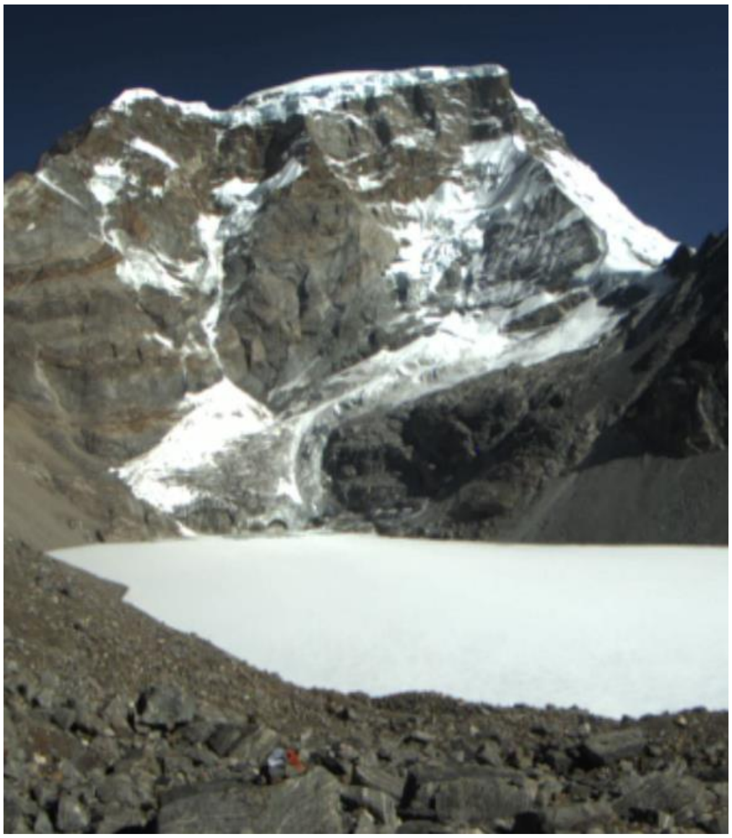


Mission report of GLOF Risk Assessment & Installation of AWS in Sikkim

NATIONAL DISASTER MANAGEMENT AUTHORITY

Contents

Abbreviations used in this document

3SCA	Strengthening State Strategies for Climate Action (referring to phase I)
AMS	Acute Mountain Sickness
BSNL	Bharat Sanchar Nigam Limited
CBRI	Central Building Research Institute
C-DAC	Centre for Development of Advanced Computing, India
CSIR	Council of Scientific and Industrial Research
CSTEP	Center for Study of Science, Technology and Policy
CWC	Central Water Commission
DDMO	District Disaster Management Officer
DECCC	Directorate of Environmental Conservation and Climate Change
DEM	Digital Elevation Model
DGRE	Defence Geoinformatics Research Establishment
DOECC	Directorate of Environment and Climate Change
DRR	Disaster Risk Reduction
DST	Department of Science and Technology
EWS	Early Warning System
GLOF	Glacial Lake Outburst Flood
GPS	Global Positioning System
GSI	Geological Survey of India
IHCAP	Indian Himalayas Climate Adaptation Programme
IHR	Indian Himalayan Region
IIRS	Indian Institute of Remote Sensing
INMARSAT	International Maritime Satellite Organization
ITBP	Indo Tibetan Border Police
LiDAR	Light Detection and Ranging
LR&DM	(Dept. of) Land Revenue and Disaster Management, Govt. of Sikkim
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
MHA	Ministry of Home Affairs
MoD	Ministry of Defence
MoEFCC	Ministry of Environment, Forest and Climate Change
MoJS	Ministry of Jal Shakti
MoRD	Ministry of Rural Development
NAFCC	National Adaptation Fund for Climate Change
NAPCC	National Action Plan on Climate Change
NCPOR	National Centre for Polar and Ocean Research
NDMA	National Disaster Management Authority
NLRRM	National Programme on Landslide Risk Reduction and Mitigation

NMSHE	National Mission for Sustaining the Himalayan Ecosystem
NRSC	National Remote Sensing Center
SAPCC	State Action Plans on Climate Change
SCA-Himalayas	Strengthening Climate Change Adaptation in Himalayas
SDC	Swiss agency for Development and Cooperation
SoI	Survey of India
SOP	Standard Operating Procedures
SSDMA	Sikkim State Disaster Management Authority
WSL-SLF	Swiss Institute for Snow and Avalanche Research

Attachments

A detailed conceptual sketch showing the expedition plan (Annex 1) Some glimpses of the expedition (Annex -2), List of Indian participants from various organizations: Team A and B (Annex - 3), List of participants in the workshop on 8th September 2023 (Annex 4), Agenda of the kick-off workshop (08 Sept, 2023) (Annex - 5)

Executive Summary

In September 2023, a pioneering expedition was conducted to two high Risk Glacial lakes of Sikkim named South Lhonak and Shako Cho Lake. Both these lakes are glacial moraine-dammed lake nestled in the pristine landscape of the Sikkim Himalayas. Both the lakes were identified as the risky glacier lakes in terms of GLOF in many of the previous scientific studies.

The Indian Himalayan Region (IHR) is confronting the escalating challenges posed by climate change. Glacial retreat and the formation of large glacial lakes have emerged as dynamic manifestations of this phenomenon. These changes elevate the threat of Glacial Lake Outburst Floods (GLOFs), necessitating proactive measures in hazard assessment and risk management. The National Disaster Management Agency (NDMA) of India recognized the urgency of addressing these issues, and this expedition to these risky lakes exemplifies a vital step toward comprehensive hazard assessment and risk mitigation.

The primary mission of this expedition, led by the National Disaster Management Authority (NDMA), in collaboration with the Swiss Agency for Development and Corporation (SDC), the Sikkim State Disaster Management Authority (SSDMA) and a team of state and national experts, was to install an Automatic Weather Station (AWS) at both the lakes and conduct a comprehensive risk assessment for future installation of Early Warning Systems (EWS) through the Teesta Valley to provide the GLOF Early Warning. This mission also had an agenda of training the State and National Experts for future installation of similar kinds of instruments.

The Automatic Weather Station (AWS) that has been installed provides data of many weather parameters like Temperature, Humidity, Air pressure, Wind speed, Wind direction, precipitation, radiation etc. Two cameras were also installed along with the AWS to capture daily photographs of the lake and the surrounding areas. Both the AWS and the cameras are providing daily updates of the lake.

This Expedition report provides a detailed account of the expedition, emphasizing the installation of the AWS and the risk assessment conducted in the two glacial Lakes situated in the remote and vulnerable region. It also aims to disseminate the findings and insights derived from this expedition, paving the way for disaster-resilient communities and future need for mitigation measures in all the risky lakes of this region.

Abstract:

A Pilot Project on Glacial Lake Outburst Flood (GLOF) risk assessment in two glacial lakes of Sikkim was taken up. This twelve-day expedition was organized by National Disaster Management Authority (NDMA) in collaboration with Swiss Development Cooperation (SDC), the Embassy of Switzerland in New Delhi, and the Sikkim State Disaster Management Authority (SSDMA). The expedition commenced from Gangtok on 09 September 2023 and concluded on 20 September 2023 with the submission of a joint brief report on outcomes and recommendations at the Debriefing session at Gangtok, Sikkim. During the expedition, Automatic Weather Stations were installed at south Lhonak and Shako Cho Lake. Field surveys including Bathymetry survey were conducted by the participating organizations. Recommendation like lowering of the lake water, widening, and deepening of the discharge point, and construction of gated check dams etc. were suggested as short-term as well as long-term prevention and mitigation measures for GLOF.

01. Background

The Himalayas, with their awe-inspiring grandeur, have long captivated the human imagination. Its towering peaks, vast glaciers, and pristine lakes paint a picturesque canvas. Yet, beneath this surface beauty lies a formidable challenge - the escalating risks associated with climate change. The Indian Himalayan Region (IHR) is confronting the escalating challenges posed by climate change. The rapid retreat of glaciers and the formation of large glacial lakes have brought to the fore the ever-growing spectre of Glacial Lake Outburst Floods (GLOFs), with the Himalayan region facing this grim reality. These necessitates proactive measures in hazard assessment and risk management.

In accordance with the National Guidelines established by the National Disaster Management Authority (NDMA) for the assessment and management of Glacial Lake Outburst Floods (GLOFs), developed in partnership with SDC, an initial first-order, desk-based analysis of GLOF risk within the state of Sikkim was conducted. Within the framework of hazard and risk assessment introduced by these guidelines, GLOF risk was evaluated as a physical event (hazard) intersecting with exposed and vulnerable systems, such as communities or sectors.

The preliminary assessment[1] of Glacier Lake Outburst Flood (GLOF) risk and hazard scenarios for Shakho Cho and South Lhonak lakes in Sikkim has been comprehensively detailed. Subsequently, responding to partners' requests, the downstream area below Chungthang dam was incorporated into the assessment. The results yield crucial insights into the lead time for alerts to exposed settlements (notably brief in certain cases) and potentially vulnerable infrastructure. These modelling outcomes, coupled with a preliminary Emergency Warning System (EWS) design, were shared at a stakeholder meeting co-organized by the Sikkim Department of Science and

[1] First-order assessment of Glacial Lake Outburst Flood risk for Sikkim and preliminary detailed hazard modelling of South Lhonak lake

Technology (DST) and SSDMA at Sikkim in May 2022, and two meetings at the National Disaster Management Authority (NDMA) in Delhi.

The EWS was conceived to be deployed in five steps – i) installation of monitoring stations to help define the EWS design components and warning thresholds; ii) design of final EWS along with identification of potential installation sites; iii) advise on conceptual design of hazard mitigation measures; iv) preparation of standard operating procedures (SOPs) for each responsible agency; and v) installation and initiation of early warning system (EWS).

The South Lhonak Glacial Lake, located at an altitude of 5,200 meters, is one of the fastest expanding lakes in Sikkim Himalaya (Eastern Himalaya), has become a prominent emblem of glacial change in the Indian Himalayan Region. It is a glacial-moraine-dammed lake. The lake was 18 ha in 1976 which grows to more than 70 ha in 2000 and more than 170 ha in 2023. The lake was 250 m (approx.) long and 125 m (approx.) wide in 1978 (SOI Toposheet 78A/1). Its rapid expansion, attributed to the melting of the South Lhonak glacier and contributions from the North Lhonak and main Lhonak glaciers, underscores the pressing need to address the risks associated with glacial lake outburst floods (GLOFs).

In view of this, so far, some intervention towards mitigation and prevention of GLOF has been undertaken since 2012. The first field visit to the lake was undertaken in 2012. In April 2012, the Department of Science and Technology (Climate Change), Sikkim Team first constituted a working group, who visited the South Lhonak Lake for a recce (general survey) of the glacial lakes in the Lhonak Valley. The team surveyed the moraine-dammed lake and observed the discharge point conditions, collected field photographs, and returned. DST (CC) was monitoring the lakes from time series satellite data. In the meantime, scientists from the NRSC Hyderabad studied the lake through satellite data and reported that South Lhonak Lake is highly vulnerable to GLOF events, though, it was suggested for ground observation to validate the remote sensing data. On the recommendation of the DST, the Government of India a multi-departmental working group was constituted for further study of South Lhonak Lake. Working Group approved a bathymetry survey of the lake and a resistivity survey of the moraine-dam for further scientific intervention. DST (CC), Sikkim carried out another scientific expedition in August 2014 to do a bathymetry survey of the lake and an electrical resistivity survey of the Moraine dam. The team successfully carried out bathymetric studies and calculated the volume of lake water. In addition to this, the team also did a resistivity survey of moraines and found the presence of dead Ice and permafrost beneath the moraine. After the analysis of data and a series of meetings with the working group constituted for South Lhonak Lake some short-term and long-term interventions for mitigations were suggested and the development of an early warning system was recommended along with siphoning. With this background, with the support of the Land Revenue and Disaster Management Department and CDAC- Pune, a multi-departmental expedition to South Lhonak Lake was carried out in September 2016. Siphoning of the lake and installation of Glacier Lake Monitoring System in the South Lhonak Lake was done. The siphoning was done with the expertise of the LR & DM Department, and SECMOL, Ladakh. GSI was also part of this expedition along with other organizations. However, the sensors of the monitoring system were damaged after two years of installation. Later, in 2018, controlled widening of the discharge point of the lake was undertaken by SSDMA. However, despite these interventions, the size of the lake has increased further with the melting of the glacier. (Field Report, GLOF Expedition, 2023). However despite of these interventions, the size of the lake has increase further with the melting of the glacier. As such the lake has been one of the major concerns in Sikkim due to the threat of the GLOF. The lake is likely to expand further in coming years due to the flat surface of the glacier till it reaches to its maximum threshold level. So it is very important to intensify the mitigation as well as preventive measures in the lake including scientific studies of the lake.

02. Objectives of the mission

The aim of the mission was to install monitoring stations (first step) for designing an early warning system on two lakes of North Sikkim. The specific objectives were as following:

i. Identify Indian experts from various agencies to be a part of the mission,
ii. Identify appropriate sites for installing the equipment,
iii. Understand the looming hazard in terms of the moraine dams and their stability,
iv. Install the monitoring stations,
v. Establish the satellite-based communication,
vi. Receive the data on cloud servers,
vii. Share the data with Indian agencies and
viii. Identify responsible Indian experts to maintain the monitoring stations and train them for any troubleshooting.
ix. Build capacity of the national experts by facilitating interaction with the Swiss experts Subsequent objectives include generating an early warning system (EWS) and preparation of SOP for flood emergency management.

03. Importance of the expedition:

The South Lhonak Glacial Lake is one of the fastest expanding lakes in Sikkim Himalaya (Eastern Himalaya). It is a glacial-moraine-dammed lake. The lake was 250 m (approx.) long and 125 m (approx.) wide in 1978 (SOI Toposheet 78A/1) which has now (in 2023) expanded to 2650 m (approx.) long and 650 m (approx.) wide (Landsat 8 Imagery, 2023, Fig.6) in size. The lake has expanded more than ten times longer and more than five times wider in 45 years. This fast-expanding lake has tremendously increased the threat of GLOF. Some mitigation measures have been taken up since 2012 including siphoning and widening of the lake. However, despite these measures, the size of the lake has increased further with the melting of the glacier. The lake is likely to expand further in the coming years due to the almost flat surface of the glacier till it reaches its maximum threshold level.

Its rapid expansion, attributed to the melting of the South Lhonak glacier and contributions from the North Lhonak and main Lhonak glaciers, underscores the pressing need to address the risks associated with glacial lake outburst floods (GLOFs). The expedition to South Lhonak Lake was conceived in response to the evolving threat landscape in the IHR. Climate change-induced alterations in glacial systems and the increasing proximity of residential, tourism, and hydropower infrastructure to high-altitude valleys necessitate a concerted effort in assessing and managing glacial-related hazards. GLOFs, characterized by the sudden release of water from reservoirs within or near glaciers, pose a significant risk. While GLOFs have been relatively rare in the IHR, notable incidents, such as the 2013 Kedarnath GLOF, underscore the catastrophic consequences of such events. The vulnerability assessment of the region highlights that Sikkim, in particular, is exposed to a significant number of potentially critical lakes, with South Lhonak Lake being a notable example.

04. Location and Environment of the Lakes:

The state of Sikkim is located between Nepal in the west and Bhutan in the east. It covers a total area of about 7300 km2 of which about 900 km2 is covered by glaciers (Worni et al., 2013). Climate is predominantly influenced by the monsoon with high precipitation from April to September followed by the winter season. Sikkim hosts numerous high-altitude lakes of glacier origin amongst which the South Lhonak lake (27°54′20″N and 88°10′20″E) is located at an elevation of 5200 m a.s.l. in the Teesta Basin, Sikkim, Himalaya (Fig. 2A). The South Lhonak glacier has a total area of 12.5 km^2, as mapped in 2019. During the past 29 years, the glacier retreated from 6.4 km to 5.1 km, while the overall glacier area shrank by ~0.96 km2 (Fig. 2D-G). The lake has been exhibiting significant growth over the years as it grew from 0.42 km2 in 1990 to 1.35 km2 in 2019 (Fig. 2D-G). The frontal moraine damming the lake has a width of approximately 500 m and it gets narrow towards the north, where a surface outflow from the lake is located. The surficial outflow channel cuts the moraine dam in the north-northeast direction while the main valley is oriented towards the east (Fig. 2C). The crest height of the frontal part of the damming moraine (south from the outflow channel) is 7 m above lake level, as measured in the field by Sharma et al. (2018). This part of the moraine is characterized by a hummocky surface indicating the presence of ice within the dam with several small lakes on the moraine surface (thermokarst of precipitation-filled), and the absence of vegetation cover. So far, there has not been any reported GLOF; however, Kumar and Murugesh Prabhu (2012) presented a report to the Government of Sikkim, where the lake outlet is stated to show evidence of a previous GLOF (Fig. 2C). The flow channel of the South Lhonak Lake originates as “Goma Chu” from the South Lhonak lake and flows SSE for a distance of 22.8 km, from where it flows as “Langbo Chu”, "Lhonak Chu”, and “Zemu Chu” till it joins the Teesta River at Hema. The channel is characterized by steep side slopes and varied land use land cover. The valley downstream of the lake is moderately populated, with a major town being Chungthang located 62 km downstream of the lake where the Teesta Stage III hydropower dam is located. According to the 2011 census report (censusindia.gov.in), Chungthang had more than 10,000 inhabitants, living in more than 1900 households. The town has evolved over the years and has especially seen rapid growth after the construction of a hydropower station in 2015. Other small townships like Latong, Yuigang, and Chuengtong exist along the flow channel (Fig. 3) (Sattar et al., 2021). The Shako Cho glacial lake (27°58′29″N; 88°36′ 58″E) is located at 5000 m a.s.l. in the northern part of Thangu valley. The lake is located approximately 10 km upstream of the nearest settlement of Thangu village (3900 m a.s.l.). The Shako Cho Lake is a large proglacial in Sikkim and is highly critical due to various key indicators including low width-to-height ratio of the end moraine, steep damming moraine composed of loose granular material, the presence of a 1000-m high mountain slope rising above the lake, and the location of nearest Thangu village (Worni et al., 2013). Previous studies reported that, as the freeboard of the damming moraine is 10 m, mass impacts into the lake from the mountain face above the lake can lead to dam overtopping waves. The dam is susceptible to erosion due to the sharp dam geometry and weak dam structure (Worni et al., 2013). The flow channel originating at the lake is characterized by steep side slopes and a lack of vegetation in the upper part till the nearest settlement at Thangu. Both South Lhonak and the Shako Cho lakes are potentially exposed to avalanches originating from the glacier headwall located upstream of the lakes (Fig. 4A and B). In this study, we identify avalanche sources from these steep slopes that can have a fall height of 1600 m and 1100 m for South Lhonak Lake and Shako Cho Lake respectively. Avalanches originating from these slopes can potentially impact the upstream end of the lake. The impulse waves from the impact zone can eventually lead to overtopping at the damming site causing a GLOF event. Most importantly, the settlement at Thangu is potentially exposed to GLOF from the Shako Cho Lake while Chungthang is exposed to GLOFs from both the lakes including the South Lhonak Lake (Fig. 4C-E). Also, several other small settlements including Yathang, Talam, Latong, Yuigang, and Chuengtong are exposed to GLOF from the lakes.

South Lhonak Lake:

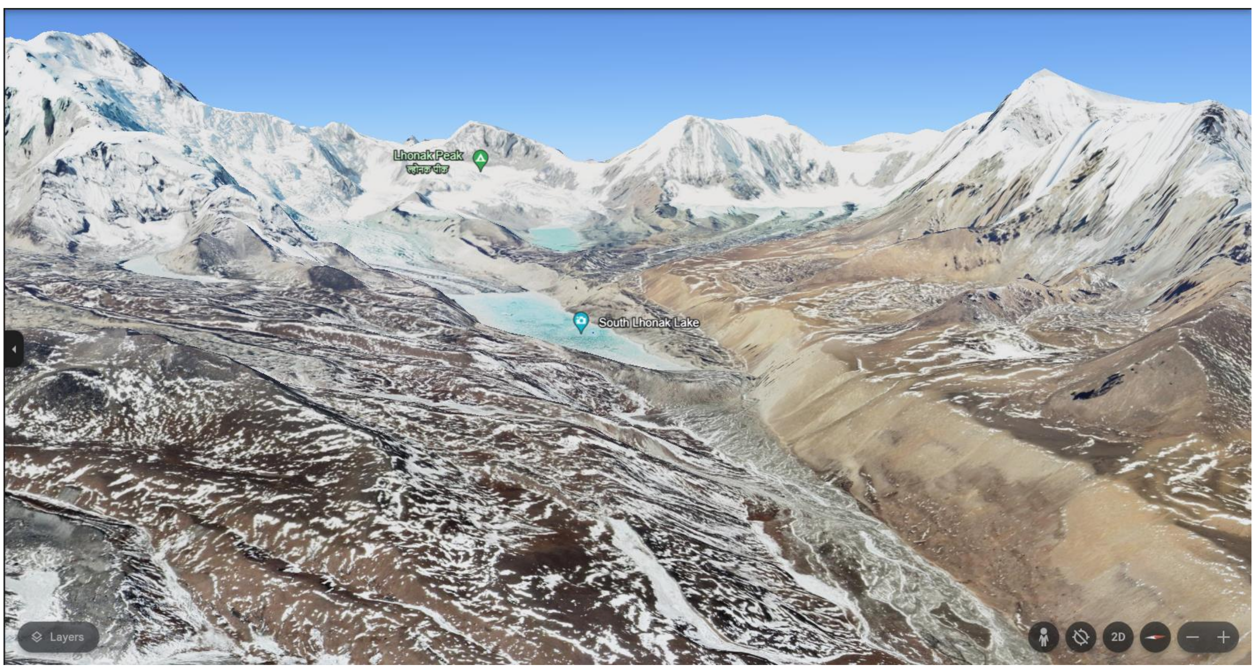


Fig. 1: 3D view of South Lhonak Lake and nearby areas (source: Google Earth).

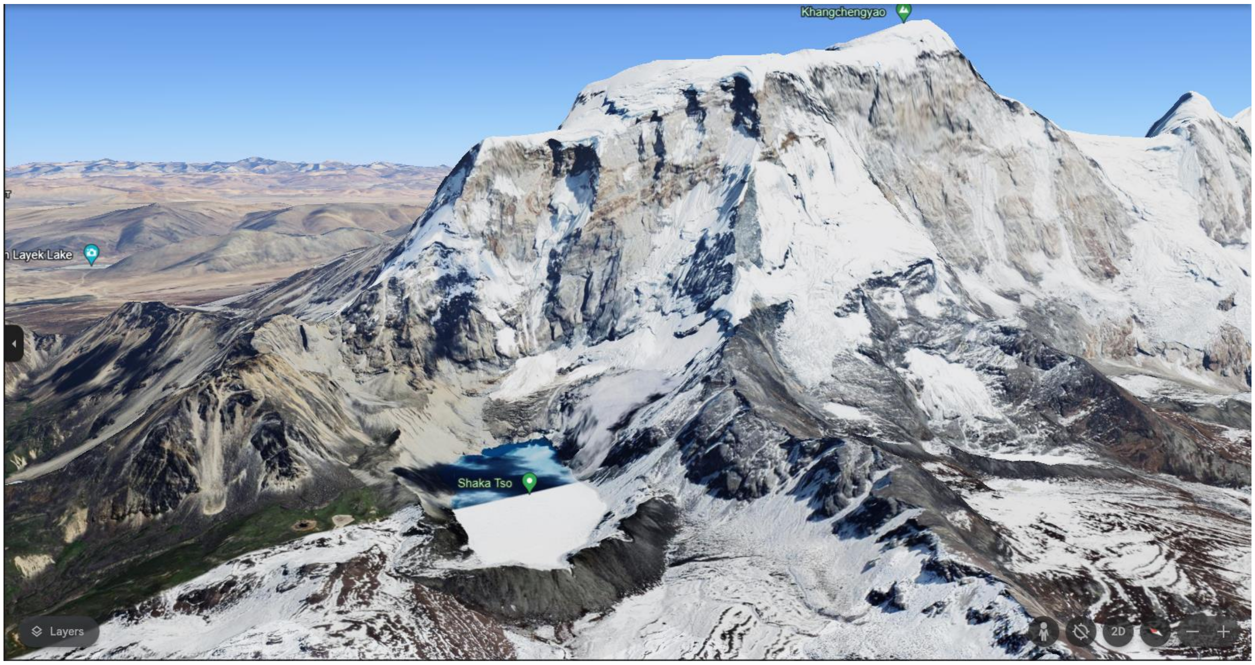


Fig. 2: 3D view of Shako Cho lake and source glacier (source: Google Earth).

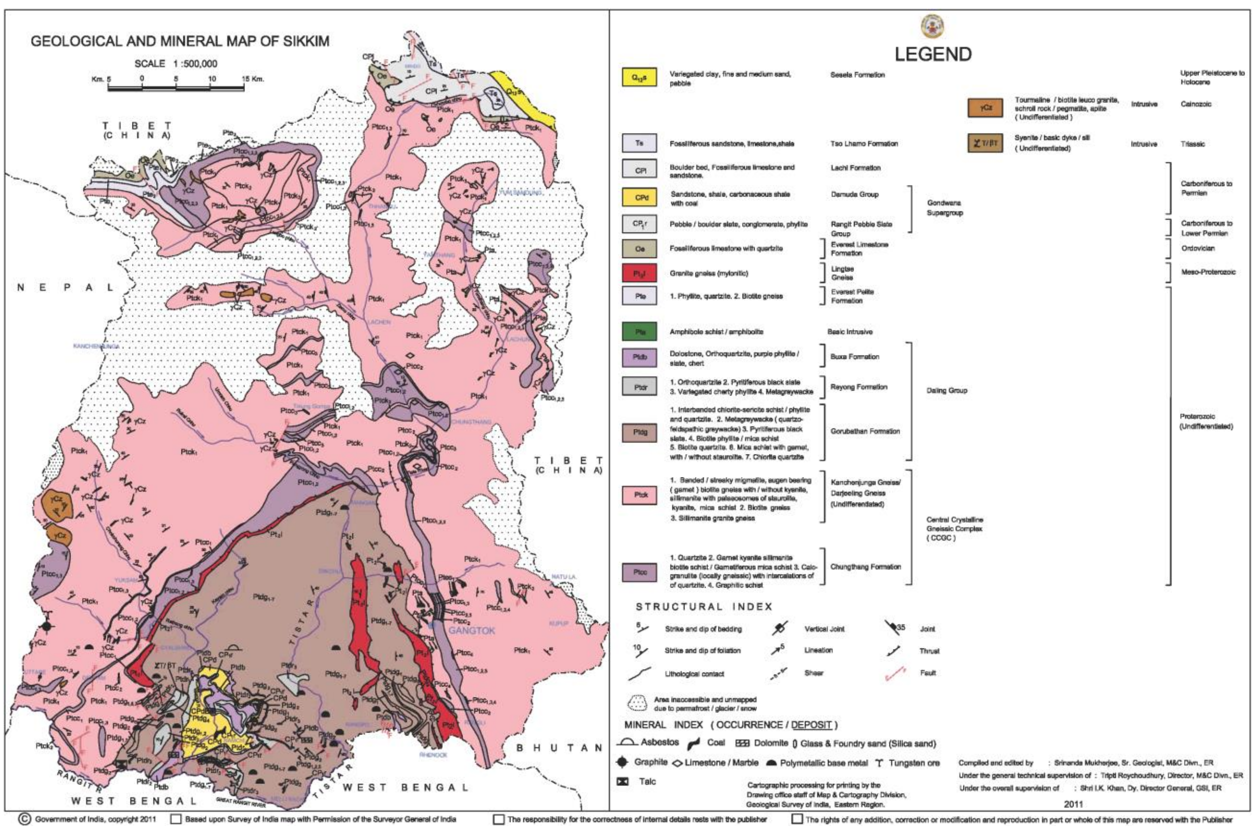


Fig. 3: Geological and Mineral Map of Sikkim (Source: ENVIS Hub Sikkim).

05. Overview of the mission

As part of step 1, a multi-agency Indo-Swiss mission to the two lakes, was proposed to be held under the lead of NDMA and SSDMA in the month of August/September 2023.

As part of this mission, it was agreed that an automatic weather station and two cameras to capture changes in the lakes would be installed on both the lakes and a functional satellite-based data communication system would be established. The Swiss consortium designed the weather monitoring stations and imported the whole setup to India with the help of NDMA.

The sections below capture the objectives, outcomes and lessons learnt from the mission that took place between 4 -21st September, 2023.

The mission was from 4th September to 23th September. The expedition to the lakes took place between 9th to 19th September. Below Table 1 shows the participation and The Swiss experts arrived on 3rd of September as per the schedule and reached Gangtok on 4th accompanied by expert from SDC. The monitoring equipment was to be unpacked and reassembled in Gangtok to ensure that the international transit didn't cause any damage to the sensitive equipment. Other Indian experts arrived on 6th onwards and followed the schedule, as per Table 2.

Table 2 shows the details of the overall mission from 5-22 September.

The mission was divided into two components – capacity building through various interactions and installation of the monitoring stations. The capacity building of Indian experts was carried out through formal and informal interactions with Swiss experts from 6 Sept to 8 Sept. More details of this capacity building are given in section G below. Installation of the monitoring stations with the help of the Indian experts was carried out from 9 Sept onwards till the Swiss team departed to Delhi on 20 Sept.

Below table shows a detailed participation of various agencies in the GLOF mission. Broad types of agencies that were part of the mission were: National level agencies led by NDMA, State level agencies, Indian army and ITBP and Embassy of Switzerland (through SDC and experts from Geotest and Geopraevent). Following Table 1 shows the details of participation.

***Table 1**: Overall participation in the GLOF mission to Sikkim*

Type of agency	Agencies participated	Names of participants
Swiss agencies	**GeoTest**	Christoph Haemmig, Bernard Krummenacher
	GeoPraevent	Christian Kuster, Susanne Wahlen
National agencies	**NDMA**	Dr. Sweta Baidya, Sr. Consultant, Mozart Maxon, Consultant, Mr. Abhishek Sharma SRO, Mr. Neel Kamal, EA
	GSI, SOI, NRSC, CWC, NCPOR, C-DAC, DGRE	For the list, please refer to Table 4 and Table 5

	Indian Army and ITBP	Capt Saurabh Singh, Naib Ris Palwinder Singh (10 Armd Regt/ 27 Mtn Div.); Capt Saurabh Singh, Naib Subedar Pawan Kumar (8 RAJ Rif/ 27 Mtn Div.); Shri Sheo Shankar Prasad Dy. Commandant (ITBP)
Govt of Sikkim agencies	**LR&DM, DST, Health & Family Welfare Dept, Sikkim Urja, Home Guards & Civil Defence**	For the list, please refer to Table 4 and Table 5
Other state participants	**Arunachal Pradesh Uttarakhand Himachal Pradesh**	Beru Dulom, DDMO, Yingkon, Upper Siang district Arunachal Pradesh Dr. Ruchika Tandon, Senior Geologist, (ULMMC), Uttarakhand
Swiss Embassy	**SDC, PIU**	Eveline Studer, Divya Sharma, Divya Mohan, Ajay Katuri, Ada Lawrence

06. Role of National Agencies

6.1 National Disaster Management Authority (NDMA)

NDMA extended all possible support for the following critical aspects related to the mission. This support included from technical, logistics, liaison, financial and import of equipment to provision of experts to the expedition. Following list identifies some tangible support items:

1. Provided support in getting permits and approvals from relevant agencies as below:
    a. Approvals from the Ministry of Home Affairs and Ministry of External Affairs (approvals needed for the Swiss experts to visit the border areas and install the monitoring stations),
    b. Approvals for all the Indian experts to visit the restricted areas of the international border (along with the SSDMA),
    c. Approvals for installing the monitoring stations in the border areas of Sikkim,
    d. Approvals for installing the INMARSAT satellite communication system to share data generated by the monitoring stations to a cloud storage,
    e. Gettings necessary approvals from the Central Pollution Control Board (CPCB) for import of solar power compatible batteries for the monitoring stations;

2. Held extensive discussions with ISRO scientists for developing an indigenous satellite communication system (Very Small Aperture Terminal - VSAT) for exchanging data from the monitoring stations to cloud;
3. Approval of INMARSAT satellite communication system after a thorough discussion with Swiss experts and analysis of the system proposed by the ISRO scientists;
4. Extensive support in acquiring the Wireless Planning and Coordination (WPC) license, WPC Equipment Type Approval (ETA) for the Hughes 9502 device, DPL (Dealer

Processing License), acquisition and initiation of Broadband Global Area Network (BGAN) SIM cards for the monitoring stations;
5. Liaison with the Ministry of Finance and DGCA for the import of the equipment and batteries needed for the monitoring stations;
6. Support in import of the equipment from Switzerland to India through the Central Board of Indirect Taxes & Customs;
7. NDMA provided financial support to SSDMA for carrying out the GLOF Mission 2023;
8. Requested nominations from the national agencies to depute officers to be a part of the mission and expedition;
9. Identified the medical tests needed for the expedition members in order to identify the vulnerable officers from acute mountain sickness (AMS);
10. NDMA has also deputed two officers to be part of the expedition to the lakes, in order to maintain a continuity of knowledge transfer.

It was also agreed that the data received from the monitoring stations would be stored on a Geopraevent operated portal and access to the same would be provided to the various Indian agencies, through NDMA.

6.2 Support from Indian Army

The expedition was supported by the Indian Army and Indo-Tibetan Border Police (ITBP), especially on the high altitudes. Support from India Army and ITBP was requested, especially for the emergency evacuation and logistical support, because of their presence and operations in the higher elevations. Officers of the rank, Captain were deputed by Indian Army and a senior commandant from ITBP. The support in scouting for an ideal location for the installation of the monitoring stations, installing the stations, medical support and evacuation of the mountain sick expedition members was provided by the Indian Army and ITBP.

6.3 Support from Govt. of Sikkim – SSDMA (LR&DM)

Overall coordination of the mission was taken up by the nodal agency for disaster management – SSDMA. The department of Land Revenue and Disaster Management headed by the Chief Minister of the State has taken a keen interest in this project, given the GLOF risk posed to the state. SSDMA, represented by Special Secretary and Director had shouldered the responsibility of hosting all the experts, Swiss as well as Indian and facilitate the mission. Overall logistics, coordination, identifying and engaging a trekking agency for conduct of the expedition were some of the tasks taken up by the SSDMA. SSDMA had also set up a base camp (with sat-phone connectivity) at Thangu for the close coordination with the expedition team 24x7.

The Hon. Minister of LR&DM had flagged off the expedition on 9th September, which boosted the morale of the team members.

6.4 Health and Family Welfare department

HFW had conducted medical checkup of all the Indian experts, for any signs of acute mountain sickness prior to the expedition. Also, Govt. of Sikkim had deputed two medical doctors along each team for the expedition. The constant support of the doctors kept the expedition member's health and spirits up during the expedition.

6.5 Participation of the National Agencies

Indian agencies as mentioned in Table 1 have been quite active and inquisitive regarding the instruments and the process of installing them. A lot of interactions between the Swiss experts and the Indian experts made it possible to transfer the technical knowhow and building the capacity of the Indian experts in the fields of weather monitoring stations, early warning systems, design of EWS, assembling of the early warning systems for harsh and remote environment, like north Sikkim, etc. A list of the participating agencies and the names of the officers are annexed at Table 4 and Table 5.

07. Schedule of the mission

The Swiss experts arrived on 3rd of September as per the schedule and reached Gangtok on 4th accompanied by expert from SDC. The monitoring equipment was to be unpacked and reassembled in Gangtok to ensure that the international transit didn't cause any damage to the sensitive equipment. Other Indian experts arrived on 6th onwards and followed the schedule, as per Table 2.

Table 2: Schedule of the mission from 5th to 22nd of September

Date	Activities	Mission members
5 – 7 Sept	Unpacking and assembly of monitoring equipment	Swiss experts and SDC
6 – Sept	Arrival, health check-up expedition members	Indian experts
7 – Sept	Demonstration of monitoring stations to all Indian experts	Swiss experts and SDC
8 – Sept	Pre-expedition workshop: EWS design and DRR response Field Mission Kick-off Meeting	NDMA, SSDMA, DST, LR&DM, GoS, SDC, Swiss experts, Khangri Treks
9 – Sept	Flag off by Hon. Minister of Land Revenue and Disaster Management, GoS at Gangtok. Team moved to Lachen, 9000ft and halted for the night.	-do-
10 – Sept	Started from Lachen and reached Thangu (38km in 2hrs) Accommodation was provided in lodges Huts/ tents. Equipment was checked and repacked in two different vehicles to send to two lakes.	Expedition members
11 – Sept	Thangu acclimatization day - hike to Chopta valley, Kalapathar and after lunch walk to nearby places.	Expedition members

Date	Activities	Mission members
12 – Sept	Brief meeting after breakfast with all the members of the expedition. A Lhama performed prayers for all the members and blessed the mission. Expedition members were divided into two groups. Team (A) drove to Gaygong and start, trek to Shako Cho, 4982 metres 6 km up trail, 6-7 hrs, Accommodation in Tents at basecamp. Team (B) will drive to Muguthang camp, nearer to Chumekgyatsa, 16450 ft. 3hrs drive and tented camp.	Expedition members
	After the teams left for the expedition, returned to Gangtok from Thangu	NDMA, SDC
13 Sept	Team (A) Shako Cho group started the work, at fixed camp and Team (B) drove till Chumekgyatsa 12-14km 1.5 hrs drive and hike to south Lhonak Lake 5500 mtrs 4-5km about 3-4hrs, Tents camp, (The last camp)	Expedition members
	Drove to Bagdogra and flight to Delhi	NDMA, SDC
14 to 17 Sept	Both the Teams (A) (B) work on installation at their respective sites, (A) Shako Cho and (b) South Lhonak Lake. Tents, camp.	Expedition members
17 Sept	Travel from Thangu to Gangtok by road	Susanne Wahlen
18 Sept	Team (A) wind up and moved to road head and drove down to Lachen Team (B) Wind up and moved to Lachen	Expedition members
	Drive to Bagdogra and flight to Delhi	Susanne Wahlen
19 Sept	Both Teams arrive at Gangtok and stayed	Expedition members
	Flight from Delhi to Zurich	Susanne Wahlen
20 Sept	Debriefing with SSDMA and other experts in Gangtok Elaboration on SOP	Expedition members
21 Sept	Experts left Gangtok for Bagdogra by road and flew off to Delhi	Swiss experts
	Indian experts left from Gangtok	
22 Sept	Debriefing meeting at NDMA	Swiss experts, SSDMA (virtual), DST (virtual), GoS (virtual), some Indian experts and SDC

7.1 Structure of the mission

The whole mission can be divided into two time slots – upto 8 Sept and after 8 Sept. In the first time slot, lot of interactions were facilitated between the Indian experts and the Swiss experts, which included a national workshop in Gangtok with many technical deliberations. Post expedition to the lakes, these interactions were of informal in nature and were around the technical aspects of the instruments and how these monitoring processes can be improved in the subsequent missions.

7.1.1. Pre-expedition Workshop (8 Sep, Gangtok)

- A pre-expedition workshop was organized in Gangtok on 8 Sept by SSDMA with participation of expedition members and representatives of relevant government departments. The composition was as follows:[2]
- This included deliberations on specific risks related to the two glacial lakes in Sikkim and the Teesta River valley, assessments carried out so far for the lakes, and the need for EWS and mitigation measures.
- The Swiss experts talked about the monitoring instruments to be installed on the lakes and the proposed design of an EWS system.
- The trek operator apprised all the participants of the conditions of the trek and precautions to be taken.

7.1.2. Flag-off of the expedition – 9 Sept

In an important event, attended by the Hon. Minister of Land Revenue & Disaster Management, Min. of Forest and Environment, other dignitaries from the state of Sikkim, the Hon. Minister of LR&DM flagged off the expedition.

7.1.3. Expedition (9 Sep onwards)

- The officers nominated by the respective national institutions participated in the expedition and travel to the lakes. Due to lack of physical fitness, some of the officers could not participate in the expedition or who had joined had to be evacuated to Thangu and further to Gangtok, amidst the mission in want of medical care. Some of the Indian experts suffered Acute Mountain Sickness (AMS). This was observed in the officers, who were cleared by the medical tests carried out by the Sikkim Govt.
- The expedition was flagged off by the Hon. Minister of Land Revenue and Disaster Management, Government of Sikkim from Gangtok. Both the teams A and B ascended to the lake sites in a phased manner leaving sufficient time for acclimatisation.
- NDMA and SDC teams went upto Thangu to provide support for the mission, and came down after the ascent of the teams to the lakes on 12 Sept. Subsequently the SDC team returned to Gangtok and then to Delhi on 12 and 13 Sept respectively.
- Both the teams installed the monitoring stations at the lakes and the expedition was completed according to the plan following a de-briefing session in Gangtok.

[2] A detailed list is annexed at Annex 3

08. Main achievements

8.1 Identify appropriate sites for installing the equipment

The Swiss experts along with the Indian experts have conducted a recce on the lake sites to identify ideal location for the monitoring stations. It was important that the location is selected so that the safety of the instruments is ensured and also the viewing angle of the cameras is ideal for covering the glacier, lakes and also the moraine outlet of the lake (in case of the Shako Cho there is no outlet, as of now). This task was achieved on day one after reaching the basecamps.

8.2 Understand the looming hazard in terms of the moraine dams and their stability

Reconnaissance survey was conducted around the lake, wherever possible, to understand the impending hazard of landslides or avalanche that may send debris into the lake. The lakes are bound by the moraine dams on all sides. For the South Lhonak Lake, there is an outlet in the eastern direction, from where the water continuously flows out in eastern direction Dzanak valley to merge with Dzemu rivulet and subsequently into Teesta River at Lachen. For the Shako Cho, there is no outlet.

8.3 Install the monitoring stations

The Swiss experts had installed the equipment, as a part of a dry run, in Gangtok. All the components were tested and satellite-communication was also established. Some initial hiccups with satellite communication were dealt with by changing the SIM cards and trying new SIM cards issued by the BSNL. All the components – weather monitoring stations, router for communication, data logger, solar panels, battery module, control cabinet, cameras, were checked with satisfaction. Satellite communication was also established successfully. On 7th September, all Indian experts were invited for a demonstration of the monitoring station, where experts were encouraged to ask questions and seek answers from the Swiss experts. This demonstration went for more than 1.5 hours in spite of the drizzle on the open terrace.

The Swiss experts had installed two monitoring stations on the lakes, along with a group of Indian experts. Two teams, A and B were divided to go to two different lake sites. Team A to Shako Cho and Team B to South Lhonak. Team A installed the monitoring station on 14 Sept at Shako Cho, and Team B had installed the monitoring station on 17 Sept at South Lhonak. Following are the snapshots of the pictures and data received from monitoring Stations.

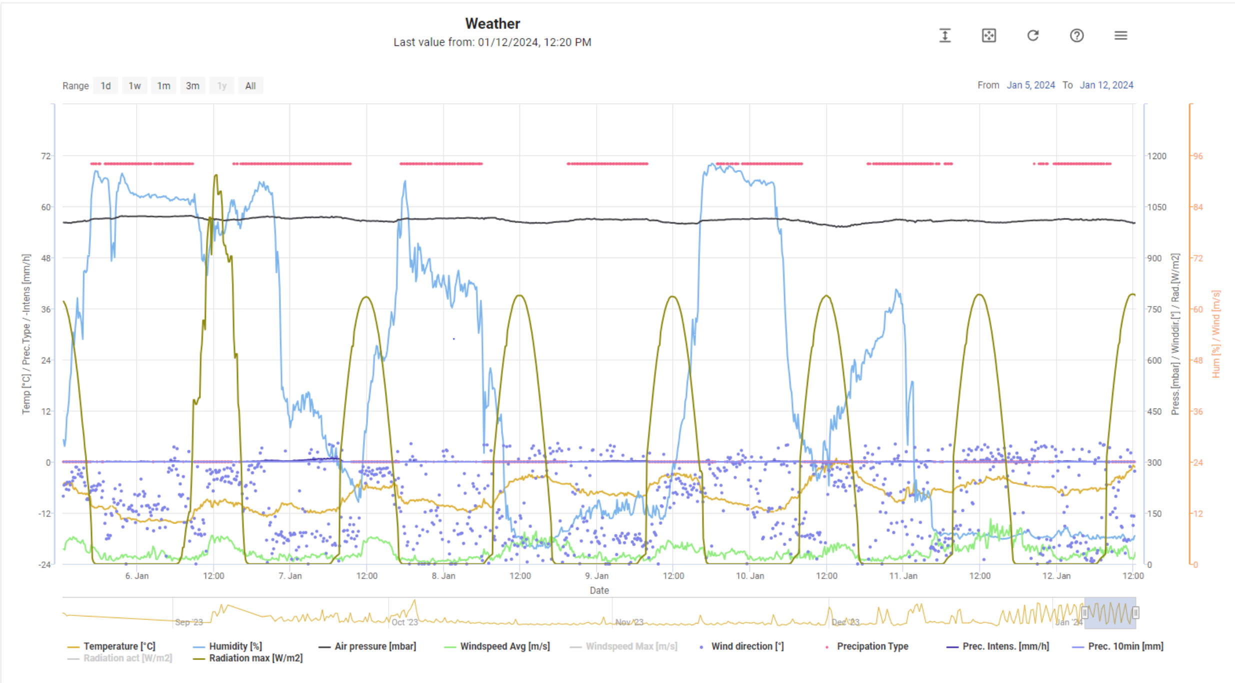


Fig. 4: Data on weather parameters received through the installed EWS

Fig. 5: Photograph of western side of Shako Cho Lake taken by the camera installed in the AWS

Fig. 6: Photograph of eastern side of Shako Cho Lake taken by the camera installed in the AWS

8.4 Establish the satellite-based communication for receiving the data on cloud servers

One of the components of the monitoring stations is satellite-based communication (satcom) of data to the designated cloud server. The data collected on daily basis, which consists of weather data, two images from the cameras are to be uploaded to the server everyday based on the availability of satellite connection. The monitoring stations were designed in such a way that the data is communicated via satellite to the server using minimum battery charge. The experts had installed the monitoring station and connected both the stations to INMARSAT satellites for data communication. While the expedition team was there, both the communication systems were checked for satisfaction of the experts.

8.5 Share the data with Indian agencies

While the data is stored on the cloud servers, the access was provided to Indian agencies based on their request. The calibration of the data and communication of data was being carried out by GeoPraevent team from Zurich, after the mission was completed. The troubleshooting of the South Lhonak station was also going on using the two-way communication established with the monitoring station. After the GLOF event of 4th Oct, NDMA and SSDMA were provided access to the Shako Cho monitoring station (which is under continuous monitoring and calibration).

Table 3: Various interactions as envisaged by the project

Date	Interaction	Details
6 – 7 Sept	At Gangtok, hotel terrace	Regarding monitoring stations and demonstration of the equipment
8 Sept	Pre-expedition workshop in Gangtok	Participation of expedition members and representatives of relevant government departments
9 – 13 Sept	Expedition and interaction with the experts	Lot of informal interactions with the experts regarding EWS, monitoring stations, installation, operation and maintenance of the stations, etc.
14 – 20 Sept	Various debriefing meetings at Gangtok	Update on the installation and next steps to be followed with SSDMA, NDMA and national experts
22 Sept	Debriefing at NDMA in Delhi	Update on the installation and next steps to be followed with NDMA, SSDMA, national experts and SDC.

09. Environmental conditions, including climate, terrain, and vegetation:

Sikkim’s geographical location from Thangu to the glacierized mountains near Lhonak Lake allows it to have temperate to alpine climatic conditions. Temperature conditions vary from temperate to cold deserts in the snowy mountains. No meteorological station has been set up in this region. However, weather data from different sources at different locations in Sikkim reveals temperatures seldom exceeding 28°C (82°F) in summer in the entire Sikkim. The average annual temperature for most of the Sikkim is around 18 °C (64 °F). Sikkim receives regular snowfall and the snow line ranges from 6,100 m (20,000 ft) in the south to 4,900 m (16,100 ft) in the north (Hooker, J. D., 1854). The tundra-type region in the north is snowbound for four months every year, and the temperature drops below 0°C (32°F) almost every night (Choudhury, M., 2006). In north-western Sikkim, the peaks are frozen year-round because of the high altitude, temperatures in the mountains can drop to as low as -40°C (-40 °F) in winter (Choudhury, M., 2006). It is also the most humid region in the whole range of the Himalayas, because of its proximity to the Bay of Bengal and direct exposure to Southern monsoon. The area is part of Eastern Himalaya and is notable for its biodiversity, including alpine and temperate climates. Terrain: The study area is part of the Higher Himalayas, though, the level of deformation is less compared to the Western Himalayas where folding, faulting, and thrusting of rocks are common. The study area is moderately rugged with undulating topography. The study area is a U-shaped valley with erosional as well as depositional features of a glacio-fluvial environment. Vegetation: Tundra is an area where tree growth is difficult because of cold temperatures and short seasons. Vegetation in tundra is limited to a few shrubs, grasses, and mosses. The ground is often too cold for plants to set down roots, and without plants, few animal species can survive. Alpine tundra is separated from a forest vegetation region by the tree line, the area beyond which conditions are too harsh or cold for tree growth. The weather in the alpine tundra is cold, snowy, and windy. Animals like mountain goats live in this vegetation region.

10. Findings and Observations:

10.1 South Lhonak:

Following are the presentation of the main findings and observations in terms of Hazard and Risk Assessment. After reaching the South Lhonak Lake, an initial survey (geological & geomorphological) was done surrounding the lake area. However, the survey was in general and limited to a small area of the eastern portion of the lake only because of the difficult terrain, logistics, time constraints, safety, and security concerns (As the study area is at the junction of the India-China-Nepal border). Rock outcrop was not seen near the lake because of thick deposits of moraines. Exposed outcrops of Phyllite and Biotite-Gneiss in the northern nearby area and outcrop of Biotite-Gneiss in the southern nearby area (just next to the lateral moraines at both end) to the lake were crushed and unconsolidated because of movement of Lhonak glaciers. Exposure of outcrop/bedrock was not present in the nearby area for the installation of AWS except at the moraine. Finally, a suitable location was identified which covers the entire lake, glaciers, and accumulation zones at one end and the discharge point of the lake at another end. The AWS was installed on a boulder of 3.5x 2x 2.5 m (approx.) which is sturdy and resistant to weathering. It was stable and embedded into the moraine. The site was at the end moraine of the glacier at the eastern end of the lake (Fig.7).

Fig. 7: Installed AWS at South Lhonak Lake (Photo clicked during the expedition)

The massive boulder was of gneissic rock of alternate thick and thin bandings of plagioclase feldspar and biotite mica respectively. The glacial valley of Lhonak is a broad U-shaped valley. The base of the valley was biotite-gneiss which was observed during the initial excursion around the base camp area (27°54'44.52"N latitude and 88°12'57.80"E longitude). Though the base of the valley was mostly covered with materials brought by glacio-fluvial media. The S. Lhonak is a pro-glacial lake of 2.65 km long and 0.675 km wide (approximately) which is formed due to the continuous retreat of the Lhonak Glacier Snout and the natural check-dam formed due to the end moraine and, further, by successive recessional moraines. As this lake holds a great volume of water and the discharge of the lake is narrow like a bottleneck at the north-eastern end of the lake, a sudden outburst of the lake may create a disaster-like situation and may cause loss of human life and property in the downstream of Teesta River Basin. This is the reason why the assessment and monitoring of this lake becomes vital. The slope gradient of the accumulation zone in the upper reaches of the Lhonak Glacier is from high to very high (at the headtop) at the southern margin of the mountain which is prone to avalanches. This could be one of the major reasons for GLOF in the future. The lithology of surrounding areas (north, south, and east) of the lake are unconsolidated moraines which are further surrounded by crushed and loose materials of phyllite and biotite-gneiss from two sides of the lake (north, and south). The narrow discharge point of the lake is also bounded by crushed and loose materials of phyllite and biotite-gneiss from the northeastern side. Such kinds of surroundings make the lake vulnerable by blocking the discharge point completely or partly. The surrounding rock materials are loose and non-resistant to weathering and erosion. This may lead to filling the lake suddenly with debris/mud and snow/ice specifically during monsoon when it may get lubricated with water causing a complete block of the discharge point. The lake water may be squeezed suddenly during torrential downpours and/ or during a cloudburst by filling up the loose materials and snow/ice from the surroundings and accumulation zones respectively. Discharge of all three glaciers, North Lhonak, Lhonak, and South Lhonak is into the South Lhonak Lake. This is one of the reasons for the fast expansion of this lake. The other reason for the fast expansion of this lake is that this is a pro-glacial lake (Fig. 8, 11), which means, the South Lhonak Glacier directly terminates into this lake. Water has a quality of high latent heat due to this reason the snout of this glacier continues melting even during the winter periods, as, the lake water transfers its heat to the glacier snout when the upper layers of water freeze. The South Lhonak is a low-dipping (~4°) Glacier till 1.65 km from its snout (Fig. 3, Elevation Profile from Google Earth Image), which indicates that the lake will continue expanding if the climatic and morphological conditions prevail. This will worsen the situation for GLOF on a bigger scale to the downstream settlements and infrastructures.

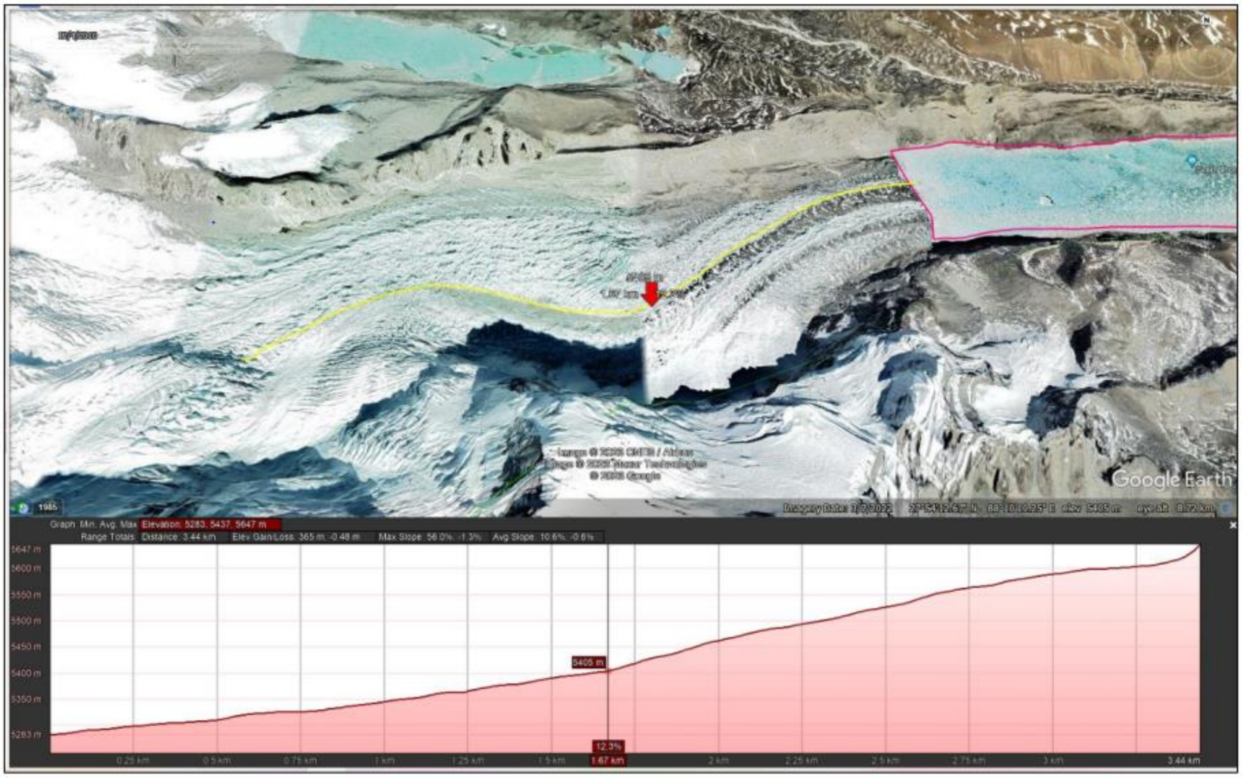


Fig. 8: Elevation profile of the S. Lhonak Glacier (yellow line in the Google image).

10.2 Shako Cho (Tshaka Tso):

Similarly after reaching the Shako Cho Lake, an initial survey (geological & geomorphological) was done surrounding the lake area. However, the survey was in general and limited to only eastern and southern portion of the lake, because of the difficult terrain, logistics, time constraints, safety, concerns. Rock outcrop was not seen near the lake because of thick deposits of moraines comprising of loose boulders.

The Shako Cho is a moraine-dammed glacial lake in the northern part of Sikkim Himalaya at the elevation of 4962 m ASL. The lake is SW to NE elongated and is about 15 km northeast of Thangu village (3900 m ASL). There is no clear lake outlet and is surrounded by potential avalanche sites (PASs). It takes about 3 hours trek from Gegong above Thangu village. The lake has a maximum depth of about 96 meter that has potential of GLOF accelerated by the snow avalanches process chains.

Exposure of outcrop/bedrock was not present in the nearby area for the installation of AWS except at the moraine. Finally, a suitable location was identified which covers the entire lake, glaciers, and accumulation zones at one end and the discharge point of the lake at another end. The AWS was installed on a boulder of 3.5x 2x 2.5 m (approx.) which is sturdy and resistant to weathering. It was stable and embedded into the moraine. The site was at the end moraine of the glacier at the southern side of the lake.

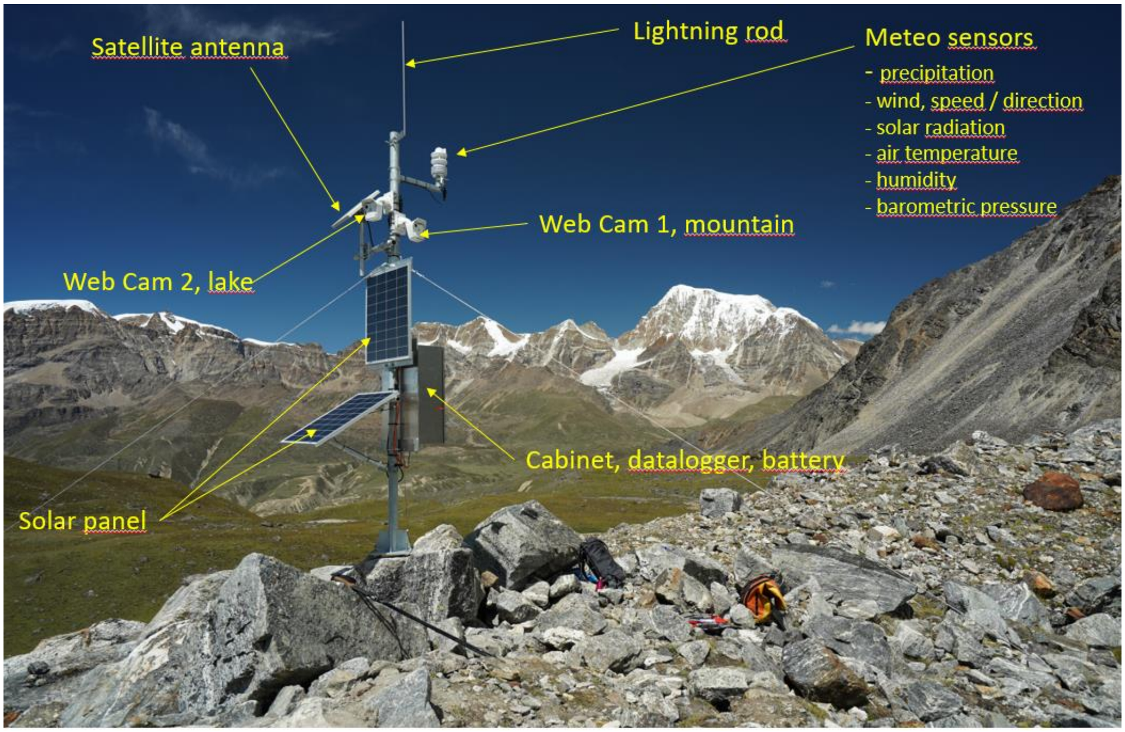


Fig. 9: Installed AWS at Shako Cho Lake and different sensors attached to it (Source: Geopraevent)

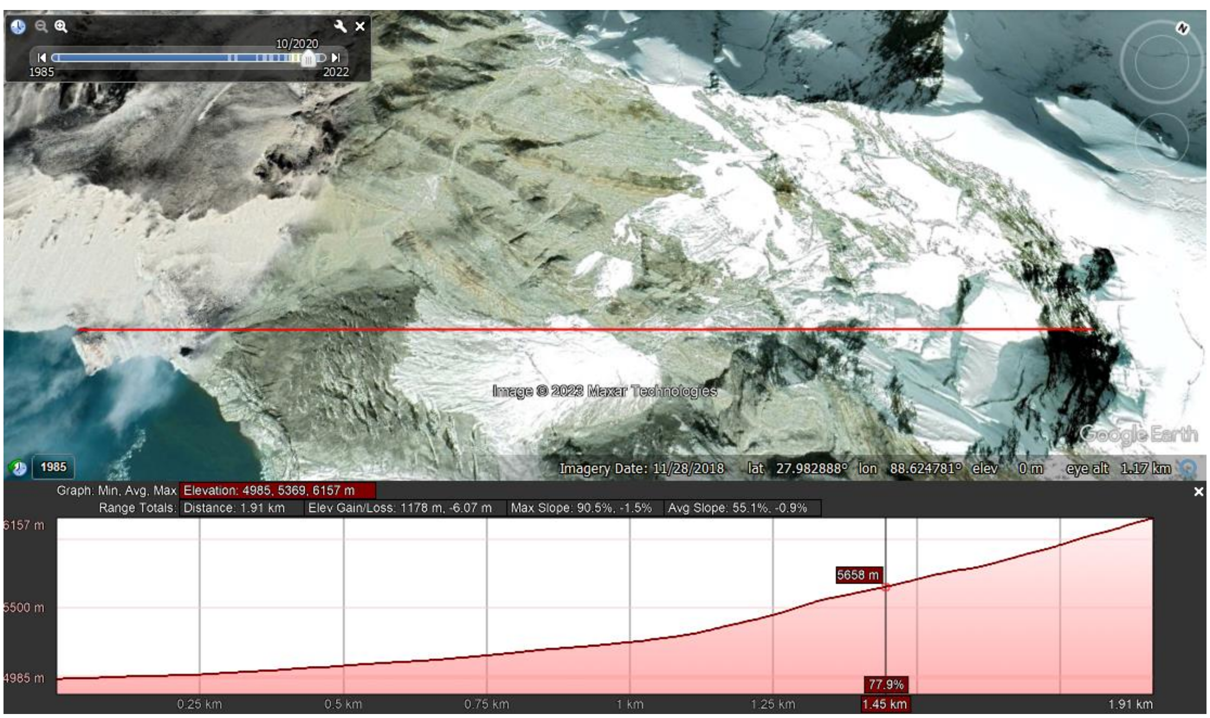


Fig. 10: Elevation profile of the Shako Cho glacier (red line in the Google image)

10.3 Bathymetric survey of South Lhonak Lake:

All together about 1300 discrete depth points have been taken using the USV for the South Lhonak Lake. The maximum depth has been estimated as 119 meter with average depth of 58 meter during the study. It is further recommended to use the remote control range in the USV of above 2 km to complete the survey. Further, it is realized to use the raft boat to reach the potential locations for USV set up and complete the bathymetric survey of the lake.

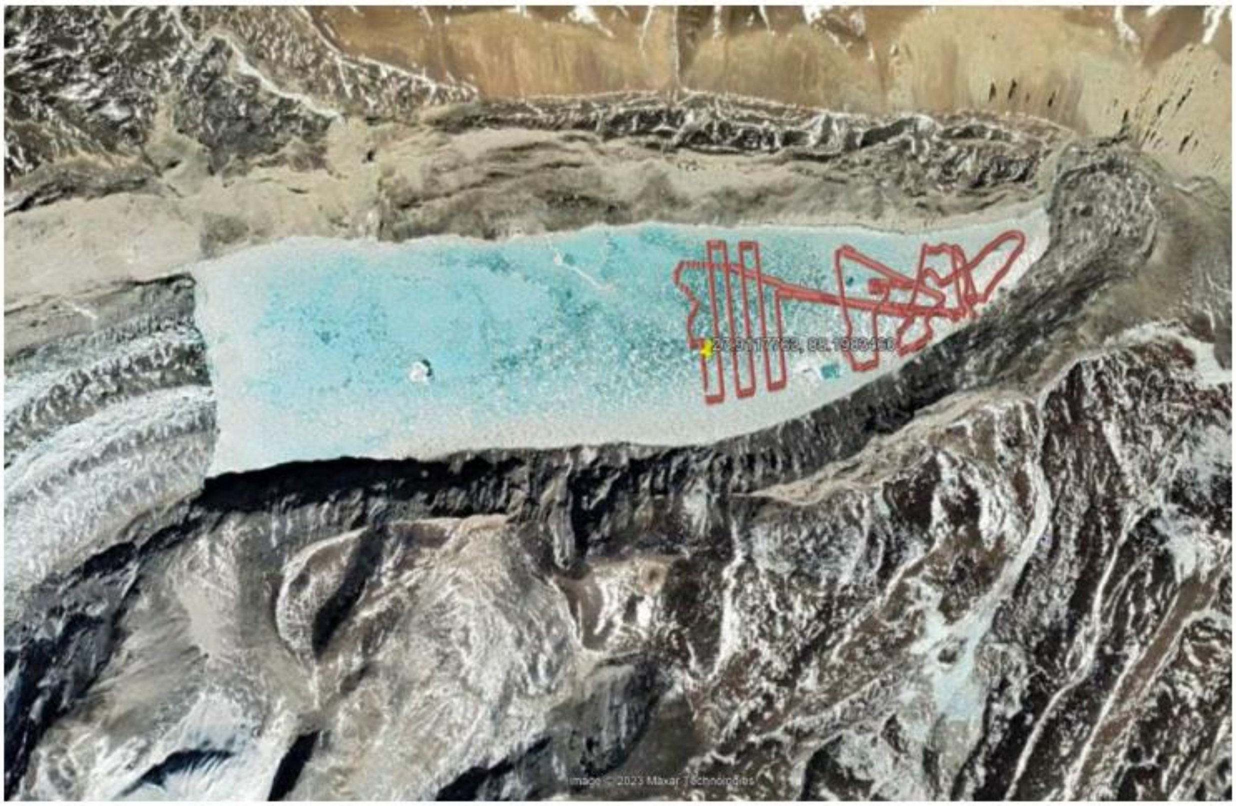


Fig. 11: Area covered for the depth measurements during recent expedition (Sept 2023) [Photo credit: DST Sikkim]

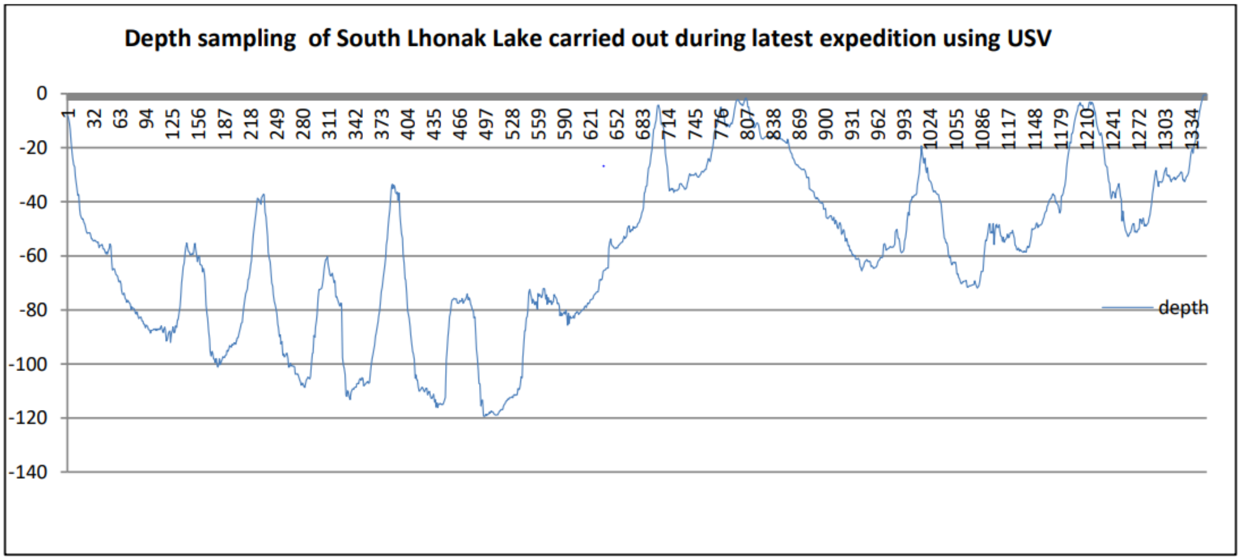


Fig. 12: Depth distribution at discrete points over S. Lhonak lake during recent expedition (Sept 2023) [Source: DST Sikkim]

11. Recommendation for Mitigation Measures for Both the Lakes:

1. **Construction of Check Dams:** Multiple gated Check-dams/Retention dams/ Deflection dams can be constructed as long-term mitigation measures to prevent the entire flow of water in the event of GLOF in downstream area of the lake. It should be noted that these check dams should not be used for holding/storing daily or seasonal Runoff and always should be in half-opened condition. These check-dams should only be used during a GLOF and/or during similar events to retard/reduce the momentum or flow speed of flood water and to hold the bed materials. ***A normal GLOF from a small lake is of about 5000000 m^3 volume. But a GLOF from Shako Cho Lake could be of three times more i.e., 15,000000 m^3 or even more. Therefore, a retention dam of volume 20,000,000 could be ideal to hold the GLOF water from Shako Cho Lake.*** In case of South Lhonak Lake, The GLOF volume can be approximately 60,000,000 and for that a retention dam of the same size can be constructed in a place where the discharge from other nearby lakes are also confluencing, so that one dam can serve the purpose for couple of other lakes as well. This also holds good for the proposed retention dam for Shako Cho Lake. The most ideal location of the check dam will be in the flat area in the downstream area near Muguthang and Zanak area. The construction of Check dams in the downstream locations is useful in controlling the velocity of GLOFs in entire valley/ catchments. Professional geologists and civil engineers should be involved during the entire period from site selection (recce and survey) to

construction of check-dams. Some of the possible areas for constructing different types of dams are marked in the following map.

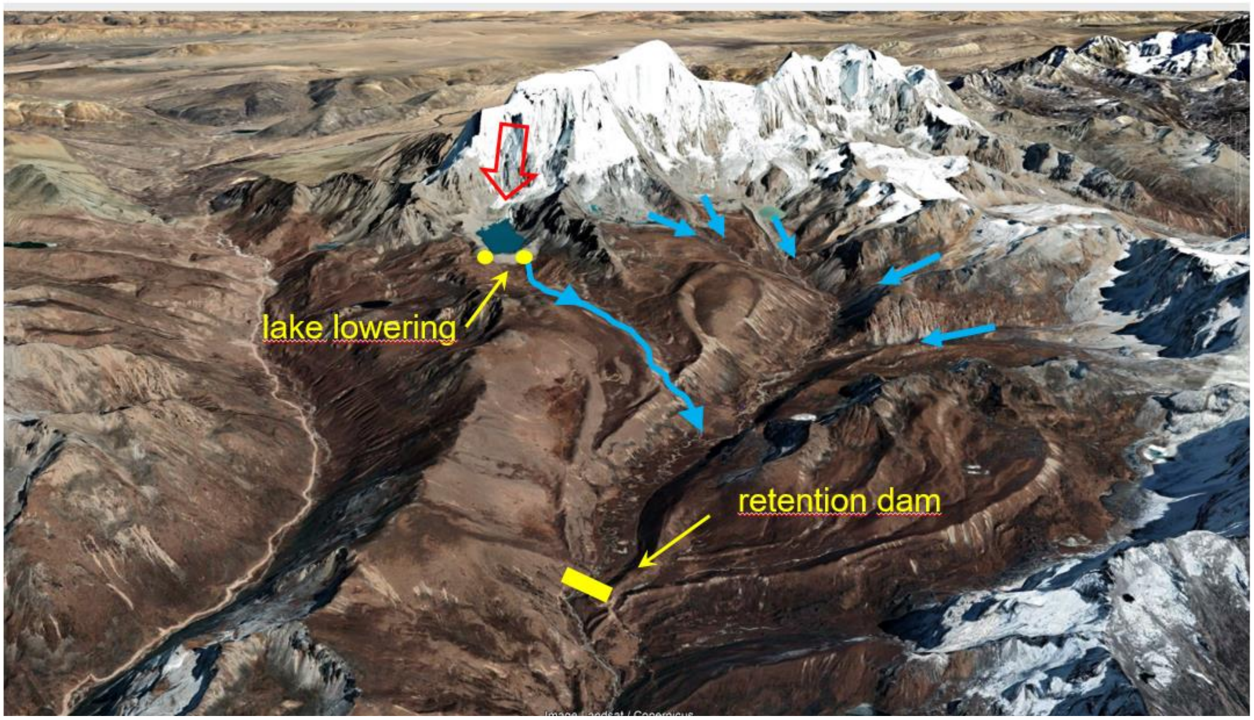


Fig. 13: Shako Cho Lake: Probable position of Retention Dam (Source: Geopraevent)

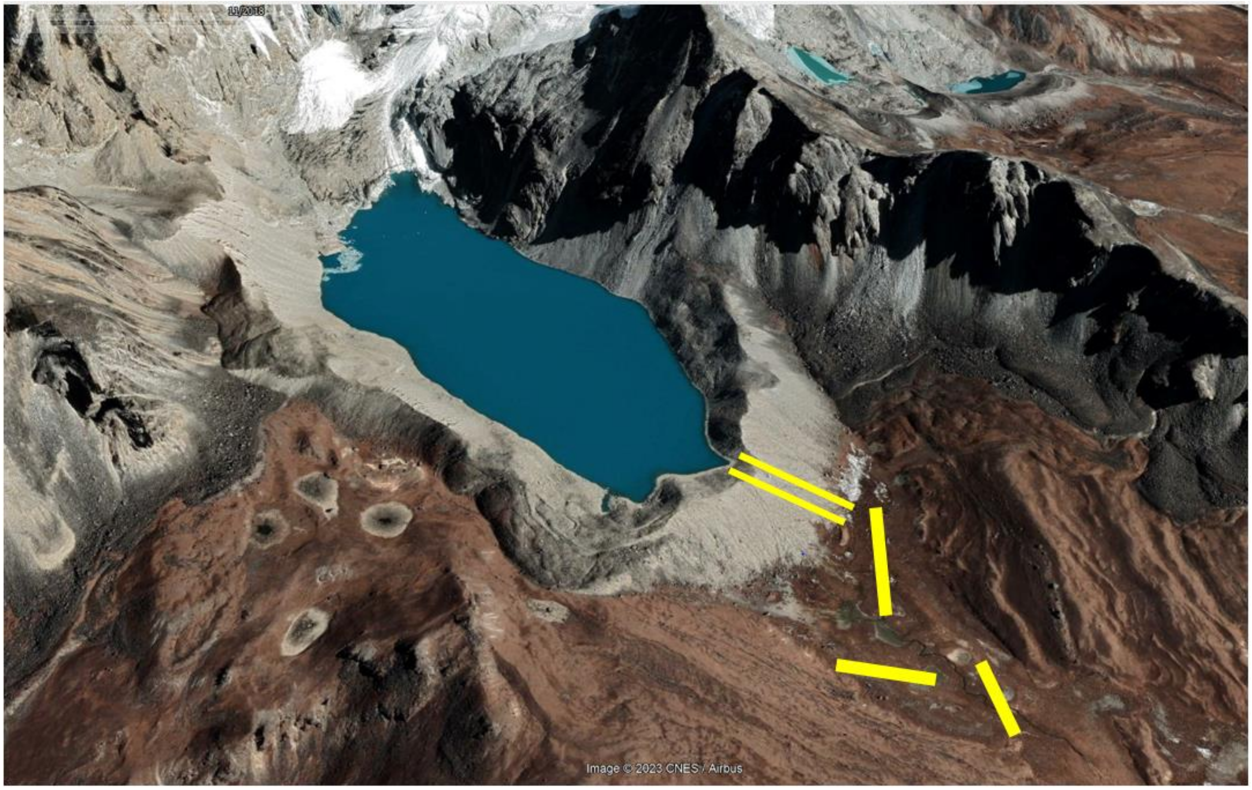


Fig. 14: Shako Cho: Lake Lowering and Deflection Dams (Source: Geopraevent)

Fig. 15: Possible volume of the Retention Dam near Shako Cho Lake (Source: Geopraevent)

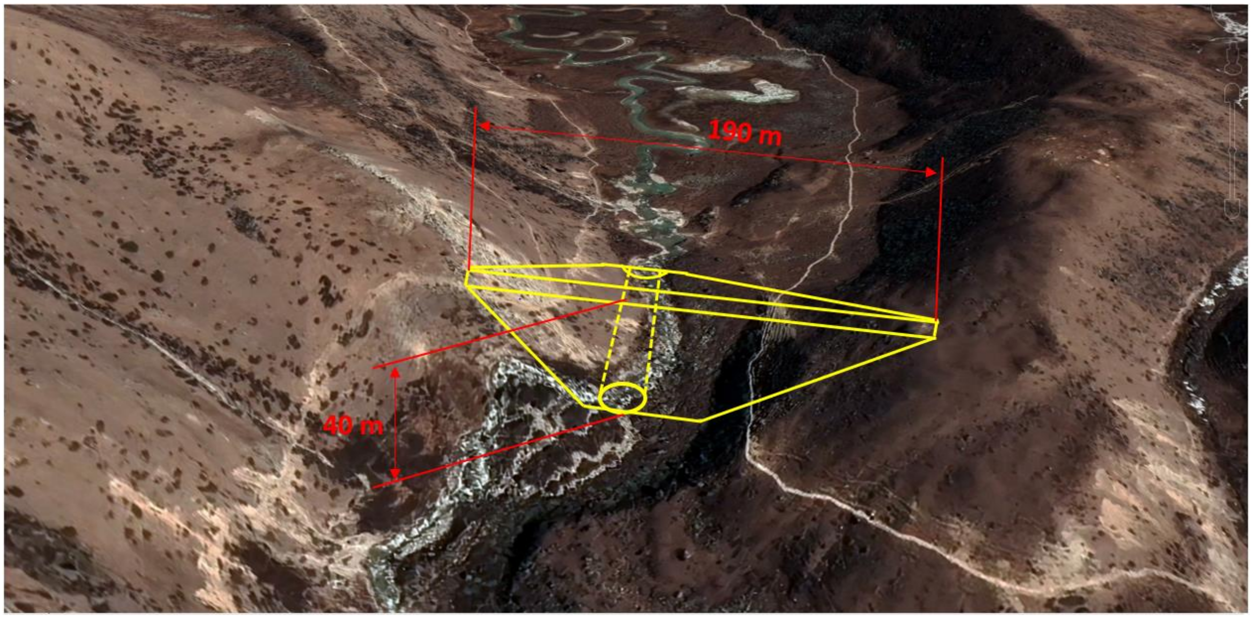


Fig. 16: Probable simplistic design of the retention dam near Shako Cho Lake (Source: Geopraevent)

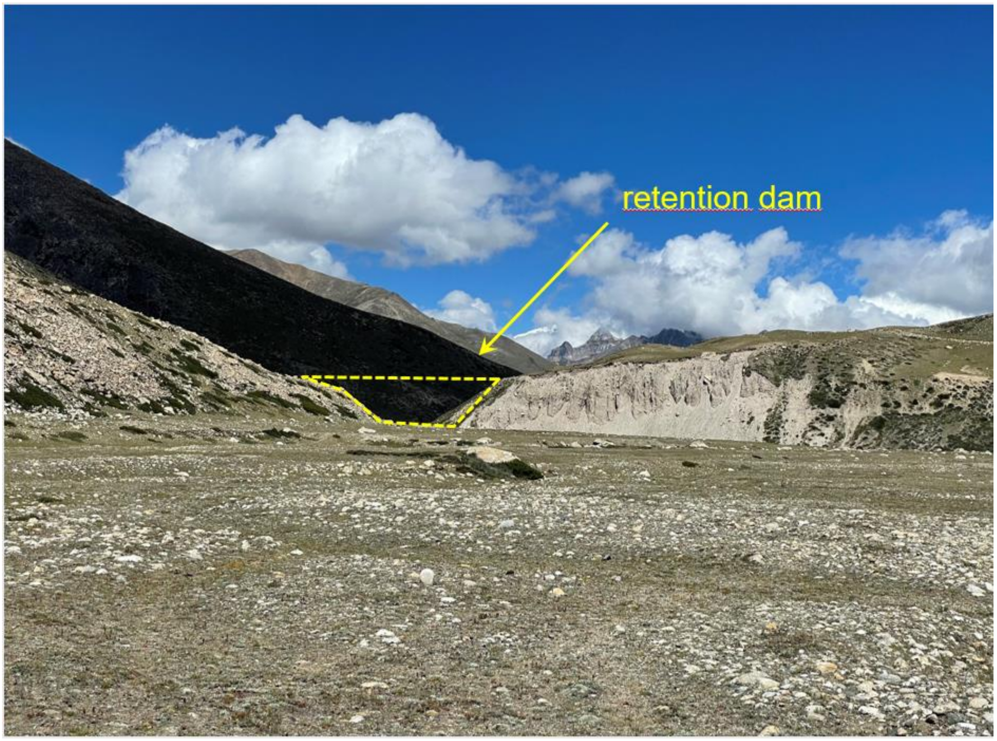


Fig. 17: Probable place for constructing a retention dam near South Lhonak Lake (Source: Geopraevent)

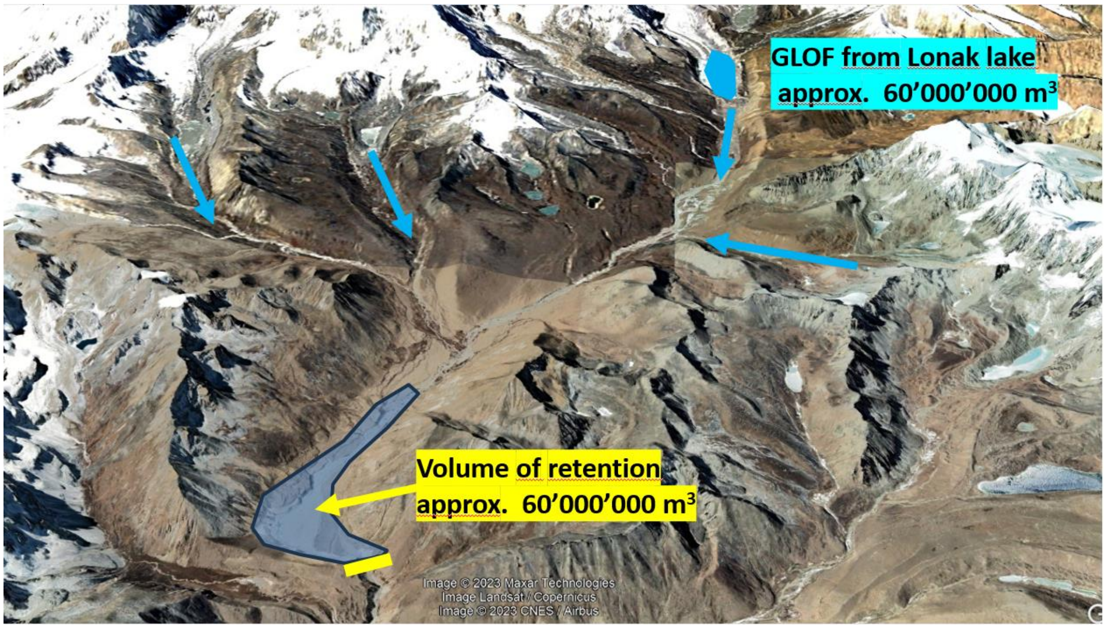


Fig. 18: Possible volume of retention dam near South Lhonak Lake (Source: Geopraevent)

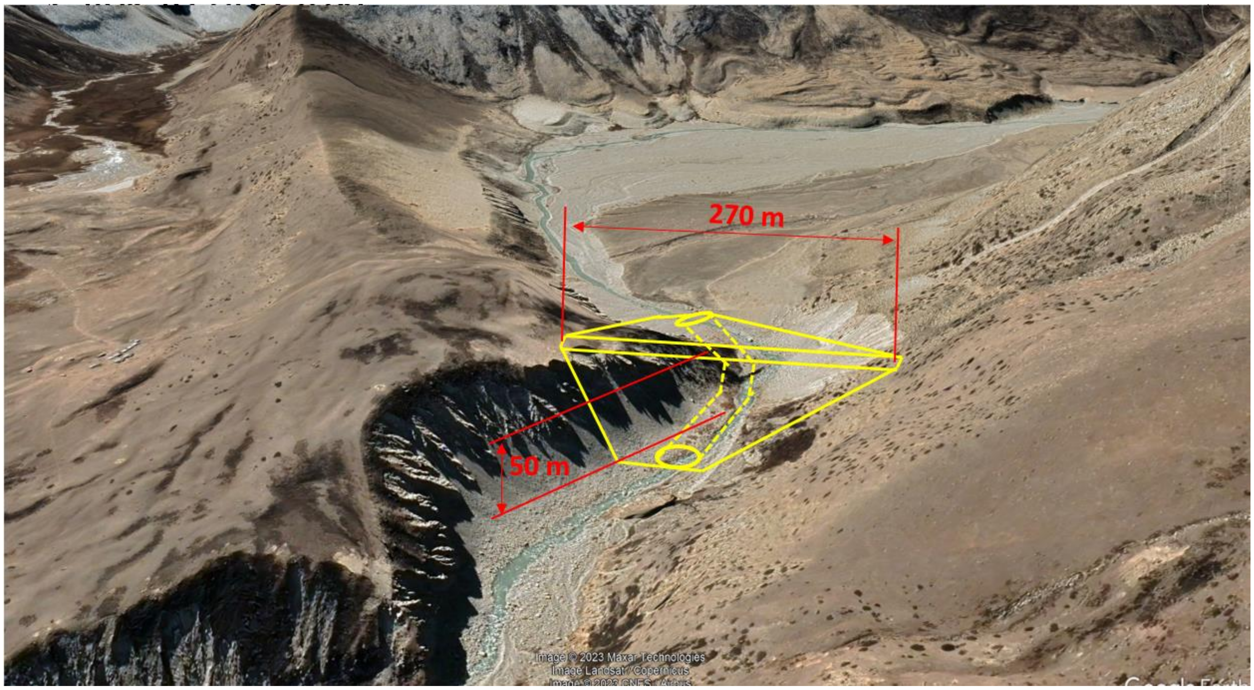


Fig. 19: Probable simplistic design of the Retention Dam near South Lhonak Lake (Source: Geopraevent)

2. **Controlled Deepening of the Lake Water Discharge Point:** Lowering the lake water level is one of the most important measures to mitigate the GLOF hazard. Lowering the lake water level can be achieved by siphoning high-quality pipes (to prevent any damage from freezing of surface water) at least 40-45 meters deep into the lake at one end and keeping the pipes at 50-55 meters down to the present water level at the other end. This will ensure the hydrostatic discharge of water from the lake. Solar panel-operated high-capacity pumps may be utilized for this purpose which will increase the discharge of the lake water.

3. **Widening of the Lake Discharge point**: After achieving this widening and deepening of the lake discharge point can be done cautiously. Once the water level is lowered by 40-45 meters the widening and deepening (till 40-45 meters) of the lake discharge point can be done by a small walking excavator and/or other such tools and machinery in a controlled manner (Under the guidance and supervision of concerned professionals). During the deepening and widening of the discharge point, the terminal moraine should be avoided to be tempered as much as possible. This discharge point should be monitored on a regular interval basis specifically before the onset of monsoon and during the monsoon. Help from ITBP Janak Camp may be requested. A retaining wall/ wire mesh to be constructed to prevent the lateral erosion below the outlet of South Lhonak Lake and the outlet of Changsang River, only after it is resurveyed by the civil engineer for design of the structures.

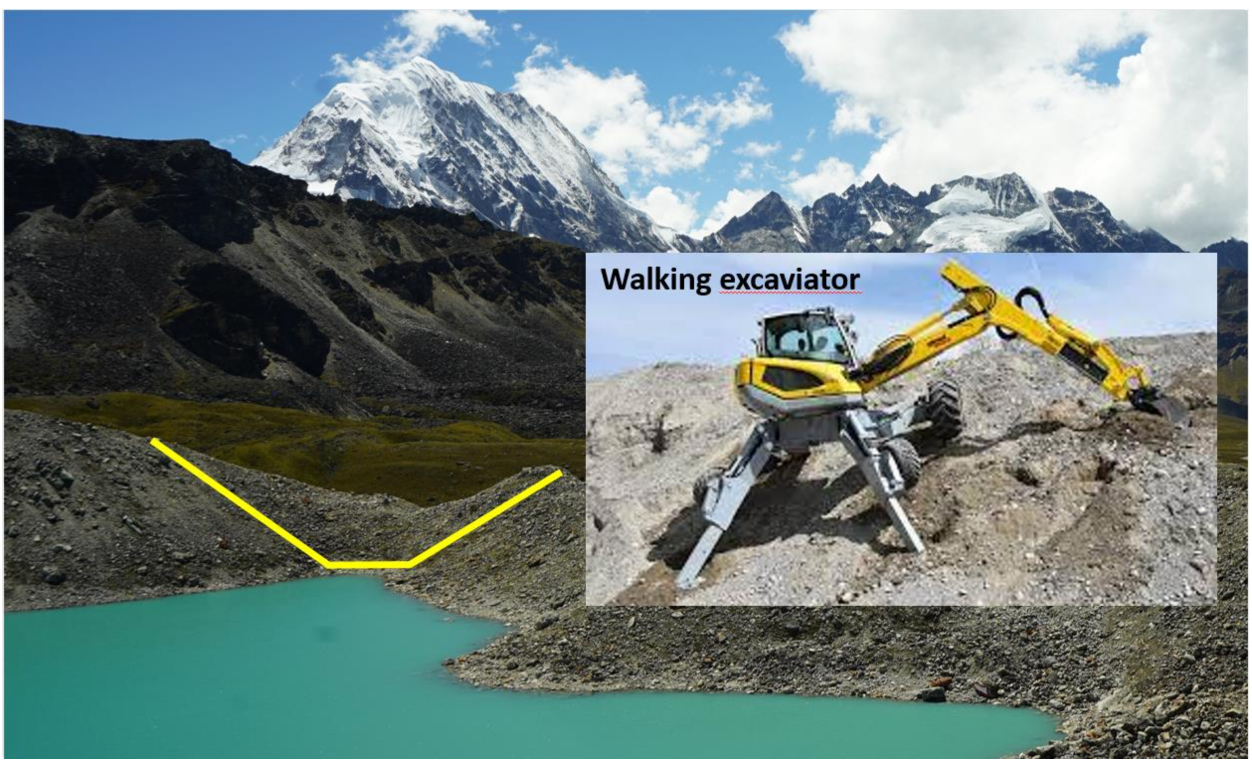


Fig. 20: The yellow marked area is the lowest height of the moraine dam. Since Shako Cho is a closed lake with no river discharge, this yellow marked place can be digging can be done to open a discharge route from the lake (Source: Geopraevent)

4. **Installation of metered gauge**: A metered gauge should be installed at the bank of the lake for fortnightly/monthly data collection of water level change. Discharge of the lake water should also be measured at the same time. The data should be collected for a complete cycle of the year. The volumetric input and output of the lake water will help to plan in a better way for long-term mitigation. An ITBP personnel may be, temporarily, trained for this purpose. As the area is restricted for civilian entry.

5. **Earthquake Monitoring:** An earthquake of intensity >5.5 may be causing as well as a triggering factor for a GLOF. The entire Sikkim falls under Seismic Zone-IV (High). Such earthquakes occurring in the surrounding areas of Sikkim should be kept on watch to alarm all the competent and concerned authorities (administrative and technical) of Teesta Drainage Basin from the South Lhonak Lake to Rangpo or further for evacuation and necessary actions. Mock drills may be conducted from time to time to evaluate alertness and preparedness/promptness. Help and coordination from the Mangan Seismic Observatory may be asked for this purpose.

6. **Lake Bathymetry:** In this expedition, DST Sikkim has conducted the bathymetry survey of the of the South Lhonak lake using USV boat. However due to the vastness of the lake and communication problem between controller and boat, the bathymetry survey of the lake could not completed this time. As such a raft boat is also required to solve the communication problem. So complete bathymetry survey using USV and raft boat is very necessary. Lake Bathymetry Survey of Shako Cho Lake is also required to be conducted. As per the GSI report, another lake, Changsang Glacial Lake (Fig. 21 & 22) which is almost similar in size to the South Lhonak Lake, and potentially hazardous for a GLOF, should be surveyed for ground conditions. A bathymetry survey should be conducted for volume estimation of this lake water.

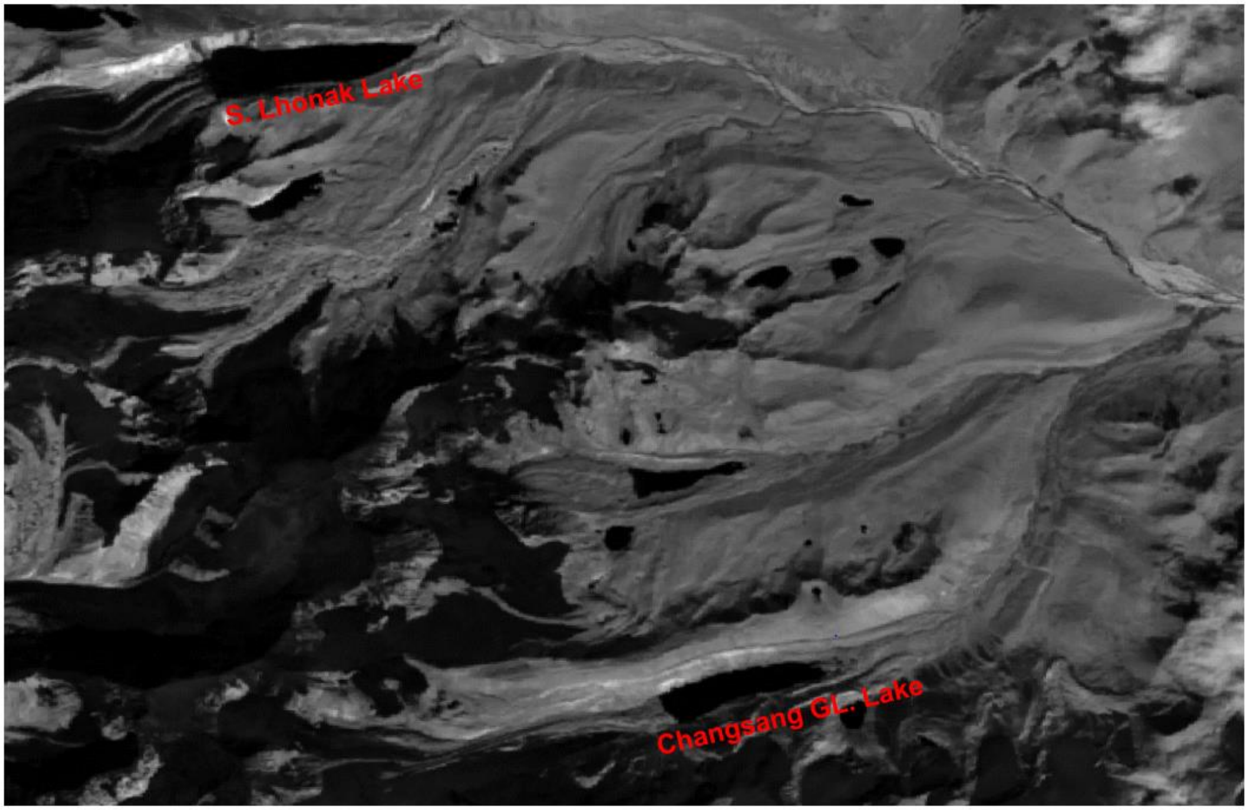


Fig. 21: Potentiality of the Changsang GL. Lake for a GLOF. Landsat 8 image, October 2023. (Source: GSI)

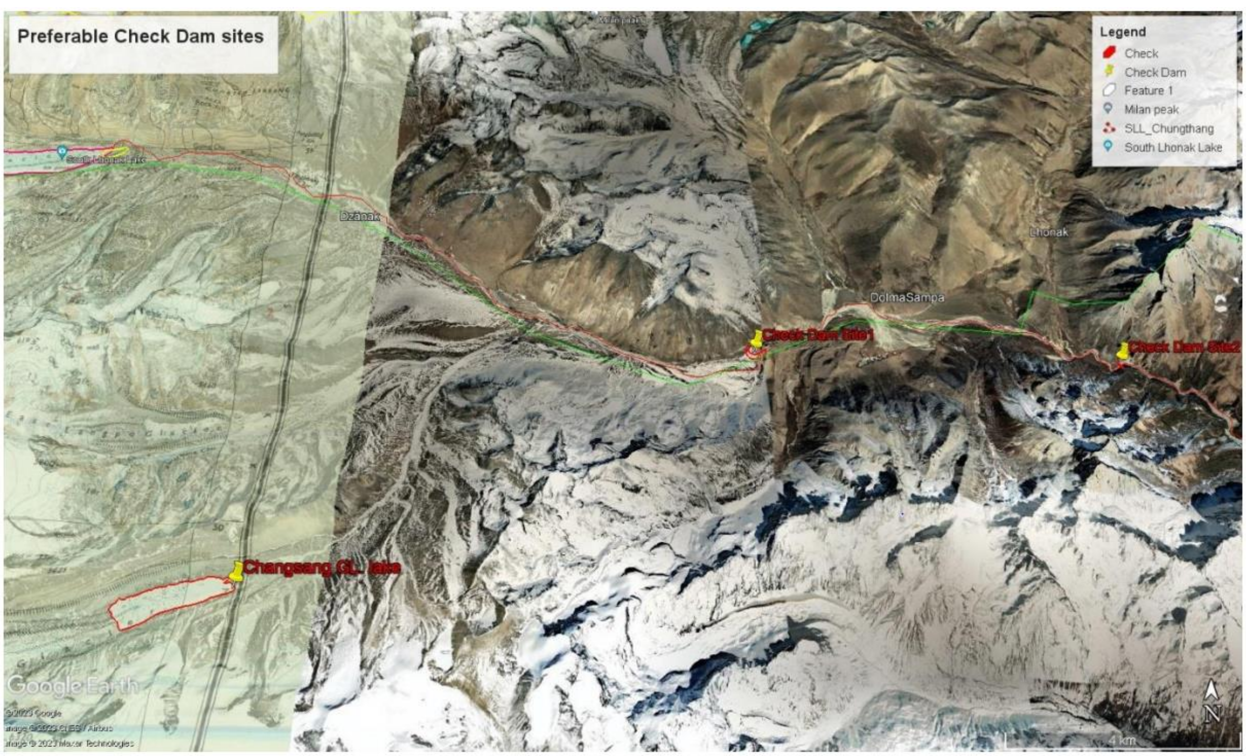


Fig. 22: Preferable sites for check dams in the Lhonak downstream valley.

7. **Resistivity survey**: needs to be repeated in both the lakes to understand the present strength of moraine damming the lake. Subsequently other studies that can be taken up like following:
   - Estimation of glacier melts vis-a-vis its discharge
   - Water budgeting of glacial lakes
   - Mapping of entire geometry along the river valley downstream upto the strategic locations using sophisticated drones to develop high resolution DEM.

8. **DEM Creation:** It required to map the entire geometry along the river valley downstream up to the strategic locations using sophisticated drones to develop high resolution DEM.
9. **Installation of Early Warning System:** Installation of the Early Warning System (EWS) through the river basin of both the lakes are important. So that during any GLOF situation people residing along the river basin can be shifted to safe places well in time. For this early warning several trigger lines needs to be installed along the river basin. Some of the possible areas are marked in the following map.

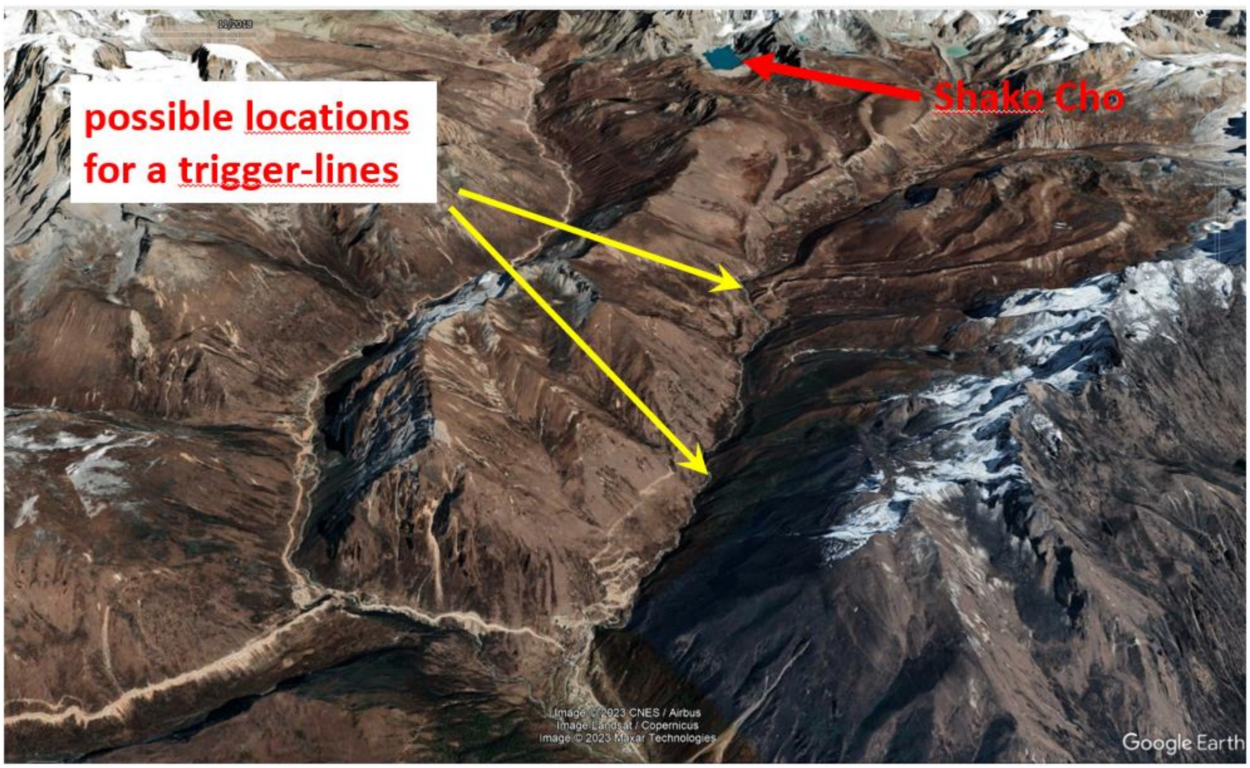


Fig. 23: Possible location of installing Trigger lines near Shako Cho Lake to provide Early Warning System (Source: Geopraevent)

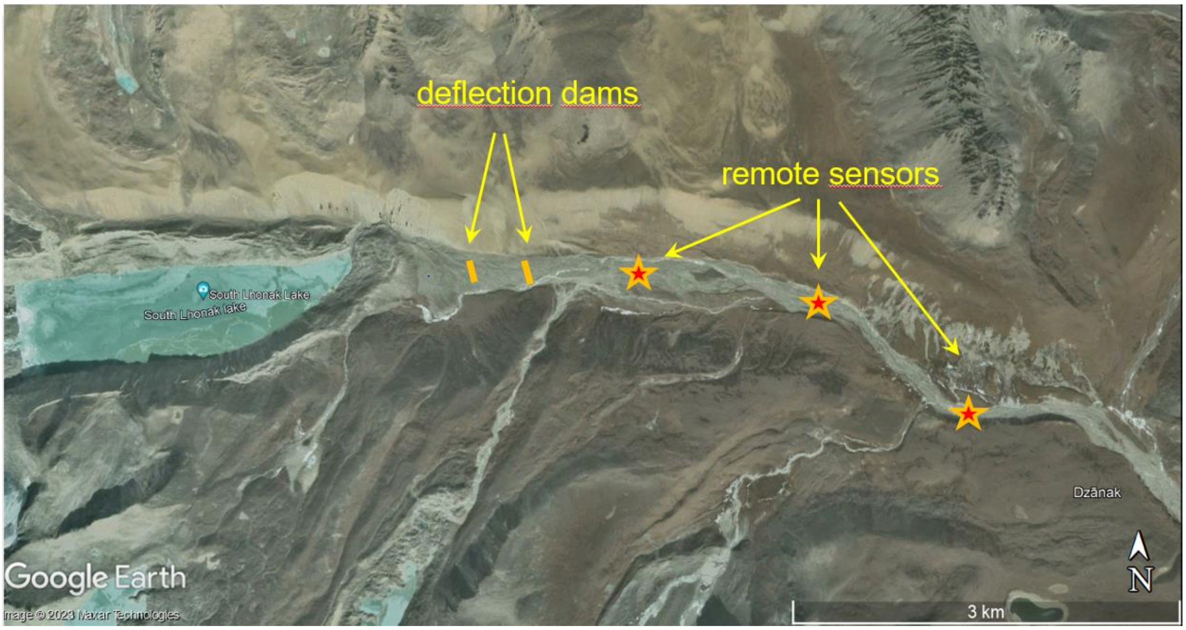


Fig. 24: Possible locations for constructing Deflection Dams to reduce the flow of GLOF water and installing several disposable remote sensors (sort of trigger-lines) near South Lhonak Lake to provide Early Warning System (Source: Geopraevent)

Fig. 25: Suggestive multi hazard alarm-triggering stations (multi hazard) at Zemu Valley (Source: Geopraevent)

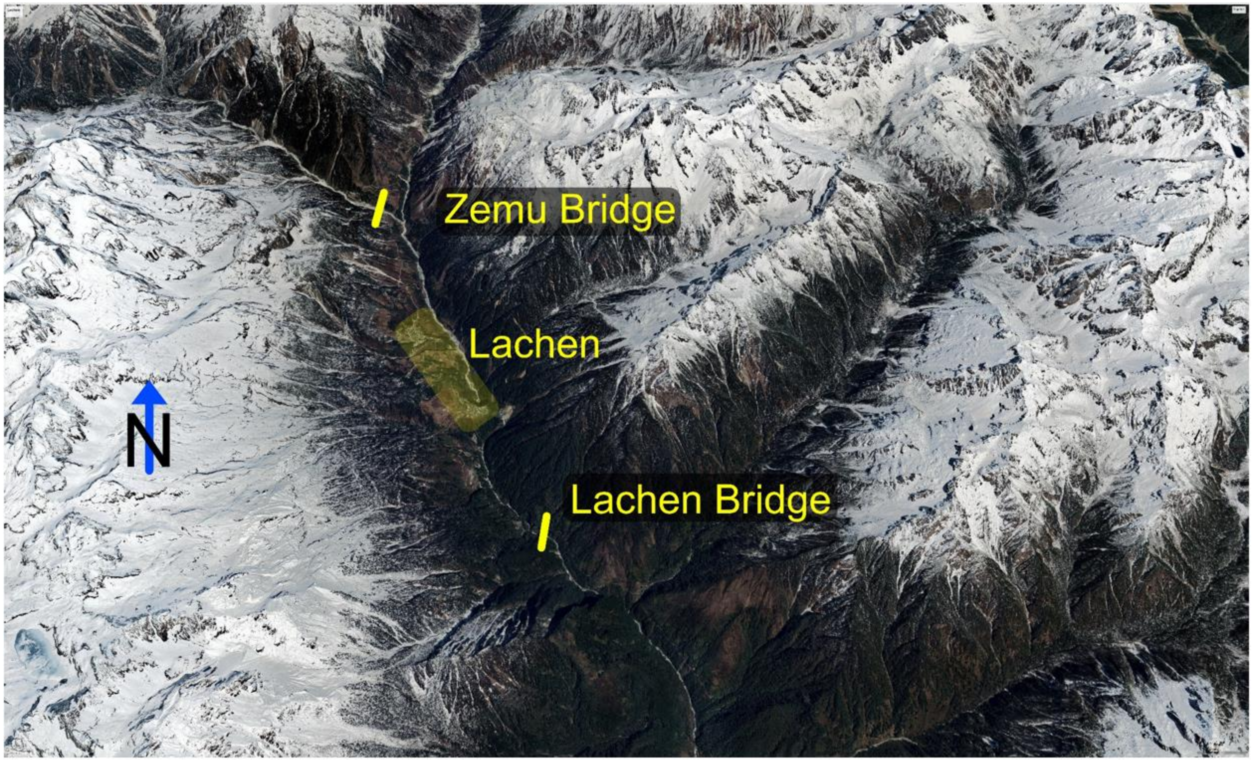


Fig. 26: Suggestive EWS: Installations at Zemu & Lachen Brigde (Source: Geopraevent)

Fig. 27: Suggestive location of the AWS Installation near Lachen Bridge to raise alarm from the GLOF emerging from both Shako Cho and South Lhonak lake (Source: Geopraevent)

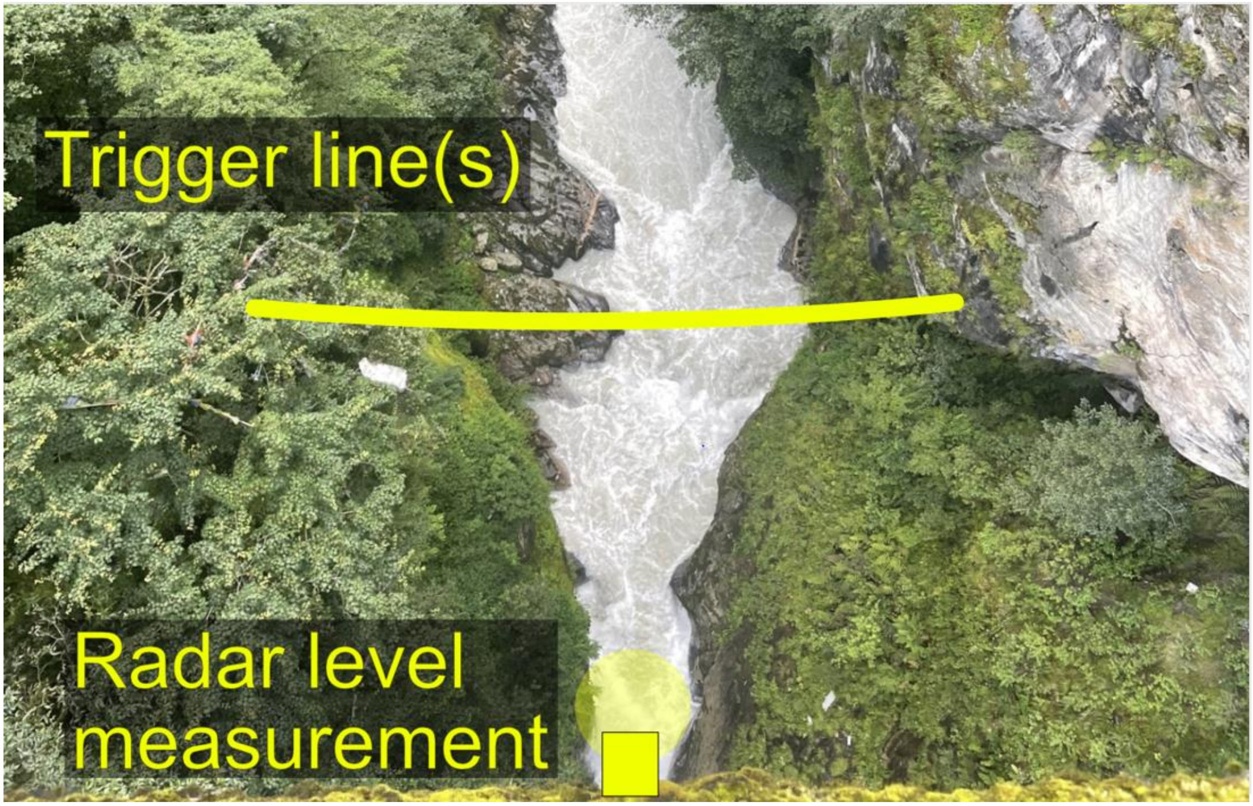


Fig. 28: Suggestive location for EWS Installation near Lachen Bridge to raise alarm from the GLOF emerging from both Shako Cho and South Lhonak lake (Source: Geopraevent)

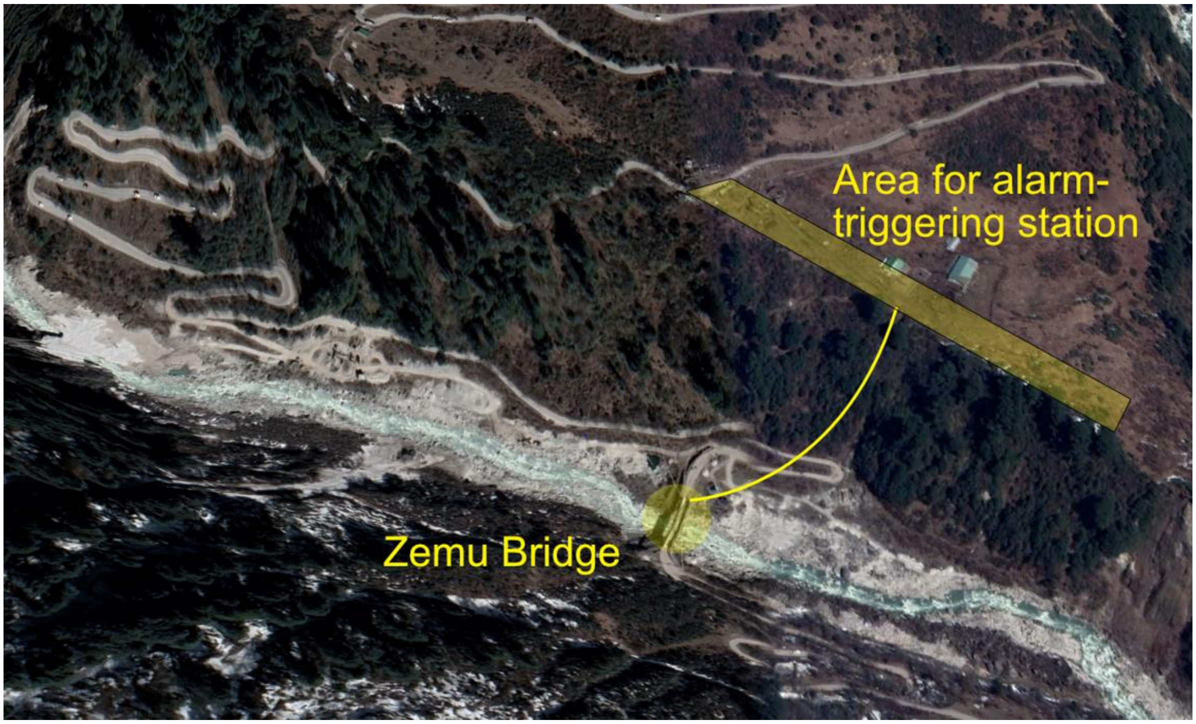


Fig. 29: Suggestive location for EWS Installation at Zemu Bridge (Source: Geopraevent)

Fig. 30: Diagram showing how the trigger lines and sensors could be installed at bridge sites for generating EWS (Source: Geopraevent)

10. **Centre for Monitoring and Dissemination of Early Warning:** One Centre can be established to gather data from all automatic weather stations installed at the different lakes,

and the data captured by all the other AWS sensors. The centre will be responsible for processing of all such data and dissemination of any Early Warning if required.

Further, it is advised to go for a detailed survey before executing these mitigation measures under the supervision of geologists and engineers and/or other such professionals.

12. Key lessons learnt

- It was observed that some of the officers in the expedition fell ill due to the high altitude environment. These officers were cleared by the medical tests conducted at Gangtok. Therefore, the medical tests carried out prior to the expedition, for the subsequent missions, may be clearly defined, so that the physical fitness and durability needed for such high-altitude treks may be ascertained.
- In order to maintain and keep the monitoring stations in good health, physical checking and maintenance may be needed from time to time. Some local experts may be identified and trained for carrying out this maintenance. As per the debriefing on 20 September, SSDMA will identify 2 experts of electronics, who will be trained by GeoPreavent to take care of the regular maintenance, including the components inside the installed instrument.
- Many tools and instruments were acquired to support in the mission. Many of these tools/instruments are reusable and can be put to use. The same may be inventoried and handed over to SSDMA for further use of the same.

13. GLOF event of 3 Oct, 2023

It was disheartening for the whole team involved in the mission that there was a GLOF event occurred on the South Lhonak Lake on the late night of 3rd October, mere 15 days after the installation of the monitoring stations. Many lives were lost, including an expedition team member, Dr. Pema Tenzing Bhutia (DGM, Sikkim Urja), who went missing from the Chunthang dam site. The monitoring station installed on South Lhonak Lake, as a part of this mission was also washed away in this GLOF. The monitoring station at Shako Cho is functional and providing data on regular basis.

From DRR point of view, understanding and studying the GLOF will help in building a stronger domain within. We can learn from the experience firsthand and improve on our strategy for better early warning systems for GLOF.

14. Immediate Activities taken up after the GLOF event

NDMA engaged the Swiss experts to understand the events on the South Lhonak lake with the help of SAR interferometry and Remote Sensing images – both visual and radar images. Immediate analysis of the remote sensing images revealed that the GLOF was triggered by a debris movement from the northwest side of the moraine dam of the lake. NDMA kept monitoring the event and subsequent changes to the lake water levels and possible secondary GLOF using all available sources. NDMA had requested the ITBP personnel to physically verify the status of the moraine dam, based on the expedition experiences and received visuals of the lakes' latest status.

15. Road ahead

1. GLOF EWS mission with specific tasks needs to be planned in all the states which have risky glacial lakes. Working EWS need to be installed in each of these states and lake specific mitigation measures has to be implemented for GLOF risk reduction.

2. Need to generate a new DEM for the modified topography caused by the GLOF event. Extremely high sedimentation in the Teesta valley have changed the topography entirely. A new digital elevation model (DEM) of the river valley will inform which areas were deposited with sediment and to what extent. This modified DEM will give new input to future GLOF event (if happens) and help calculate the new High Flood Level (HFL) which will be helpful for future construction of Dams, bridges, roads etc.
3. A detailed hazard assessment of the moraine dams of all risky glacial lakes need to be conducted.
4. Mitigation measures for risk reduction: a set of mitigation measures, including syphoning off some water mechanically can be done. Under the new circumstances, as suggested by Member, NDMA during the debriefing, widening of the lake opening may also be looked at.
5. Considering the possibility of future GLOF incidents, adding additional sensors to the monitoring system may be considered. Additional sensors may include infrared/thermal, LiDAR, network of GPS sensors, etc. These additional sensors will help in mapping the changing topography and any creeping hazards along the moraine dams.
6. Identify responsible local experts and train them to maintain the monitoring stations. During the debriefing meeting with SSDMA and NDMA, it was discussed that two Indian experts, mostly from Gangtok/Sikkim would be identified by SSDMA and the same would be trained by GeoPraevent for maintenance of the monitoring stations. Basic condition for the selection of the experts was knowledge of electronics, as maintenance may include not just the external maintenance, but also of the control centres of the monitoring stations. SSDMA informed NDMA and SDC that the selected experts will be on the payrolls of SSDMA. However, before the GLOF of 4 October, the experts were not identified.

Acknowledgement:

The Automatic Weather Station has been procured by Swiss Development Coorporation and installed by Swiss agencies named Geopraevent and Geotest. The expedition is facilitated by Sikkim State Disaster Management Authority.

16. Annexures

Annexure 1 A detailed conceptual sketch showing the expedition plan is shown below

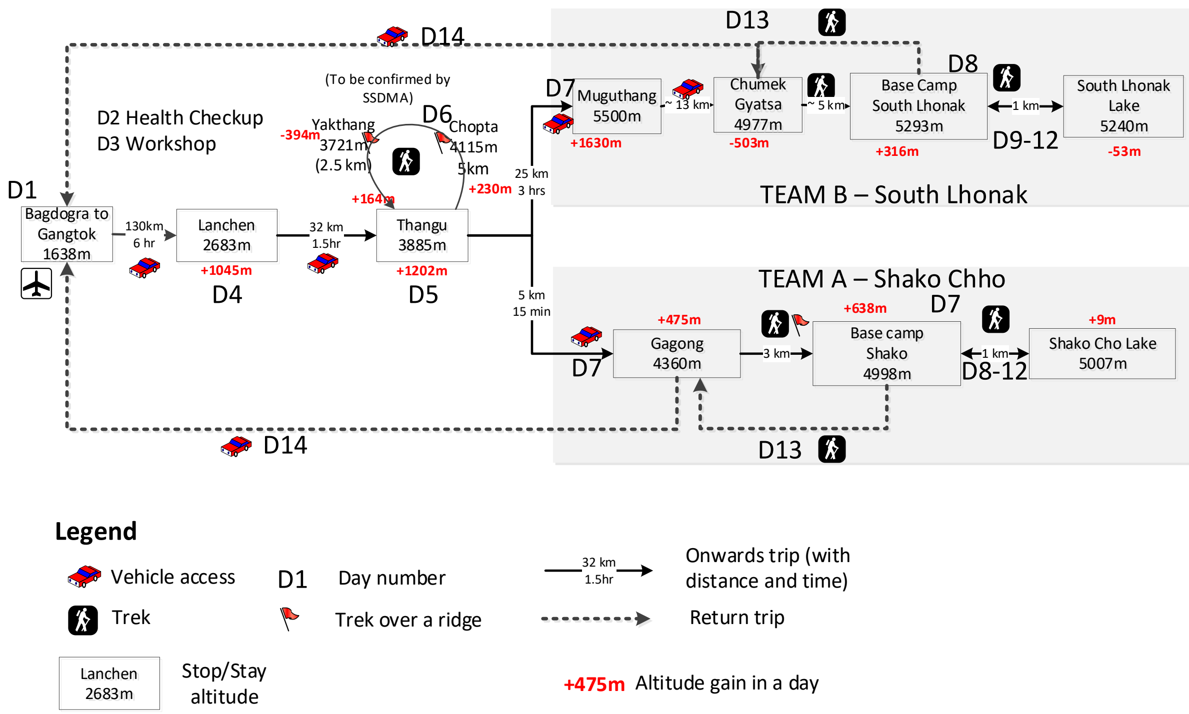
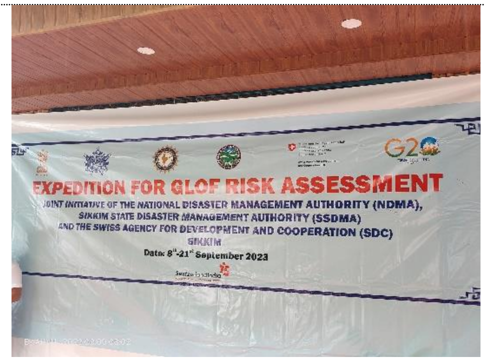


Figure: Conceptual sketch of the expedition

Annexure 2 Some glimpses of the expedition


EXPEDITION FOR GLOF RISK ASSESSMENT


EXPEDITION FOR GLOF RISK ASSESSMENT
JOINT INITIATIVE OF THE NATIONAL DISASTER MANAGEMENT AUTHORITY (NDMA),
SIKKIM STATE DISASTER MANAGEMENT AUTHORITY (SSDMA)
AND THE SWISS AGENCY FOR DEVELOPMENT AND COOPERATION (SDC)
SIKKIM
Date: 8th-21st September 2023


EXPEDITION FOR GLOF RISK ASSESSMENT

Annexure 3 List of Indian participants from various organisations

Table 4: Team A - Shako Cho - List of Participants/ Experts going up till the Lake.

No	Name/ Designation	Organization	Contact Info
1	Dr, Suraj Dhakal, MO	Chungthang	9609018058
2	Sh. Roshan Tamang, Scientist D	DGRE, Chandigarh	9501785136
3	Sh Beru Dulam	Govt. of Arunachal Pradesh	8132887868
4	Dr. Ruchika Tandon, Sr. Geologist (ULMMC)	Govt. of Uttarakhand	9634709880
5	Dr. Sweta Baidya, Sr. Consultant	NDMA	9158210843
6	Sh. Rohit Kumar Yadav, Assistant Director	CWC	7007117473
7	Shri Shumiran Rai	Khangri	8927794271
8	Shri Biplob Rai	AD Films	6297720814
9	Sh. Karan Hang Subba	AD Films	7908091977
10	Dr Pema Lachungpa, General Manager	Sikkim Urja Ltd, Chungthang	9002360543
11	Sh. Sonam Wangyal, Deputy Director (Team Leader)	LR & DMD	9679889137
12	Sh. Karma Wangyal Bhutia, Deputy Director	LR & DMD	8370844907
13	Ms. Tshering Yangzom, ASP	Home Guards & Civil Defence	8436750990
14	Sh. Sangay Gyatso Bhutia, JS	LR&DMD	9434174754

Table 5 Team B - South Lhonak - List of Participants/ Experts going up till the Lake

Sl.No	Name/ Designation	Organization	Contact Info
1	Sh. Tshering Norgyal Theengh, SDM (Team Leader)	Yangang/ LR& DMD	9474428280
2	Dr. Ajay Chettri	Health & Family Welfare Dept	7908930501
3	Sh. Mozart Maxon, Consultant	NDMA	9711028875
4	Sh. Dhiren Shrestha, Principal Director	DST	9434164409
5	Dr Parmanand Sharma, Scientist F	NCPOR, Goa	8390807194
6	Sh. Narpati Sharma, Scientific Officer	DST	7407184204
7	Sh. Sandeep Chettri, Project Associate	DST	8670616583
8	Sh. Bhaichung Lepcha, Project Associate	DST	8927119178

Sl.No	Name/ Designation	Organization	Contact Info
9	Sh. Jahangir Alam Surveyor	Survey of India	9609897649
10	Sh. Vikash Chandra, Senior Geologist	GSI, Faridabad	8130152052
11	Sh. Ritwik Mazumdar,	NRSC, Hyderabad	9441930070
12	Shri Prashant Darjee	AD Films	7001869818
13	Shri Adarsh Rai	AD Films	9832661924
14	Sh. Tashi Chopel, DC	DAC Pakyong	9474774456

Annexure 4 List of participants in the workshop on 8th September 2023

Table 6 List of workshop participants

No	Name	Designation	Department
1.	Dr. Krishna Vatsa	Member	NDMA
2.	Sh. Safi Ahsan Rizvi, IPS	Advisor (Mitigation)	NDMA
3.	Col Kirti Pratap Singh	Advisor (Ops & Communication)	NDMA
4.	Sh. Prabhakar Rai	Special Secretary-cum-Director	SSDMA
5.	Sh. Rajiv Roka	Executive Director	SSDMA
6.	Sh. Keshav Koirala	Asst. Director	SSDMA
7.	Sh. Bharti Reddy K	Sci/Eng SD	NRSC, Hyderabad
8.	Dr. Ritwik Majumdar	Sci/Eng SF	NRSC, Hyderabad
9.	Sh. Vikas Chandra	Senior Geologist	GSI, Polar Studies Div. Faridabad
10.	Dr. P. Sharma	Scientist F	NCPOR, MoES, Goa
11.	Sh. Narender Kaith	Training & Capacity Building Coordinator	DDMA Kinnaur, Himachal Pradesh
12.	Sh. Surjay Lama	Meteorologist	IMD Gangtok
13.	Sh. P.V Rajasekhar	Addl Surveyor General	Survey of India
14.	Dr. Ruchika Tandon	Senior Geologist	ULMMC, Govt of Uttarakhand
15.	Sh. Roshan Tamang	Scientist D	DGRE RDC Lachung
16.	Sh. Beru Dulom	DDMO, Disaster Management	Arunachal Pradesh
17.	Sh. Saran D Kalilotey	DPO DDMA Namchi	Land Revenue & Disaster Management
18.	Dr. Pema Bhutia	DGM	Sikkim Urja Ltd
19.	Dr. Suraj Dhakal	MO, I/C PHC Chungthang	Health and Family Welfare
20.	Sh. Sonam Wongyal Lepcha	Dy Director DDMA Gangtok	Land Revenue & Disaster Management
21.	Sh. Uday Shanker Prasad	Director	Survey of India
22.	Sh. Debabrata Palit	Superintending Surveyor	Survey of India
23.	Sh. Jahangir Alam	Surveyor	Survey of India

No	Name	Designation	Department
24.	Sh. Pinaki Raha		Central Water Commission
25.	Sh. Neel Kamal Chaudary	Project Assistant GLOF	SDC/NDMA
26.	Sh. Mozart Maxon	Consultant-GLOF DRR	NDMA
27.	Smt. Tshering Yangzom Bhutia	Addl SP	Sikkim Police HG&CD
28.	Sh. Baichung Lepcha	PA - I	Dept of Science and Technology
29.	Dr. RK Sharma	Asst Scientific Officer	Dept of Science and Technology
30.	Sh. Pranay Pradhan	Asst Scientific Officer	Dept of Science and Technology
31.	Dr. NP Sharma	Scientific Officer	Dept of Science and Technology
32.	Dr. Sundeep Chettri	PA - I	Dept of Science and Technology
33.	Sh. Karma Wongyal Bhutia	Dy Director	DAC Gangtok, LR&DMD
34.	Sh. Kritika Sharma	SIA	IPR
35.	Mr. Christoph Haemmig	Geologist	Geotest
36.	Ms. Susanne Wahlen	Head Monitoring	Geoprevent
37.	Ms. Eveline Studer	Senior Regional Advisor on DRR	SDC
38.	Mr. Christian Kuster	Head Engineering	Geopraevent
39.	Sh. Rohit Kumar Yadav	Assistant Director – II	Central Water Commission
40.	Ms. Divya Mohan	Team Leader, SCA Himalayas	SDC
41.	Sh. Kiran Thatal	SDM Chungthang	Land Revenue & Disaster Management
42.	Sh. Tshering Norgyal Theengh	SDM Yangang	Land Revenue & Disaster Management
43.	Dr. Ajay Chettri	Emergency physician	Health and Family Welfare
44.	Dr. Bernard Krummenacher	Expert Switzerland	Geotest
45.	Ms. Ada Lawrence	Technical Expert, DRR, SCA Himalayas	State PIU, SDC
46.	Sh. Ajay Katuri	Sector Lead, DRM, SCA-Himalayas	SDC

Annexure 5 Agenda of the kick-off workshop (08 Sept, 2023)

Time	Agenda	Resource person
09:30 -10:00 am	Arrival of guests with tea/coffee	
10:00 -10:15 am	Welcome address to the expedition members	Special Secretary-cum- Director, SSDMA
	Opening remarks	Dr. Krishna Vatsa, Member, NDMA
	Special remarks	Mrs. Divya Sharma, Deputy Head of Cooperation, SDC
10:15-10:25 am	Report on the two glacial lakes	Principal Director, DST
10:25-10:45 am	Official handover of the equipment	SDC NDMA Sikkim
	Closing remarks	Shri. Safi Ahsan Rizvi, Advisor, NDMA
	Group photo	All
10:45-11:15 am	Session 1: Presentation of Monitoring Stations	Swiss Experts (Geoprevent)
11:15 -11:35 am	Session 2: EWS design and DRR response	Swiss Experts (Geotest)
11:35 -12:45 pm	Session 3: Presentation on SOP and in the State of Sikkim Discussion on experience and needs Working Session	SSDMA Key stakeholder preparedness/response system
12:45-01:00 pm	Presentation	Mr. Binay Kumar, CDAC
01:00- 02.00 pm	Lunch	
02:00 -3:00 pm	Session 4: Field mission Kick-off Meeting	Swiss Experts (Geotest) Khangri Tours and Treks