 for having real time video feed from the lake site.

Search and rescue operations

Despite 02 personnel of their team being missing, the local police immediately started search and rescue operations and the same were reinforced by specialised forces, as they reached the disaster site. 12 people trapped in an adit of the hydropower project at Tapoban were rescued on February 7, 2021, and therefore, the rescue personnel hoped to save other people trapped in the tunnel.

Assistance of the hydropower project authorities was taken, for understanding the layout of the tunnels, so as to effectively plan the rescue operations. Specialised equipment was also mobilised from other hydropower projects in the state, to augment the rescue efforts. Despite round-the-clock operations, no one could, however, be rescued alive from the tunnel, and till May 23, 2021, bodies of only 22 people could be retrieved.

Figure 7. Search Operations along the Bank of Alaknanda River.

Search operations to trace the washed off people, were also carried out along the course of Alaknanda River (Figure. 7), as also in the debris deposited at various places, including the dam site at Tapoban. Only 84 bodies could, however, be recovered till May 23, 2021, and of these, only 50 could be identified.

Missing cell and unidentified bodies

Missing cells were organised both at the state and district level to compile the details of the missing people, and facilitate information exchange with the officials of the concerned state as also to provide required information and assistance to the next of kin of the missing persons.

Most of the retrieved bodies, however, could not be identified. Police and Health Department were, therefore, directed to carry out DNA sampling of the unidentified people, keep safe custody of the belongings recovered from the dead bodies, and maintain a record of specific personal identification marks observed on the body of the unidentified individuals. Next of kin of the missing people were, at the same time, requested to provide DNA samples, to match these with the samples collected from the unidentified bodies.

Declaration of death

As regards, declaring a missing person dead, Section 108 of the Indian Evidence Act, 1872 (19) requires that the person concerned, not be heard of for seven years by those who would naturally have heard of him/her, if he/she had been alive, with the burden of proving him/her alive, shifted to the person who affirms it. Next of kin of the missing people, however, requires death certificate for claiming the ex gratia relief amount payable by the state, as also for settling various property and inheritance related issues. Non-issuance of death certificate, thus, adds to the trauma of the next of kin of the missing people.

With only 50 of the 84 bodies recovered being identified, issuing death certificate in accordance with the provisions of Registration of Births and Deaths Act, 1969 (20) was a major challenge for the provincial government. The Registrar General of India (RGI) was, therefore, requested to issue specific guidelines for declaring missing people in this incidence as being dead.

Scientific investigations

The state government, promptly, constituted a high level committee of scientists and researchers of various technical and academic institutions, to investigate the causes of the disaster, and put forth suggestions to ward off possibility of similar incidences in future. Assistance was provided to the scientists for undertaking aerial reconnaissance of the affected area.

National Disaster Management Authority (NDMA), also constituted a multi-institutional joint assessment team, for carrying out investigations on various aspects related to the disaster, and suggesting measures for minimising the threat of similar incidences in future. This team carried out field investigations in the last week of March 2021.

Draining out the lake

Even though depth of the lake formed on Rishiganga River was not determined, scientific organisations started to come up with different scenarios, using dam break modelling tools assuming different depths. The state government, therefore, deputed the divers of the India Navy to estimate the depth of the lake. At the same time, the personnel of ITBP and SDRF were deployed, to physically widen the breached channel, and rule out the possibility of sudden release of the impounded water. The channel was thus cleared of obstructions and widened between February 22 and March 2, 2021, to ensure smooth draining out of the lake. A satellite-based quick deployable antenna was also set up at the lake site, to stream live video of the lake, so as to rule out rumours related to the lake breach in the media, and continuously monitor the lake level.

Discussion

Disaster risk assessment

Flood history of Dhauliganga River (Table 2) and evidences of previous damming in its catchment area (Figure. 3) have both been ignored, while planning the hydropower projects. Preparing a comprehensive inventory of previous disasters is therefore, recommended for establishing hazard profile of the area. Based on this, risk posed to various assets should be assessed comprehensively by taking into account extreme events with long recurrence period. It is recommended to make this practice a necessary legal requirement for all major development projects in the Himalayan region which is prone to a number of natural hazards.

It is recommended that the hazard and risk assessment reports be accessible to the public. Besides raising public awareness, this would discourage insurance companies from extending safety coverage to the unsafe projects, which in turn would ensure that only disaster-safe projects are implemented in the hazard prone Himalayan region.

Warning generation and dissemination

Considering the present level of technical knowledge, instrumentation, and communication facilities warnings, particularly of hydro-meteorological incidents, can be easily generated and disseminated. It is, therefore, recommended that a network of hydro-meteorological observatories, with real time data transmission capability, be established and calibrated for providing 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 peculiar 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 and warning dissemination measures in case of damming.

Mobile connectivity having proliferated to the grassroots level, authors recommends that the warnings be communicated, in both voice and text mode on all active mobile phones, in the area likely to be affected by the hazard. Together with this, it is recommended that authorities facilitate warning dissemination through electronic, social, and print media apart from signage and hoardings, at places where people routinely gather in large numbers. A dedicated mass awareness is also recommended for communicating the implications of different warning levels in the local context, together with actions that should be taken after receiving the warning.

Responsibility of hydropower projects

It is recommended to put in place suitable legislation, binding the management of the hydropower and other large infrastructure projects, to establish necessary warning generation and dissemination infrastructure for hazards that are prevalent in the region. Rather than standalone warning dissemination infrastructure by individual projects, the authors recommend an integrated system, into which all the projects pool their inputs and resources.

With such a system been in place, warning from the hydropower project on Rishiganga River would have certainly averted loss of human lives at Tapoban.

Diversification

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

Most investors are however interested in investment in areas, having basic infrastructure and facilities. The state could, therefore, create basic facilities and infrastructure in areas identified in different parts of the province for industrial development. This would be an incentive for the investors to explore possibilities of setting up their ventures in new areas. As a by-product, this would ensure balanced development of the province.

Death certificates for missing people

In the mountainous terrain, particularly in remote areas, it is often hard to retrieve bodies of the people affected by disaster, particularly in case of flash flood and landslide, wherein bodies are either washed off or buried under a thick pile of debris. Getting the guidelines issued by RGI after every disaster, is a time consuming affair. After June 16-17, 2013 disaster, guidelines were issued by RGI on August 16, 2013, while after February 7, 20121, Dhauliganga disaster guidelines were issued on February 21, 2021.

It is, therefore, recommended that standardized guidelines and procedures having legal sanctity, be put in place for declaring the missing people in disaster as being dead, so that the next of kin of the misdsing personns are not unnecessarily traumatized.

Specialised response

Disaster managers often fail to visualise the need of specialised response, and consider SDRF and NDRF capable of handling all emergency situations. In the present instance, timely mobilisation of people with experience and expertise in tunnel rescue could have enhanced chances of saving people trapped in the tunnel. It was because of the non-availability of ready reckoner of relevant individuals and institutions that the state could not muster the required resources.

It is, therefore, recommended that the repository of expertise, likely to be required in the aftermath of different disaster scenarios, be prepared, and accordingly, an online directory of individuals and institutions capable of providing the relevant services be maintained and updated regularly. This can be best handled by National Disaster Management Authority, which would ensure prompt specialised response and ensure saving of lives, property and infrastructure.

Clear charter of responsibilities

The lake formed during the incidence on Rishiganga River, breached naturally on February 12, 2021. Despite this, most agencies involved in post-disaster investigations, including NDMA, recommended special measures for averting threat, together with putting in place a dedicated monitoring and warning infrastructure.

No dedicated monitoring and warning system could, however, be put in place and the same is attributed to the involvement of a number of agencies, none of whom were directly responsible for implementation. It is, therefore, recommended that clear and unambiguous charter of responsibilities be prepared and enacted for all possible post-disaster actions.

Abnormal meteorological observations

The present incidence was accompanied by abnormal rise in temperature; between February 6 and 7, 2021, Tapoban at an altitude of 2000 m experienced a rise of 2.8^{o} and 5.4^{o} C respectively for minimum and maximum temperature, while the rise at Auli (2600 m) was observed to be 6.0^{o} and 9.6^{o} C respectively.

It is, therefore, recommended that abnormal changes in meteorological parameters be seriously considered and correlated with possible triggering of hazards prevalent in proximity. Precautionary actions can also be initiated based on such observations. This practice is sure to be futile in most instances, but certainly worth trying, as it could sometimes save human lives.

Conclusion

Considering the possibility of the occurrence of similar incidences gaining ground, with climate change impacts becoming increasingly prominent, the region is to face scarcity of capital investment, which in turn would have adverse impact on the pace of growth and socio-economic development of the province. With environmental groups trying to hold hydropower projects responsible for the disaster, this incidence is sure to have long-term adverse implications on the fate of hydropower, as well as other major infrastructure projects in the Himalayan region,

In order to ensure disaster resilient, eco friendly, and holistic development of the region, the authors recommend that (i) detailed, focused and long-term studies be planned and implemented for in-depth assessment of the risk posed by various hazards, with the incorporation of climate change driven extreme events, (ii) scientific documentation of past catastrophic events in the region be undertaken, (iii) robust, reliable and redundant warning generation and dissemination infrastructure be put in place, (iv) legally binding disaster risk assessment and reduction strategy be implemented, (v) diversification of assets be taken up as a policy, (vi) provision of the situation specific specialised response be put in place, and (vii) an unambiguous charter of post-disaster responsibilities be implemented.

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