EXPOSURE VISIT TO SIKKIM

A Report on Hazard Assessment and Mitigation Planning of High-Risk Glacial Lakes in Mangan District, Sikkim

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1. Introduction

The Government of Sikkim has been monitoring the glacial lakes by conducting field surveys since 2012 and has also installed Automatic Weather Stations for early warning in collaboration with Swiss agency for Development and Cooperation (SDC). In order to get the insight of works carried out by Sikkim Government under GLOF induced challenges, mitigations measures and techniques applied/planned, the Government of Himachal Pradesh had requested to include the delegates from the State during the expedition to the glacial lakes. The said expedition was organized by the Department of Science and Technology, Government of Sikkim in association with Sikkim State Disaster Management Authority (SSDMA) and objective of Himachal Pradesh was to study the best practices and approaches devised by the Sikkim in the field of GLOF so that Himachal Pradesh can proceed expeditiously to implement the mitigation measures including early warning systems.,

2. Site Overview

The Department of Science and Technology, Government of Sikkim in association with Sikkim State Disaster Management Authority (SSDMA) had organized the expedition to various Glacial Lakes in association with various Government of India agencies viz. NIDM, DGRE, CWPRS, CWC, GSI, NIH Roorkee; agencies of the Sikkim Government i.e., State Geological Department, Sikkim University including Police, ITBP, Army to study the lakes.

3. Team Members from Himachal Pradesh

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The programme of exposure visit is shown below:

Date	Site(s) Visited	Activity/study	Remarks
18.08.2025	Shimla-Chandigarh-Delhi	Journey to join the expedition	
19.08.2025	Delhi to Bagdogra & Bagdogra to Gangtok		
20.08.2025	Gangtok to Lachung	Movement with expedition team	1st Camp at Lachung
21.08.2025	Chumilamcha Lake	Reconnaissance Survey	
	Gora la Pass (16400 ft)		
22.08.2025	Lachung to Dongkyla Pass (18200 Ft)	-	2nd Camp at Thangu

Date	Site(s) Visited	Activity/study	Remarks
	Gurudongmar Lake & its upper associated two lakes	Reconnaissance Survey	
	Dorjila Pass (18700 ft)		
	Kerang Post	Visit	
	Thangu	Base Camp	
23.08.2025	Thangu to Shako Cho lake	Subsurface geophysical study of southern lateral moraine, installation of water-level gauge	Study of AWS and Water Level Sensors
	Sora Funnel in Gurudongmar valley	Field studies for retention structure	ERT/Drone Survey
24.08.2025	Thangu to Muguthang	-	3rd Camp at Muguthang
	Lonkula Pass (5200 mtr)	Visit	
	Galcial Lake downhill the Lonkula Pass	Demo of Bathymetric Survey	
	Dolma Sampa in Lhonak valley	Reconnaissance Survey	
25.08.2025	Dolma Sampa in Lhonak valley	Field studies comprising of subsurface geophysical survey, debris deposition assessment, UAV-based terrain analysis, glacial flood level mapping	
26.08.2025 to 30.08.2025	Muguthang to Janak, Janak to South Lhonak Base, Base to South Lhonak Lake, return Janak and Lachung	Bathymetric survey ERT survey, Morphometric Study, Study of AWS and Water level Sensors	4th Camp at Janak and 5th Camp at South Lhonak Lake Base
31.08.2025	Lachung to Gangtok		
01.09.2025 & 02.09.2025	Visit to DST office, Sikkim State Disaster Management Office and meetings with Sikkim Government Officers		
03.09.2025	Return journey from Gangtok to Bagdogra (Siligudi)		
04.09.2025	Bagdogra to Delhi-Chandigarh and Shimla		

The team traversed mainly the Mangan District of Sikkim as per route map shown at Figure 1

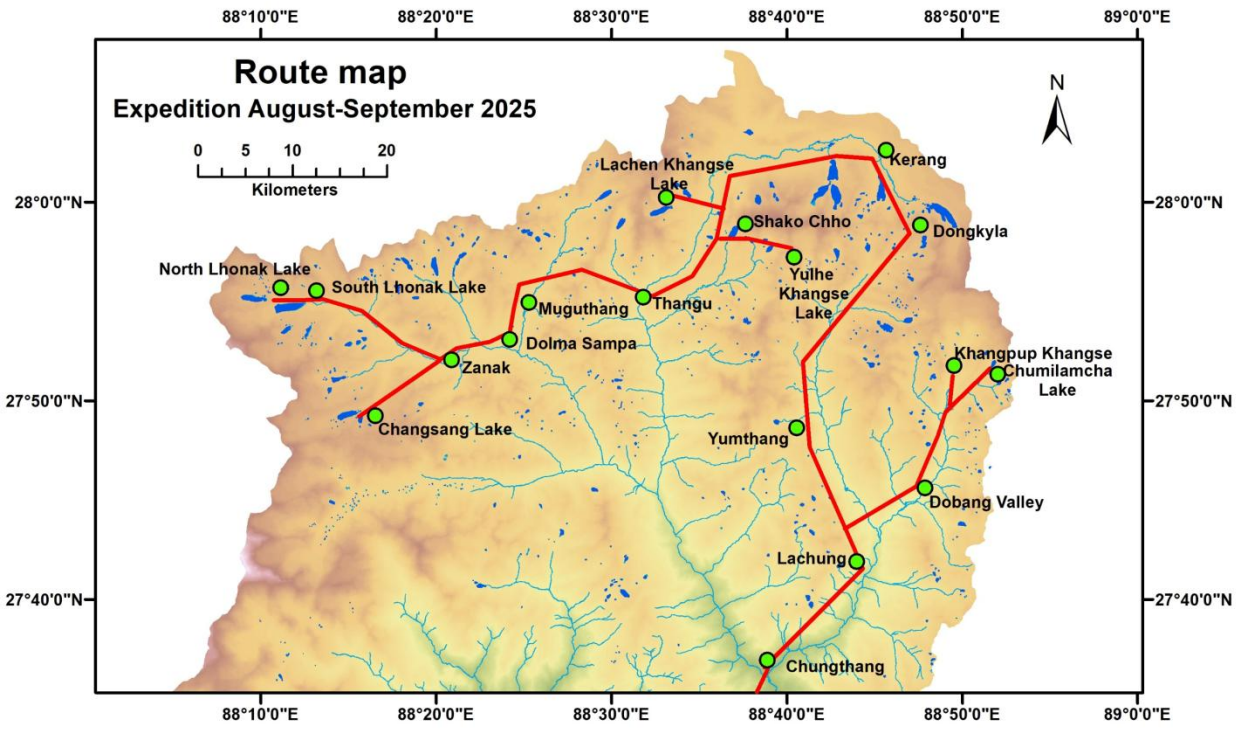

Figure 1: Route Map for the Expedition

4. Approach Adopted by Sikkim Government

The Government of Sikkim is working in GLOF risk identification, mitigation and prevention since 2012 actively and has undertaken around 30 expeditions so far to glacial lakes. Along the journey a lot of emphasis has been given towards developing in house capacity in field surveys and investigations by involving the Department of Science & Technology, Geological Department and Sikkim University. The Sikkim Government has evolved four step approach to study the GLOF risks and undertake preventive measures:

4.1. Application of Remote Sensing Technique

The State identifies potentially hazard lakes based on Satellite Imageries and Remote sensing techniques and categorizes the lakes under the three categories i.e. high, moderate and low risk.

During this expedition the team has visited the already identified high risk lakes and valley i.e. Gurudongmar lake a series of three lakes, Shako Cho lake, South Lhonak Lake, Sora Funnel in Gurudongmar valley, Dolma Sampa in Lhonak valley and other low risk lakes.

4.2. Preliminary survey which includes terrain mapping and in situ observations

In order to confirm, the findings based on studies of Satellite Imageries and Remote sensing techniques, the Sikkim Government organizes expeditions to lake sites to conduct preliminary surveys, in-situ observations and field studies. These expeditions typically involve conducting Bathymetry Surveys, Geological Mapping of the Moraines and surrounding areas, topographical surveys using drones by the in-house team. Besides, the expeditions are joined by experts from Central Government organizations & other institutes, therefore, expert opinions regarding vulnerability of the lakes & proposed mitigation measure to reduce the impact of GLOF risk are also incorporated in the reports.

The team has conducted ERT, drone survey and mapping of geological strata mapping.

4.3. Mitigation Measures (retention structure, siphoning/ solar pumping and installation of early warning system)

The mitigation measures are planned according to the findings of the previous two steps and further detailed investigations are undertaken to plan and propose the possible mitigation measures. In order to understand the process in depth the example of the South Lhonak Lake[1] is presented here:

On the recommendation of the DST, 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

[1] Mission report of GLOF Risk Assessment & Installation of AWS in Sikkim

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. 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. There was a GLOF event occurred on the South Lhonak Lake on the late night of 3rd October, merely 15 days after the installation of the monitoring stations

Further after, the GLOF event of South Lhonak, Sikkim Government is planning to build a retention structure lower portion of the Dolma Sampa in Lhonak valley, where the glacial melt from 183 lakes merges with main stream and in the recent mission drone based surveys, ERT Surveys and geological investigation were conducted to assess the suitability of the site. Further, experts from CWPRS were asked to conduct the Hydrodynamic studies taking into account the debris flow and to develop physical models afterwards for further analysis.

In addition, another site at Sora Funnel in Kerang valley has been identified as potential site for construction of retention structure, where the discharge from Gurudongmar Lake alongwith its two feeding lakes upstream and other lakes in Kerang valley merges to form main stream and during the expedition surveys were conducted on this site as well.

The identified sites in both the cases have narrow cross – section at retention site, which opens to wide and flat valley behind the proposed retention structure, thus leading to suitable conditions for storing large amount of water with relatively low height retention structure.

Sikkim Government is in the process of detailing and designing the retention structures as of now, which may further take considerable time due to technological, topographical and economic challenges involved despite availability of the potential sites. Further, the proposal to install the solar pumps at Shako Cho is also under preparation.

4.4. Execution/implementation.

It involves installation of monitoring and early warning systems, siphoning of the lake water through open cut, pipe siphon system and installing solar pumps, construction of retention structures, and continuous evaluation of the mitigation measures.

AWS have been installed at Shako Cho and South Lhonak Lakes after thorough reconnaissance and identification of ideal site taking into consideration the safety of instruments while ensuring the clear view of the Snout of glacier as well as moraine outlet (in case of the Shako Cho, there is no outlet as of now, but camera points towards the most vulnerable location of the moraine at downstream end of the lake) in collaboration with Swiss agency for Development and Cooperation (SDC) through Geoprevent. The system capture data at regular interval and transmit the same to the cloud server of Geoprevent and access has been provided to Sikkim Government view and download the datasets, although system is yet to be evolved into early warning system. During the visit to DST Office, it is also learnt that the access to Sikkim Government is valid upto December, 2025 and beyond 2025 the terms and conditions to access the datasets are yet to be agreed upon.

As evident from South Lhonak experience, in spite of widening of the outlet, the size of the lake kept increasing and finally resulted in outburst, the mitigation measures being contemplated/ implemented are of demonstrative nature and often require reiterative approach to be monitored and maintained on continuous basis rather than one time investment.

5. Observations, Findings and Recommendations to Sikkim Government

There were briefings from Dr. Sandeep Tambe, Principal Secretary and Dr. N P Sharma about the tasks to be carried out, salient features of the glacial lakes to be visited on the specific days, which gave first hand insight about the glacial lake and a perspective to explore the sites during field visit.

5.1. Chumilamcha Glacial Lake in Upper Dombang Valley

Chumilamcha glacial lake (4800 m) has been classified as Category-A high-risk lake holding 5 MCM of water beneath hanging glacier. The right lateral moraines appeared stable with limited risk of mass movement into the lake, however, the left moraine appeared more fragile having another lake behind with more steep gradient (refer Figure 2).

Figure 2: A view of Chumilamcha Lake in upper Dombang Valley in Gora La

The breached terminal moraine has made a wide outlet of about 20 m width and having a discharge of approximately 1.5 to 1.7 cumecs at the present water level which seemed to be stable. However, the hanging glacier and left moraine pose a major threat. Considering, 40% of breached volume in a time span of 10 minute generate approximate outflow of around 3000 cumecs, which will initially flow into the wider reach of the

channel upto 1 km downstream and afterwards the cross – section narrow downs sharply resulting in greater depths and velocities (typically in the range of 8-10 m/s).

Therefore, installation of water level sensors at the lake and automatic water level recorder alongwith flow measurement 1 km downstream at the bridge to Gora La Pass will help to have calibrated data and early warning system

5.2. Gurudongmar Glacial Lakes in Kerang Valley

The discharge from Gurudongmar Lake alongwith its two feeding lakes upstream and other lakes in Kerang valley merges together near Sora Funnel (refer Figure 3).

Figure 3: The Three Gurudongmar Lakes in Kerang Valley as seen from Dorjila Summit

The main Gurdongmar glacial lakes itself is stable on lateral moraines and has well established outlet on the terminal moraine. However, the upper two lakes on the glacier sides seems to be increasing in size and have glacial snouts in lakes itself, these lakes are discharging into main Gurudongmar lake and their terminal moraine seems to unstable which may burst into the main lake leading to increase in size of main lake with possible GLOF event.

As observed from Dorjila Summit, the proposed site at Sora Funnel for retention structure present suitable conditions with narrow cross – section at retention site with opening to wide and flat valley behind the proposed structure, thus leading to suitable conditions for storing large amount of water with relatively low height retention structure not only for Gurudongmar lakes but other lakes in Kerang Valley. It is suggested that the retention

structure site should be located close to the outlet of Gurudongmar lakes downstream in Kerang Valley and possibility to construct earth and rock fill dam of 15-20 m height having spillway section in concrete and sluicing arrangements to discharge normal conditions should be thoroughly investigated. Therefore, if possible, another alternative of Sora funnel should also be explored in order to have comparative analysis.

5.3. Shako Cho Glacial Lake

Shako Cho is a high-altitude, moraine-dammed glacial lake in Mangan district of Sikkim lying at the elevation of 4960 to 5200 meters above MSL and is located approximately 10 km upstream of the nearest settlement of Thangu village. The Shako Cho is vulnerable 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 nearby Thangu village.

It is one of the two lakes in Sikkim, where AWS have been installed in collaboration with Swiss agency for Development and Cooperation (SDC) through Geoprevent (refer Figure 4).

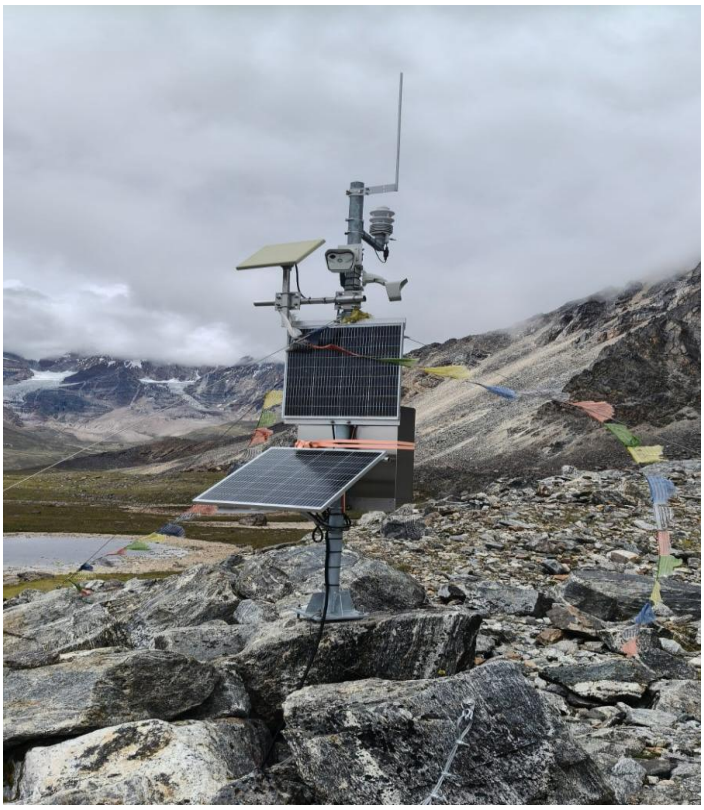

Figure 4: AWS installed at Shako Cho Lake on Right Moraine

The AWS has been installed on a large boulder, which is embedded in the moraine which around 60 – 70 metres above the lake water level and pressure type water level sensors have been adequately anchored in the lake as well as on the moraine, while the two cameras duly cover the snout of the glacier and the end moraine. The water level sensor is very critical to issue the warnings and the cable carrying the signal from water level sensor to the data logger seems vulnerable to damages due to shooting of boulders from lateral moraine.

5.4. Sora Funnel

Sora funnel area has been identified as one of the potential sites for construction of retention structure and at this site the Department of Mines and Geology carried out a 3D Terrain Mapping using a UAV Lidar drone besides carrying out a subsurface geophysical study using ERT to assess the subsurface geology at Sora funnel area (refer Figure 5 and 6).

Figure 5: 3-D Terrain mapping using UAV Lidar drone in Sora Funnel

Figure 6: Subsurface geophysical assessment using ERT at Sora Funnel

In this context, as discussed under Section 5.2, if possible, alternate site (s) close to outlet of Gurudongmar lake may be explored for construction of retention structure, which will help to make comparative analysis for selection of best site.

5.5. Retention Structure Studies at Dolma Sampa

At Dolma Sampa, the team carried out the field studies for the preparation of Pre-Feasibility Report (PFR) comprising of subsurface geophysical survey, topographical survey, debris deposition assessment, UAV-based terrain analysis, Lidar DEM and glacial flood level mapping.

Figure 7: Debris Deposited at Dolma Sampa in Lhonak Valley

The visual inspection of the proposed site for retention structure indicate the suitability of the site for topographical point of view and rock outcrop is visible on the left bank, however, on the right bank glacial deposits are accumulated, which need to be investigated for permeability as well as stability. As already envisaged Hydrodynamic studies taking into account the debris flow need to be carried out besides development of physical models as large scale debris deposition was observed not only at Dolma Sampa but upstream towards South Lhonak Lake.

5.6. South Lhonak Glacial Lake

South Lhonak Lake is moraine-dammed glacial lake in Sikkim's Northwestern region lying at the elevation of 5200 meters above MSL, which is formed due to metling of the Lhonak glacier. The area[2] of the lake increased from 17.54 ha in 1977 to 98.73 ha in 2008, which further increased in size to 170 ha in 2023. The GLOF potential of South Lhonak lake had been long identified by researchers due to ice-calving from the glacier snout, failure of the moraine, snow avalanches or landslides into the lake, and overflow

[2] Current Science, Vol. 104, No 3 by NRSC

from North Lhonak lake above it etc.. It was reported that the GLOF was triggered by a landslide of the waterlogged lateral moraine into the lake compounded with the heavy rainfall.

It is another lake beside Shako Cho, where AWS have been installed in collaboration with Swiss agency for Development and Cooperation (SDC) through Geoprevent (refer Figure 8).

Figure 8: AWS installed at South Lhonak Lake on Right Moraine

The AWS has been installed on the a large boulder, which is embedded in the moraine which around 100 metres above the lake water level and pressure type water level sensors have been adequately anchored in the lake as well as on the moraine, while the two cameras duly cover the snout of the glacier and the end moraine. The water level sensor is very critical to issue the warnings and the cable carrying the signal from water level sensor to the data logger was damaged resulting in non-availability water level data. Further, the data cable itself is more than 200 mtr long making it susceptible to damages on the surface moraine dam. Thus, it is imperative to have alternate short range data

transmission arrangement (wifi or LoRAWAN) from sensor to the datalogger alongside data transmission through cable to ensure data continuity.

Further, it was also observed that the tension cracks were developing in the end moraine which may cause slides towards the outlet of the lake leading to blockage of outflow and then sudden outburst due to hydrostatic pressure.

During the visit time at the Lake three incidents of the slide from Right Moraine were also observed, which indicate the vulnerability of the lateral moraines. South Lhonak lake is at the elevation of 5200 m and High intensity rainfall witnessed during the expedition is not common on such elevations, rain water having high latent heat will further increase the rate of snowmelt coupled with snout of the glacier is directly into the lake may lead to falling of large chunks of glacier into the lake besides rapid increase in the size of the lake. Therefore, continuous monitoring of the lake alongwith robust evacuation plan would be imperative to mitigate the impacts of any GLOF event in future.

6. Recommendations to Government of Himachal Pradesh

- The Sikkim Government has developed in house capacity over past 10 to 15 years to undertake ERT surveys, bathymetry, UAV 3D terrain mapping etc. and organized numerous expeditions to glacial lakes by involving Central Agencies, Institutes, Government Departments and Experts. Developing in house capacity for hazard assessment is long term task with strategic planning to cover administrative, technological and institutional aspect with budgetary support; it is imperative to have in house capacity to undertake such works. However, at this critical juncture till in house capacity is developed, it is recommended to get the DPR prepared through specialized agency having requisite experience in the field by inviting RFP/ Bids.
- Preparation of DPR involves a lot of survey and investigation work, data collection and analysis, and due to limited working time; preparation of the DPR may take two working seasons. In order to expedite the implementation of works, it is recommended to get the DPR vetted from the agencies suggested by NDMA so that most suitable technical solutions can be implemented at sites.
- Installation of instruments for Early Warning System can be planned early during the DPR stage by having different phases of DPR, which will help in getting calibrated data for developing functional early warning protocols.

- In Sikkim, there are either no habitated areas downstream of high risk glacial lakes upto a distance of 30 to 60 km or there are small villages with less infrastructure development, resulting in lead time of 1.5 hours to 2 hours to issue the warnings, which is further bolstered with the deployment of Army & ITBP near the lakes, resulting into validated warnings. However, in case of Himachal Pradesh, there are towns/ settlements, HEPs and other infrastructure just 10 to 15 km downstream of glacial lakes with lead time of 15 minute to 30 minute (steep gradient till habitations is another cause of lesser lead time) and we do not have deployment of Army/ ITBP near to glacial lakes. Therefore, we need to have very robust & reliable warning system which is further to be supported by manual watchtowers round the clock.
- In Sikkim, there are wide and flat valleys downstream of glacial lakes within 15 to 20 km, which make them suitable sites for planning and construction of retention structures, however, unfortunately in Himachal Pradesh, such wide & flat valleys are not available in general. Therefore, planning retention structure does not seem to be a feasible option. However, some flood routing can be planned by collaborating with downstream HEPs after conducting Hydrodynamic and Physical Modelling through CWPRS.
- Developing evacuation plans and identifying shelter sites based on the studies already carried out by NRSC and other institutions should be one of the earliest step to mitigate the impacts of GLOF, which can be further refined based on the survey and investigation data gathered during DPR stage.
- Further, based on the analysis carried out during DPR stage, other mitigation measures like lowering level of glacial lakes through open cut, siphoning system and deployment of solar pumps can planned and implemented accordingly.
- Development of community-based early warning systems (crowd sourcing) that involve local communities in monitoring and reporting changes in water levels or unusual weather patterns after sensitization of the local community as a long terms solution.
- Direct collaborations with agencies like SDC, who can install the EWS system directly after reconnaissance and available reports, similar to the methodology adopted in Sikkim can be contemplated, which however require due approvals from NDMA/ GoHP at highest level.
- It is also recommended that there is need to develop in-house capacity to conduct ERT, Drone survey, bathymetric survey and operations of early warning system with proper institutional arrangements catering to most difficult working conditions, therefore, the in

house team needs to be supported with fitness training for working high altitude areas, providing logistics support, personal protective kits comprising of the shoes, jackets, goggles, gloves etc. alongwith provision of latest survey and testing instruments with regular upgrades.

- Geological Wing of Industries Department, and HIMCOSTE should be part of the in-house team and be involved in the survey & investigations of the glacial lakes. Further, Dam Safety Wing of the Department of Energy should be involved while planning for flood routing through Dams downstream of the lakes.

7. Conclusion

The exposure visit to Sikkim provided valuable insights into the state's proactive measures for mitigating Glacial Lake Outburst Floods (GLOFs), which pose significant risks to both human lives and infrastructure. Sikkim's multi-faceted approach, combining remote sensing, field studies, and advanced mitigation techniques like retention structures, early warning systems, and solar pumping, offers a solid framework for tackling GLOF-related challenges.

For Himachal Pradesh, which faces similar risks from its glacial lakes, the key takeaway is the importance of tailoring mitigation strategies to the unique topography and conditions of the region. By focusing on high-risk areas, integrating technology such as drones and remote monitoring systems, and engaging local communities in early warning systems, Himachal Pradesh can significantly enhance its resilience to GLOF events. Collaboration with national and international agencies will also be crucial for gaining technical expertise and mobilizing resources.

Overall, the lessons learned from Sikkim provide a strong foundation for developing and implementing effective, context-specific strategies to manage GLOF risks and protect vulnerable communities in Himachal Pradesh.