Report On Rapid Assessment of GLOF Event From Thorthomi Lake on 30th October 2023

National Centre for Hydrology and Meteorology

2023

Report prepared and submitted by NCHM Technical Team:

a. **Mr. Karma, Specialist (Glaciologist), Cryosphere Services Division, NCHM**
b. **Mr. Phuntsho Tshering (Glaciologist), Cryosphere Services Division, NCHM**
c. **Mr. Sangay Tenzin, Engineer (EWS), Hydrology and Water Resources Services Division (HWRSD), NCHM**

Edited by:

a. **Mr. Karma Dupchu, Director, NCHM**
b. **Mr. Karma, Specialist (Glaciologist), Cryosphere Services Division, NCHM**
c. **Dr. Singay Dorji, Specialist, Meteorological Services Division (MSD), NCHM**

Executive Summary

The 30th October 2023 GLOF incident from Thorthormi lake partially breached the main Thorthormi lake. The rapid assessment team deputed to Lunana observed that the whole ablation part of Thorthormi glacier has been disintegrated into ice blocks. The periphery of Thorthormi lake has almost reached the bed rock (rock cliff) at the base of Table Mountain in the extreme upstream. Currently Thorthormi lake measures 4.33 km in length (max), 1.3 km in width (max) with a surface area of 4.33 km^2. Due to the partial breaching of Thorthormi lake on 30th October 2023, the lake level got lowered by 46 cm resulting in an estimated flood volume of 1.98 million cubic meters of water.

Displaced ice blocks were found at a height of 4.3 m above the subsidiary lake I indicating the probable height of first wave during the flood. Such high wave could have been generated during the disintegration of the Thorthormi glacier. Analysis of time series satellite data revealed that there was a massive mass movement (avalanche/icefall) from the accumulation area of Thorthormi glacier between 26th October and 31st October 2023. Such massive mass movement could have impacted the ablation area of the glacier and disintegrated it. Temperature analysis in Bhutan shows that the temperature in the month of July, September and October in 2023 were higher compared to the normal temperature in the country. Therefore, it can be inferred that the warmer days preceding to the GLOF incident on 30th October 2023 in combination with the extreme windy condition in the area could have triggered the massive mass movement in the accumulation area of Thorthormi glacier and impacted the ablation part of the glacier resulting in the disintegration.

Although there were no major impacts on the lives and infrastructure reported, the automatic water level station at Thorthormi lake (AWLS) was completely damaged. The foot bridge at the outlet of Thorthormi lake was also completely washed off and in the downstream the bridge between Tenchoe and Dota village was also found to be damaged by the flood.

As the extent of Thorthormi lake has now almost touch the near vertical rock wall at the base of Table Mountain, there is higher probability of mass movement (avalanches/icefalls/rockfall) falling directly into the lake and causing similar incidences in the future. It is also important to note that the recent event has weaken the moraine dam at the outlet of main thorthormi lake.

NCHM has strengthened the monitoring system at the lake site and also temporarily restored the damaged AWLS at Thorthormi lake. However, considering higher frequency of such GLOF events from Thorthormi lake (2019, 2023) in the recent time, relocation of vulnerable households in Lunana (due to short lead time they get), awareness and contingency planning of GLOF for vulnerable communities downstream, relocation of AWLS to the main lake, enhancement of current early warning system with additional sensors to provide more lead time and detail bathymetry survey of Thorthormi lake to estimate the stored water volume are some of the main recommendations.

Acknowledgement

The National Center for Hydrology and Meteorology (NCHM) would like to acknowledge the following individuals and institutions for enabling the team to complete the rapid assessment and restoration of damaged AWLS at Thorthormi within a short span of time.

The Center would like to thank the Secretary, Ministry of Energy and Natural Resources for his overall coordination during the incident and supporting the Centre in the arrangement of helicopter service to deploy the rapid team the very next day.

We would also like to acknowledge all the help and support provided by M/s TWD Construction Firm and their workers to the team during the assessment. The centre specially would like to thank the workers of the Firm who assisted our staffs in Lunana on the night of 30th October 2023. We would also like to thank our staff in Flood Warning Office, Thanza, Lunana, Wangdi GLOF EWS Control Room and National Weather and Flood Warning Centre (NWFWC), Thimphu for their work and support.

NCHM would also like to express our gratitude to Dr.Sonam Wangchuk who is based in the Netherlands for his help in the satellite data analysis and World Bank for their support for payments of emergency chopper services through the ongoing the "Strengthening Risk Information for Disaster Resilience in Bhutan" Project

Lastly, the Center would like to acknowledge contributions of all individuals institutions directly or indirectly involved with the monitoring, rapid assessment and restoration works.

Table of Contents

1. Introduction

There are 6 main glaciers and 5 glacial lakes in Lunana (fig.1). Due to the close proximity of the glaciers and glacial lakes in terms of location to each other and also different behavioral characteristics of the glaciers and glacial lakes the area is commonly called Lunana complex. Four of the glacial lakes (Druk Chung, Lugge, Thorthormi and Rapstreng tshos) are catergorized as potentially dangerous glacial lakes. Considering high level of Glacial Lake Outburst Flood (GLOF) hazard from these lakes, risk lowering work through artificial lowering of lake water level was carried out on two of these lakes in Lunana area (Rapstreng and Thorthormi) from 1996-1998 and 2009 – 2012 respectively. In addition, GLOF Early Warning System (GLOF EWS) were also installed in Puna Tsang Chu, Mangde Chu and Chamkhar river basins.

Figure 1: Image showing glaciers and glacial lakes along with the location of 2 most upstream village (Thanza & Tenchoe)

2. Thorthormi GLOF incident on 30th October 2023

At around 17.20 hrs on the night of 30th October 2023, staffs of National Centre for Hydrology and Meteorology (NCHM) stationed in Lunana reported high glow in the river as recorded at Thanza station with drastic change of water colour (muddy) in the Pho Chu river. The remote water level sensor installed at subsidiary lake I at Thorthormi lake also detected sharp drop in water level at the subsidiary lake during the same time. The NCHM staffs at Lunana were deputed immediately to the lake site for ground verification. Abrupt changes on Thorthormi glacier and displacement of ice blocks at the outlet of the Thorthormi lake was reported by verification team at around 22.20

hrs. The situation was monitored intensively at the control rooms at Wangdue and Thimphu by the officials of NCHM and a decision made on the same night to depute a technical team to Lunana to conduct a rapid assessment of the incident. Accordingly a three member team comprising of the following officials from NCHM were deputed on 31st October 2023.

a. Mr. Karma (Specialist), Cryosphere Service Division, NCHM

b. Mr. Phuntsho Tshering (Glaciologist), Cryosphere Service Division, NCHM

c. Mr. Sangay Tenzin, EWS Engineer, Hydrology and Water Resource Service Division, NCHM

3. Objective

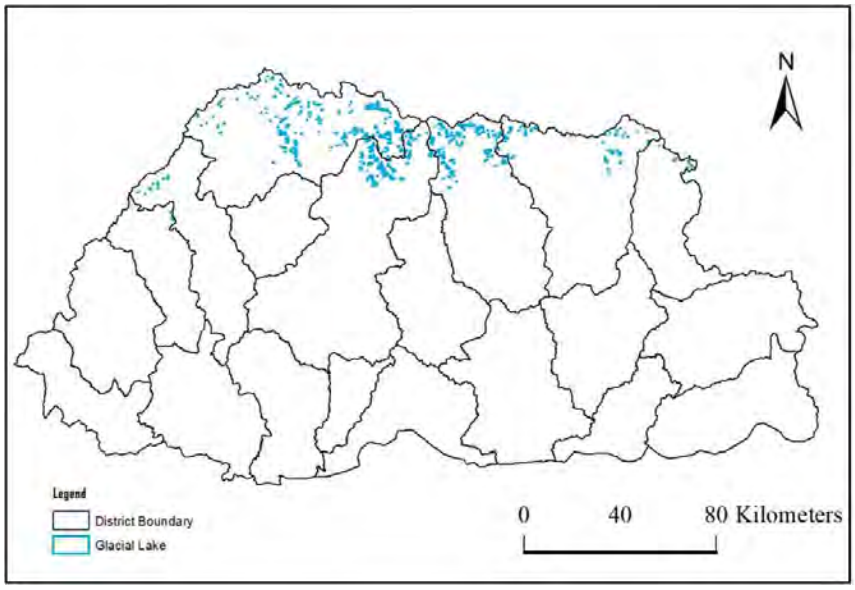
The objectives of deputing the rapid assessment team from the centre are:

a. To assess the situation of Thorthormi glacial lake after the 30th October incident

b. Assess the damages to GLOF EWS infrastructure in Lunana

c. Restore the remote automatic water level sensor at Thorthormi lake

4. Current status of glacial lakes and potentially dangerous glacial lakes in Bhutan



Sl No	Sub- basin	Basin	Lake No
1	MoChhu	Punatsang Chhu	66
2	Pho Chhu		157
3	Mangde Chhu	Manas	130
4	Chamkhar Chhu		131
5	Kuri Chhu		61
6	Drangme Chhu		9
7	Wang Chhu	Wang Chhu	13
	Total		**567**

Figure 2: Map showing location of glacial lakes in Bhutan

As per the Bhutan glacial lake inventory 2021 published by NCHM, there are 567 glacial lakes (fig.2) identified covering an area of about 55 km2 which accounts to 19.03% of the total

number of water bodies and 0.14% of the total land area of Bhutan. Pho Chu sub basin has 157 glacial lakes in total.

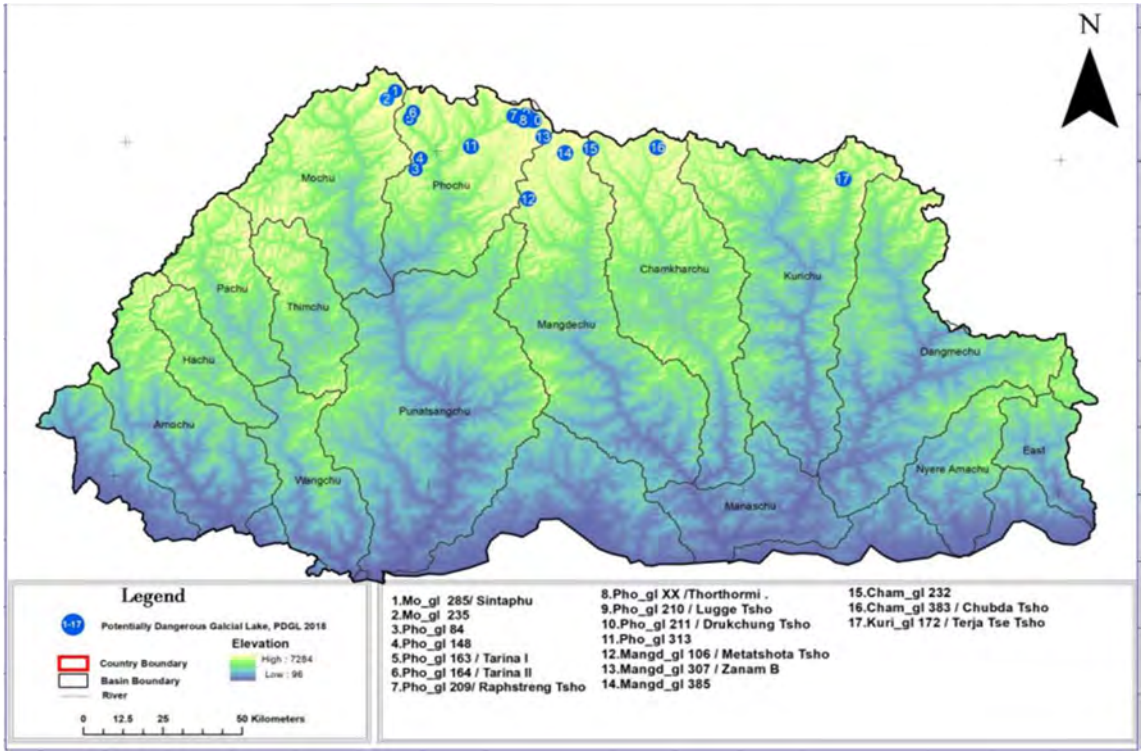


Figure 3: Potentially Dangerous Glacial lakes in Bhutan

Based on the information in the re-assessment of potentially dangerous glacial lakes in Bhutan published by NCHM in 2019, out of 567 glacial lakes in the country, 17 of these lakes are categorized as potentially dangerous glacial lakes (fig.3). There are 9 PDGL located in the headwaters of Pho Chu and 4 of these lake are found in Lunana (Rapstreng tsho, Thorthormi tsho, Lugge tsho, Drukchung tso).

5. Assessment

5.1 Observation

The rapid team carried out a thorough observation of Thorthormi tso both from the air and ground. The following observations were made focusing on the most vulnerable part of Thorthormi tsho.

5.1.1 Thorthormi glacier surface

Aerial observation by the rapid assessment team revealed that Thorthormi glacier has undergone drastic change due to the incident on 30th October 2023. The intact and continuous

Photo 1: Disintegrated Thorthormi glacier (view to the upstream)

glacier body which existed in the upper part of Thorthormi glacier got disintegrated into ice blocks and found floating (Photo 1).The lower half of Thorthormi glacier which used to be covered with ice blocks and ice cliffs with supra glacial ponds in-between has turn into complete water mass (Photo 2) unlike in the past years. Floating disintegrated ice masses/ ice blocks were found to be concentrated the upper part of Thorthormi lake.

Photo 2: Lower part of Thorthormi tsho (view towards downstream/outlet)

Photo 3: Extreme upper part of Thorthormi Tsho

At the extreme upper part of Thorthormi glacier it was observed that Thorthormi lake now has reached almost to the bed rock similar to Rapstreng Tsho. The terminus of Thorthormi glacier has shifted right at the edge of steep rock wall which lie at the base of Table mountain. It was also observed that the terminus of Thorthormi glacier which is clearly visible is in direct contact with the lake (Photo 3).

5.1.2 Thorthormi – Rapstreng barrier

One of the most critical areas when discussing about GLOF scenerios from the lakes in Lunana is focused on this part of the moraine dam surrounding Thorthormi and Rapstreng tsho. This complicated structure which forms a common moraine wall between Rapstreng tsho and Thorthormi tsho was formed as part of lateral moraine of both rapstreng and thorthormi glacier during the glaciation period. As Thorthormi lake is higher than rapstreng and considering that this moraine barrier between Rapstreng and Thorthormi tsho is ice cored, the common fear was failure of this barrier resulting in Thorthormi overtopping into Rapstreng lake and occurring a combined GLOF with an estimated flood volume of 53 million cubic meters of water which is referred to as worst case scenario. Therefore a thorough visual scan was conducted during the rapid assessment period for any impact from the incident on 30th October 2023.

Photo 4: Moraine barrier between Rapstreng tsho and Thorthormi tsho

Fresh scars of mass movement (landslides) were noticed on the slope facing Thorthormi lake as indicated in red circles (Photo 4). Except for erosional marks which might have taken place during last summer, no signs of major fresh mass movements were observed on the slope facing Rapstreng tsho. In addition, the team also scanned the top of the moraine barrier ridge for any new signs of crack development and any unusual activities from the recent incident. No major mass movement both on Rapstreng and Thorthormi side were found except for few minor slides that were observed on the slope facing Thorthormi tsho. There were also no major cracks seen on the top of the moraine barrier ridge.

5.1.3 Channel between main Thorthormi lake and subsidiary lake I

The water from main Thorthormi lake drains into subsidiary lake I through two outlet channels (Photo 5). The high flow from the main Thorthormi lake on the night of 30th October, 2023 has eroded the moraine at the outlet of main Thorthormi lake. Due to side erosion and scouring of the channel the ice underneath the debris are now exposed. The channel between the main lake and subsidiary lake I has also become wider and deeper thereby reducing the water level in the main Thorthormi lake. The water level difference between the main Thorthormi lake and subsidiary lake I was found to be about 0.6 m only. The changes at the main Thorthormi tso outlet before and after the recent event is highlighted in red circles in figure 3.

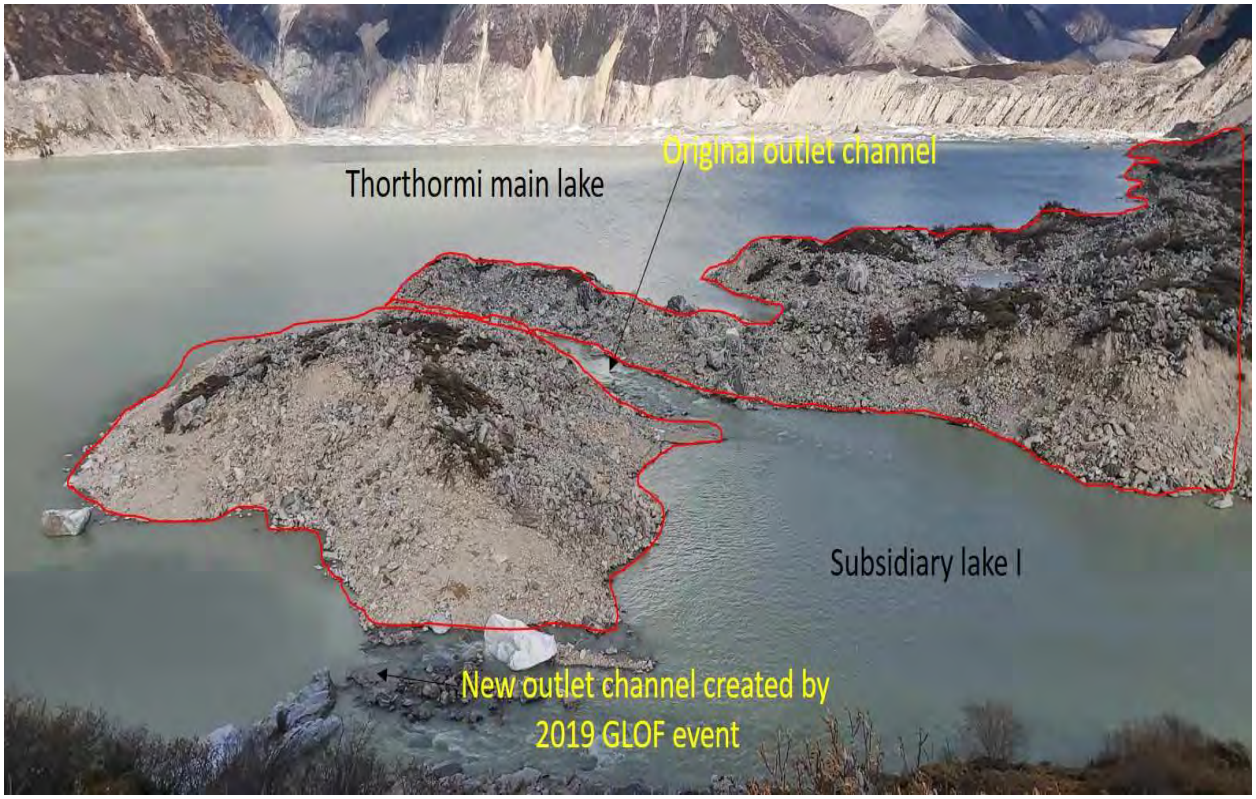


Photo 5: Condition at the outlet of main Thorthormi tsho

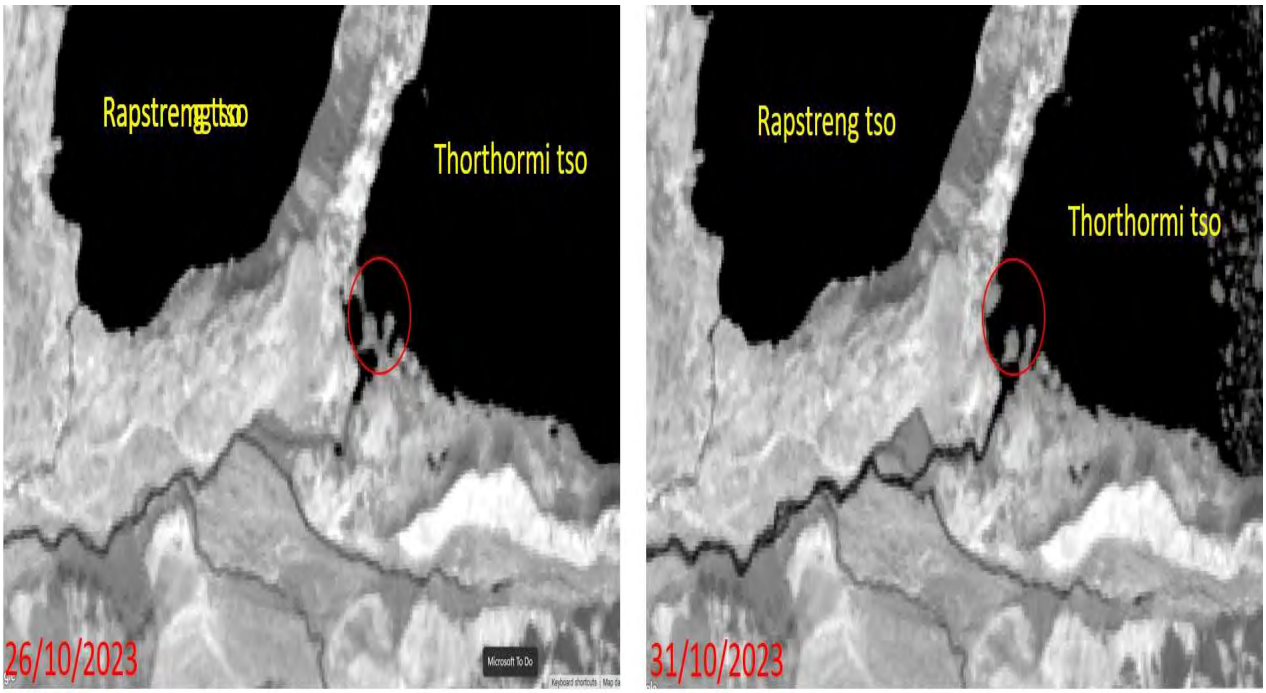


Figure 3: Image showing erosional impact at the outlet of main Thorthormi tso before and after 30th October 2023 GLOF event

5.1.4 Channel between subsidiary lake I and subsidiary lake II

Due to the high-water flow in the channel during the recent incident lot of side erosion and also scouring of channel bed was observed (Photo 6). A scouring of around 40 cm channel bed was observed.

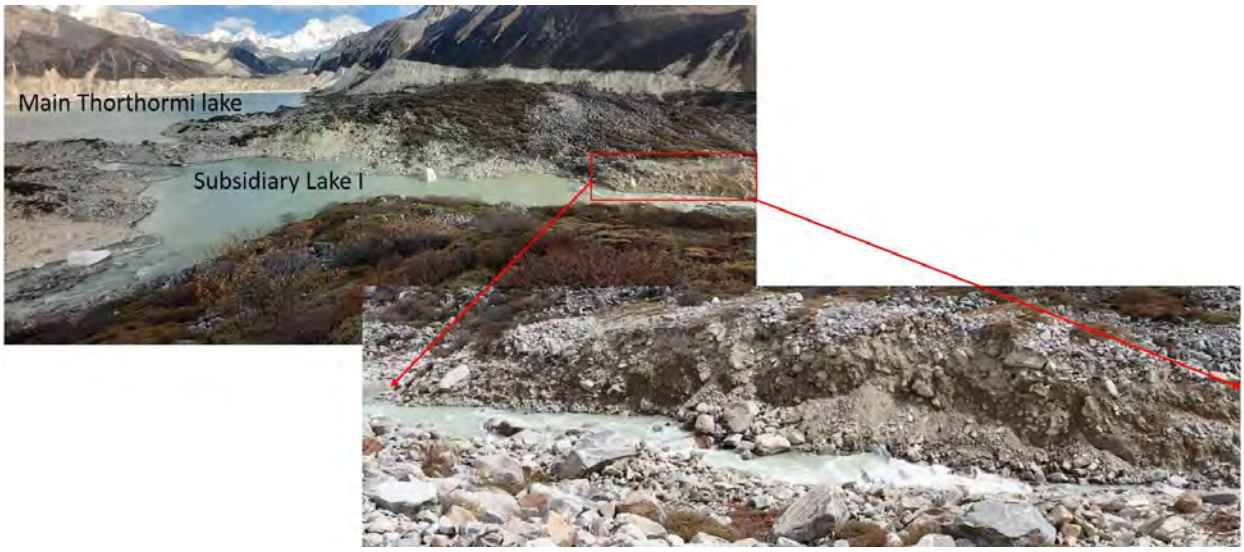


Photo 6: Erosion and scouring in the channel between subsidiary lake I and subsidiary lake II

5.1.5 Ice block displacement

Photo 7: Displaced ice blocks at the periphery of the lakes.

Ice blocks and pieces were observed at various locations around the periphery of Thorthormi lake and the subsidiary lake areas. Few blocks of ice were also seen on the river bed downstream of Thorthormi lake at a distance of about 500 m.

At the subsidiary lake I, a huge ice block was seen at the location shown in Photo 7. The displaced ice block was found at the location which is about 4.3 m above subsidiary lake I. From this height of displacement, it can be inferred that the first wave of water from Thorthormi lake during the recent incident was approximately 4.3 m high. Similarly huge ice blocks were also noticed at the outlet of main Thorthormi lake (Photo 5) and also in subsidiary lake I and II which implies lot of disintegrated ice blocks from the main Thorthormi tso was displaced and carried with the high water flow.

5.1.6 Impact and damages

As a result of the incident on 30th October 2023, the water level in the main Thorthormi lake was reduced by around 46 cm and the estimated flood volume was about 1.98 million cubic meters of water. Although there were no major impact reported on lives and properties of the communities both in Lunana and downstream, some of the damages incurred in Lunana area observed by the team are highlighted below.

a. Automatic water level sensors at Thorthormi lake

Photo 8: Damaged parts of Automatic water Level Station (AWLS) at Thorthormi tso

As a part of GLOF early warning system (GLOF EWS), an automatic water level sensor was installed at the subsidiary lake I on Thorthormi lake. Due to the recent incident this station was

damaged and became non-functional. The GI pipe which host the cable connection …….was damaged completely and all cable connections broken (Photo 8).

b. Foot bridge over Thorthormi outlet

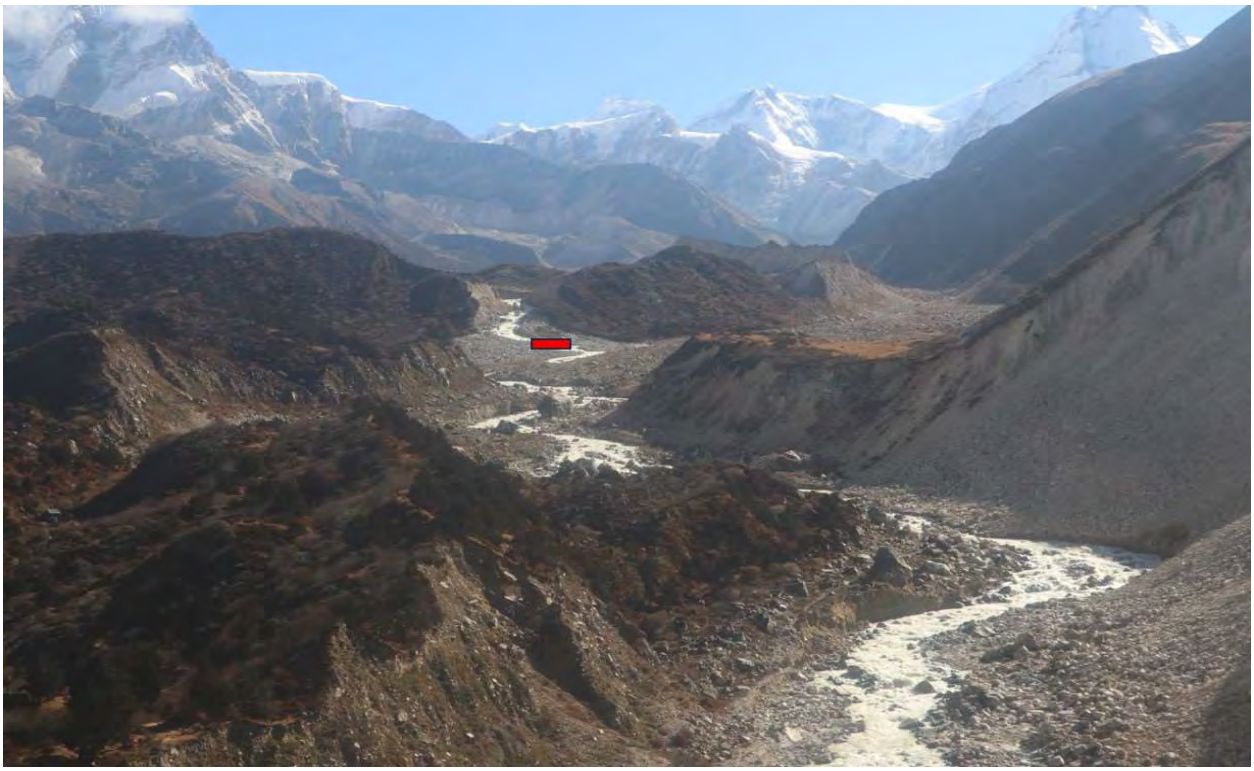


Photo 9: Location of foot bridge on Thorthormi outlet

The foot bridge over the stream which flows out from the Thorthormi lake was completely washed off (Photo 9). This bridge serves as an important means of communication for the locals of Thanza village especially to take their yaks to their winter grazing area near Lugge tsho. The bridge is also important for the staffs of NCHM posted in Lunana to conduct regular lake monitoring on Lugge tsho.

c. Bridge between Tenchoe and Dota village

This bridge is located in downstream of the lakes between the village of Tenchoe and Dota. Based on the information from the local people, it was also badly damaged during the recent incident (Photo 10).

Photo 10: Damaged bridge between Tenchoe and Dota village

6. Causes and trigger of the recent incident

An extensive satellite images of the area reveals that Thorthormi glacier had been quite active since April 2023 with lot of ice movement taking place on the ablation area of Thorthormi glacier. Image analysis focusing in the month of October 2023 shows that there was a major mass movement taken place in the accumulation area of the glacier. Comparing the satellite image dated 26th October 2023 and 31st October 2023 it is clear as indicated in the red rectangle (fig.4) that a massive ice fall from the accumulation has occurred. The remnants of the mass movement is visible further up in the accumulation region of Thorthormi glacier. Therefore, the most probable cause of the incident on 30th October 2023 could be an avalanche from the top of the accumulation area which triggered the ice fall from the steep rock cliff on the lower part and falling on the ablation area of Thorthormi glacier. Such massive mass movement from the accumulation region directly on the ice in the ablation area could have disintegrated the whole ice field in the ablation area and resulted in generating a surge wave. The propagating surge wave could have carried the ice blocks and over topped the outlet at main Thorthormi lake displacing the ice blocks at a height of 4.3 m.

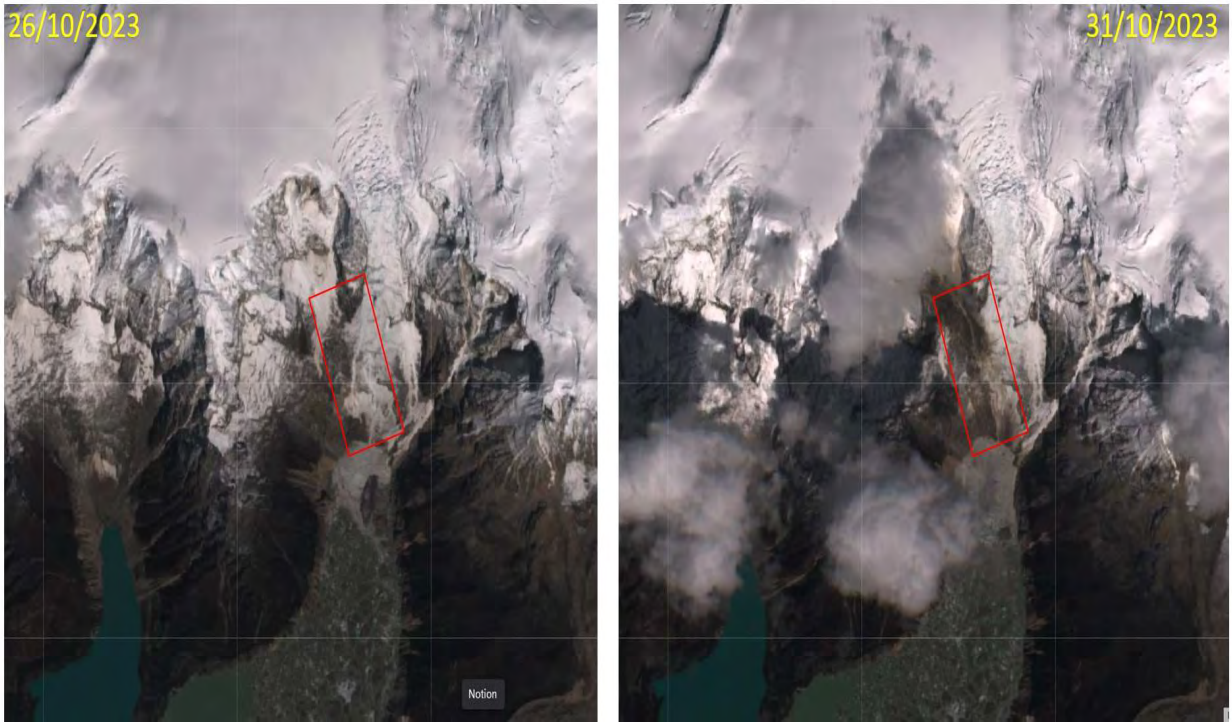


Figure 4: Satellite image showing difference in feature before and after the GLOF event on 30th October 2023 on Thorthormi glacier.

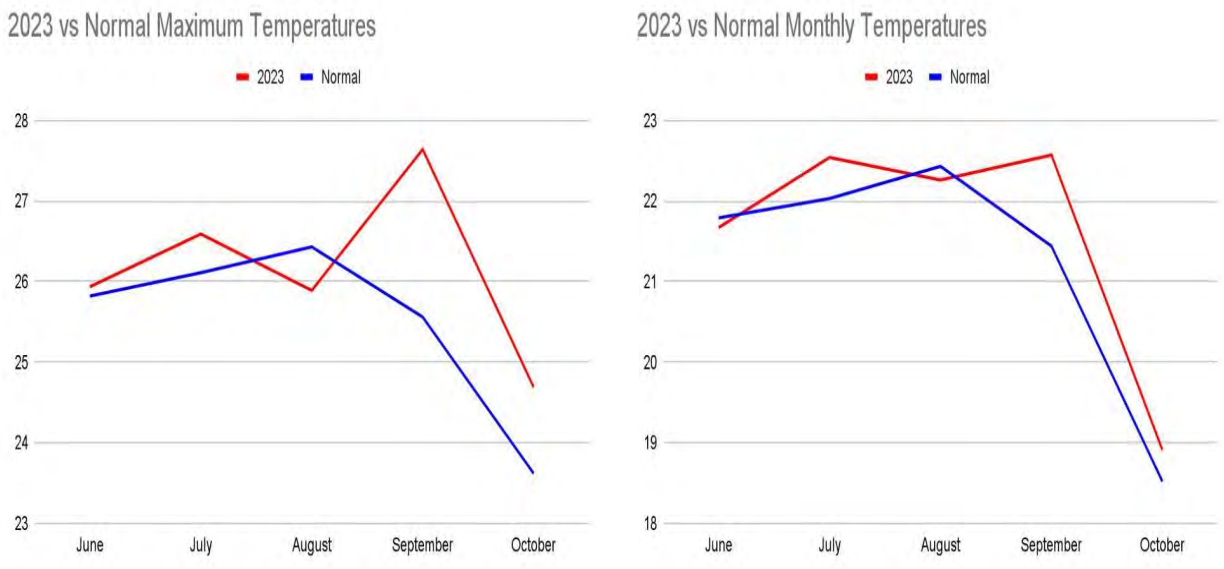


Figure 5: Comparison of 2023 temperature with the normal temperature in Bhutan for the month of June, July, August, September and October

Several factors such as seismic activity and atmospheric conditions could have triggered the avalanche and icefall in the accumulation area. There was no major seismic activity observed in the region during the period of the incident. Monthly maximum temperature (Tmax) and monthly average temperature for the month of June, July, August, September and October were analyzed and compared with the normal (1996-2022) in Bhutan. For both cases except for the month of August, the temperature was found to be higher in 2023 for June, July, September and October (fig.5). It is also important to consider that the intensity of wind in the high altitude increases in autumn and winter seasons. Considering all these factors, it is probable that the higher temperature in combination with windy condition could have triggered the avalanche and ice fall in the higher accumulation part of Thorthormi glacier.

Similar incident occurred in the month of June 2019 from Thorthormi lake where the subsidiary lake II was completely drained out. The cause and trigger of the event was attributed to disruption on Thorthormi glacier in the ablation area and higher temperature in the preceding months was pointed out to be the main cause.

7. Current situation of Thorthormi lake

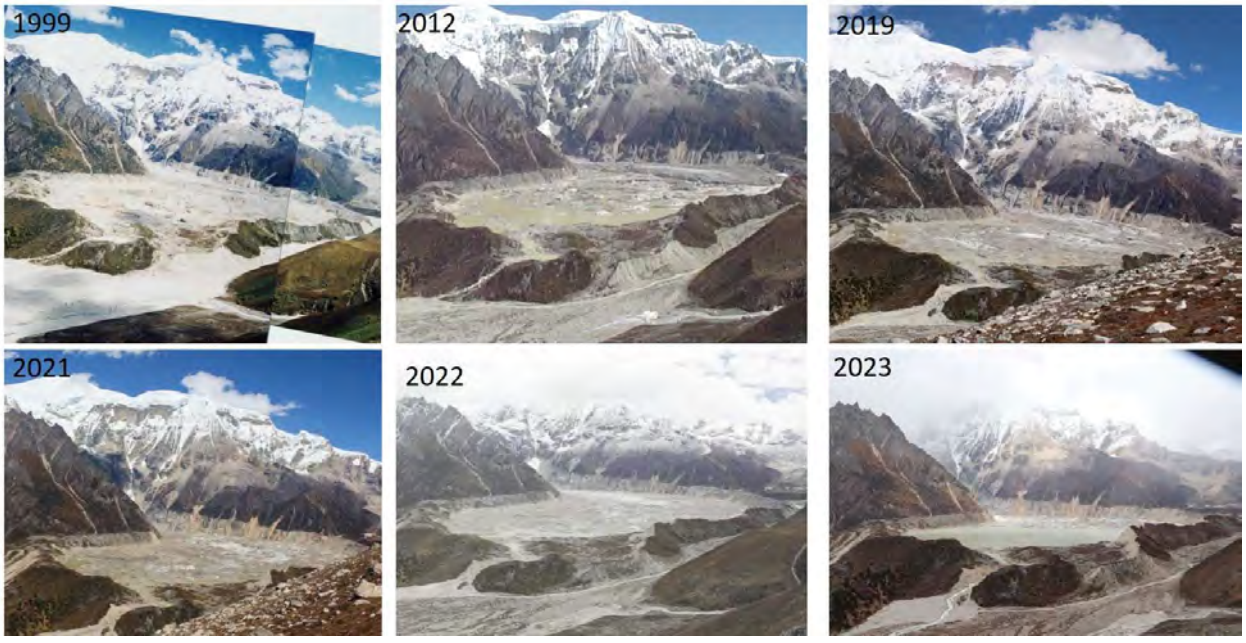


Photo 11: Time sereis changes on the surface of Thorthormi glacier from 1999 to 2023.

Time series changes that are visible on the surface of Thorthormi glacier from 1999 till 2023 is shown in photo 11. Recent changes that have taken place in the extreme part of Thorthormi glacier are shown in photo 12. Current condition of the main Thorthormi lake outlet along with subsidiary lake I are shown in photo. Based on the assessment conducted by the rapid assessment team after the recent incident, important points are highlighted in the following section:

Photo 12: Recent changes at the extreme upper part of Thorthormi glacier

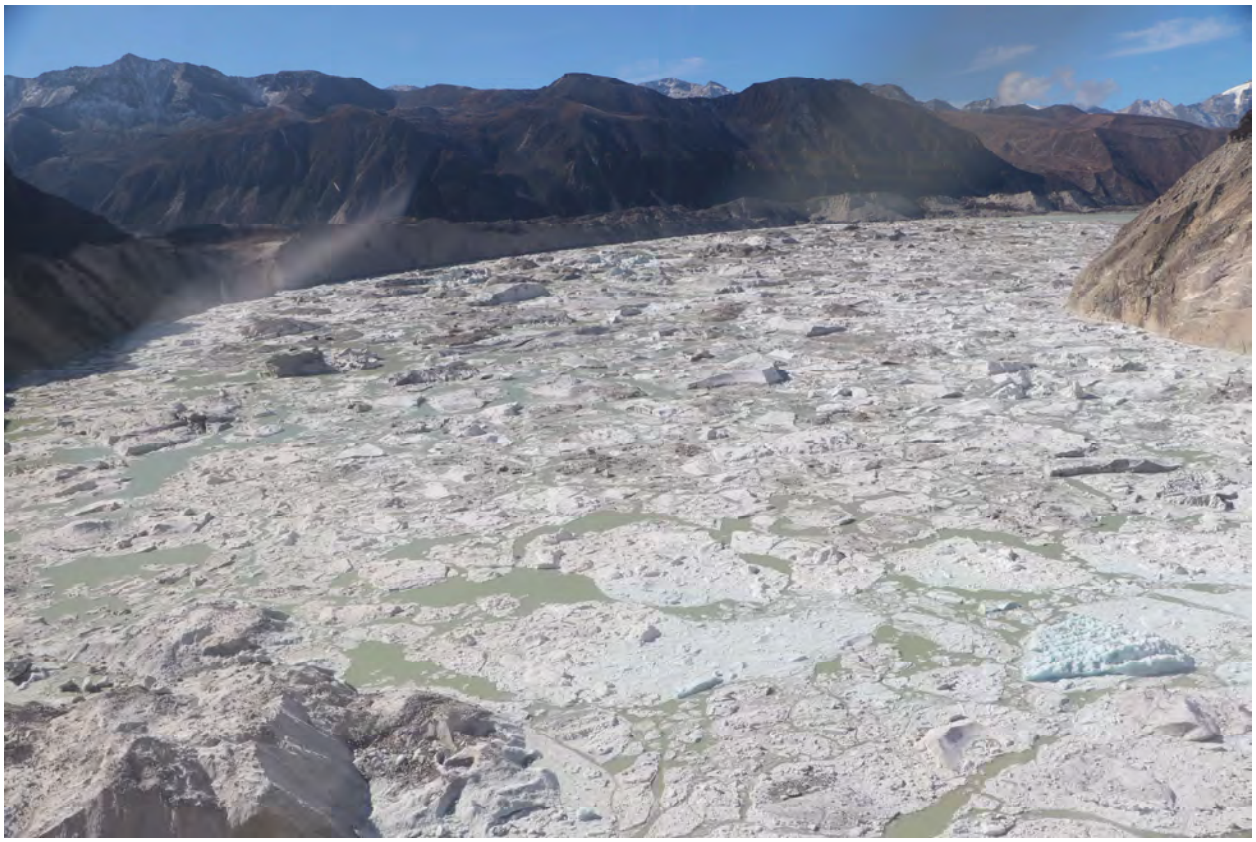


Photo 13: Surface of Thorthormi glacier

a. Almost whole of the ablation region of Thorthormi glacier has turn into water body. Upper half of the lake has ice blocks floating on water and lower half of the lake appear to be completely water body (Photo 2,5 and 11).

b. The edge of the lake boundary has almost reached the steep bed rock of the table mountain where terminus part of Thorthormi glacier occupies only a small portion clearly visible in photo 3 and 12). Due to such morphological condition of the lake (close proximity of the lake boundary to steep bed rock) the probability of mass movement (avalanche/icefall/rock fall) from the accumulation impacting the lake directly is higher which may result in similar events in the future.

c. The moraine dam at the outlet of main Thorthormi lake has reduced in size and the ice beneath the debris are exposed which may further weaken the moraine dam when the ice are melted.

d. No signs of major impact from the recent event was observed on the moraine barrier between Thorthormi and Rapstreng tsho.

e. Lot of erosion and scouring has taken place in the channels downstream of subsidiary lake I (Photo 6).

8. Action taken by NCHM

Some of the actions taken from the centre's side as immediate measure are as follow:

a. Vulnerable communities in Lunana were put on high alert considering very short lead time incase of major GLOF event.

b. Thanza water level monitoring station was strengthen and the staffs of NCHM in Lunana were asked to report water level data every 30 mins during night time (from 7 PM to 6 AM) till an interim water level station at Thorthormi lake was put in place.

c. Work on restoration of automatic water level station (AWLS) at Thorthormi lake was initiated immediately and an interim AWLS was put in place on 6th November 2023. After restoring the AWLS at the lake intensive monitoring at night at Thanza station (requirement to report every 30 mins) was withdrawn. However, an additional daily observation at 21.30 hrs was recommended beside the regular scheduled observation.

d. The frequency of lake monitoring was increased from once a week to thrice a week for Thorthormi lake.

e. Emergency fund request for shifting and restoration of damaged Thorthomri AWLS damaged by GLOF submitted to the Ministry of Finance on 10 November 2023.

9. Recommendations

Based on the observations made at the site and considering the current scenario of Thorthormi lake, the following are some of the recommendations.

a. Relocation of vulnerable households in Lunana region.

Thorthormi Lake was identified as one of the potentially dangerous glacial lake right after the publication of the first inventory on glaciers and glacial lakes in Bhutan in 2001. Considering the high hazard of GLOF from the lakes in Lunana, a GLOF hazard map was prepared during the collaborative project implemented by Department of Geology and Mines and University Vienna, Austria from 1998 to 2002. According to their report there were several houses identified in Lunana which were recommended to be relocated to a safer area (fig 6). In the recent years it has been observed that the frequency of GLOF incidences from Thorthormi lake has increased (2019,2023). Relocation of vulnerable houses in Lunana was recommended following the 20th June 2019 GLOF incident. Considering the current situation of Thorthormi lake, relocation of the vulnerable households is still recommended taking into account very short lead time they get in times of major GLOF event from the lake which are all located upstream.

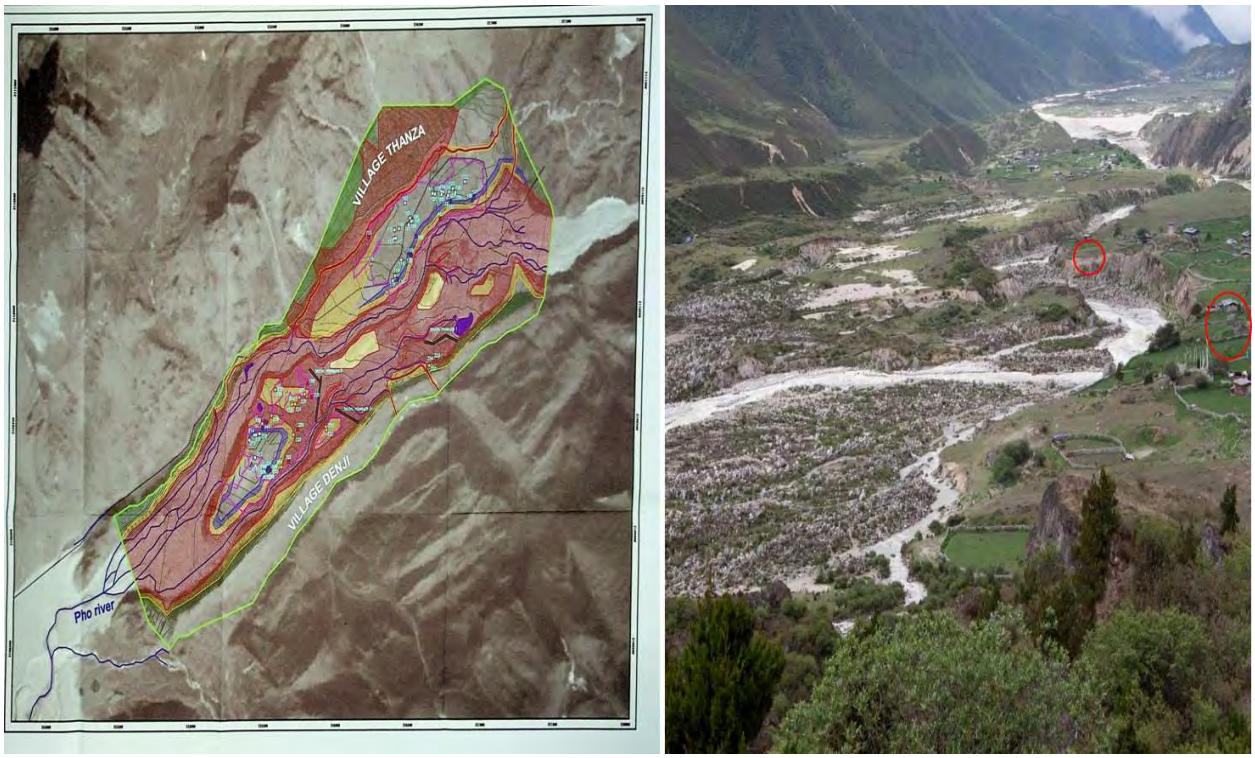


Figure 6: GLOF hazard map of Thanza and Tenchoe area in Lunana along with vulnerable houses (red circles) in Thanza village.

b. Strengthening and Enhancement of GLOF Early Warning System (GLOF EWS)

During an event of GLOF the objective and all efforts is to save lives and property of the communities in the downstream and for that to achieve the most important factor is sufficient lead time. Based on the information from the past GLOF events from the lakes in Lunana the time took to reach downstream varied depending on the flood volume. The 1994 GLOF from Lugge tsho with an approximate flood volume of 18 million cubic meters took about 7 hrs to reach Punakha. Similarly, the recent GLOF event from Thorthormi tsho with an estimated flood volume of 1.98 million cubic meters took more than 10 hrs to reach Punakha. Therefore, a timely dissemination of information and EWS is crucial for the concern authorities and vulnerable communities to respond on time and act efficiently. The existing GLOF EWS along Puna Tsang Chu was installed 2011 that need urgent upgradation and rehabilitation as it has become too old and difficult to maintain and operate due to lack of spare parts and upgradation of technology. Moreover the existing system is just a flood detection system that need further enhancement with additional sensors. The centre has included in the 13th FYP to strengthen and enhance the system with additional sensors (seismic and visual) and part replacement with an aim to provide more lead time for the communities in the downstream. This is also in line with the Centre's plan to harmonize all EWS in the country into one single system. NCHM is exploring for potential donors and collaborators currently as the task involves substantial resources and expertise.

c. Restoration of AWLS at Thorthormi tsho

The remote Automatic Water Level Station (AWLS) on Thorthormi lake is a part of the existing early system. The station was installed at Subsidiary lake II initially and relocated to subsidiary lake I after it was damaged during the 20th June 2019 GLOF event from Thorthormi lake. It was shifted to subsidiary lake I since subsidiary lake II was completely drained out during the flood event. Due to the impact of the recent event which occurred on 30th October 2023, the station suffered a major impact where most of the parts were damaged. As a consequence of the recent incident there is a drastic change in the morphological condition of Thorthormi lake and surrounding areas of the AWLS. It is recommended to shift the AWLS from the current location at subsidiary lake I to the main lake. The damaged AWLS was temporarily restored by the technical team and is transmitting water level information of the lake in real time. Considering the disintegration of glacier ice on Thorthormi glacier and drastic change in morphological condition of the lake and surrounding areas around the existing AWLS due to the GLOF incident on 30th October 2023, there is an urgency to shift the existing AWLS to the main lake and restore it completely. An amount of Nu.1.8 million is estimated for procurement of the damaged AWLS parts and accessories including civil works and labour charges.

d. Detail Bathymetry survey on Thorthormi lake

The present depth information presented in this report is the information from the bathymetry survey conducted in 2015 when most part of the ablation area of Thorthormi tsho was covered with ice cliffs and ice fields. Now the morphological condition of the lake has changed drastically, it is important to update the depth information of present Thorthormi lake. The bathymetric

information can be used to estimate the volume of water stored in the lake which can provide vital information to estimate probable flood volume incase of GLOF events in the future. Due to drastic change in the morphological of the lake with huge masses ice floating and also considering the shear size of the lake with an estimated surface area of 4.33 km^2, it is recommended to deploy automatic remote controlled sonar instruments for conducting bathymetry survey. Presence of ice block floating in the lake might damage the inflatable rubber boats used for the survey which may have consequences in compromising the lives of people conducting the bathymetry survey. The price for remote controlled sonar instruments which are currently available in the market ranges between Nu.3 to 4 million.

e. Strengthening contingency plan in the downstream

Considering the current situation at Thorthormi lake, it is recommended that the concern Central and Local authorities/agencies strengthen their GLOF contingency plans and measures for the vulnerable communities along Puna Tsang Chu. In absence of a updated GLOF hazard map for Thorthormi lake at present, the strengthening of the measures can be based on the worst case scenario for which there are abundant information available from the past scientific investigation conducted in Lunana. NCHM plans to conduct bathymetry survey on Thorthormi lake in the next field season and will be in place to provide vital information on the quantity of water stored in the lake.

f. GLOF hazard and Risk reduction options

Water level in the lake was lowered by 5 m during Thorthormi lake mitigation project implemented from 2008-2012. In addition during the GLOF incident in 2019 the water level in the main lake was lowered by 80 cm and in the recent GLOF event on 31st October 2023 the water level in the main lake got reduced by 46 cm. In total the water level in main Thorthormi lake got lowered by about 6.26 m. Following are the normal methods used in other GLOF prone countries to reduce GLOF hazard and reduce risk to the vulnerable communities downstream.

- Artificial lowering of lake water level to reduce hydrostatic pressure on the surrounding moraine dam.
- Installation of Early Warning System (EWS) to provide lead time to the vulnerable communities downstream for evacuation
- Preparing GLOF zonnation mapping to understand impact during a GLOF event
- Relocation of vulnerable houses for the areas with very short lead time.

There is already a GLOF EWS installed in Puna Tsang Chu basin which was installed in the year 2011. Details on the requirement to strengthen and enhance the existing EWS is provided under subsection (b) above. GLOF hazard zonnation map was also prepared by the experts from University of Vienna, Austria from Lunana to Punakha in 2002 through a collaboration project with Department of Geology and Mines (DGM) and recommended to relocate the vulnerable houses falling in red zone in Lunana to a safer zone. Similar maps were also prepared by DGM for the areas from Punakha to Lhamoizingkha in 2008.

Normally there are three techniques under artificial lowering of lake water level:

- Widening and deepening of natural outlet channel through excavation
- Pumping out the water from the lake using high performance water pumps
- Siphoning technique which works on gravity to pump out the water from the lake.

Widening and deepening of natural outlet channel through excavation is a permeant measure to bring down the water level in the lake. However, as it involves excavation work, a thorough scientific investigation at the outlet area of the lake to ascertain safe excavation zone is an important prerequisite. This is mainly to avoid excavation of underlain ice which is a very common characteristic of a debris covered glacier such as Thorthormi glacier and has lot of uncertainties associated with ice excavation. Based on the results of Electrical Resistivity Tomography (ERT) survey which is a geophysical method to investigate subsurface condition conducted in 2021, the existing outlet area of Thorthormi lake is mostly underlain with ice. Due to the recent GLOF incident some of this ice are already exposed on the surface (Photo 5). It is also important to note that Thorthormi lake has turn almost into a full water body with a depth of about 135 m (2015 survey). Since the behavioral characteristics of ice during excavation, chances of creating an artificial GLOF during excavation cannot be ruled out. In all the previous mitigation work on the lakes in Lunana, there were no ice encountered during the excavation.

The other techniques pumping and siphoning are effective as long as pumps and siphons are installed in such a way that the discharge through pumping and siphoning are more than the recharge from the glacier above (melt water coming in from the mother glacier). For these techniques to be effective a detail study needs to be conducted on the discharge and recharge of the lake. However, any misfunction/malfunction of the equipment will result in refilling of the lake again since the outlet area remains at the same level. In the earlier mitigation work, these methods were not deployed mainly because of cost for running the pumps and fear of the siphons not working in peak winter due to freezing of the lake surface which might interrupt the outflow.

Reference:

1. NCHM (2018): Bhutan Glacier Inventory 2018
2. NCHM (2019); Re-assessment of potentially dangerous glacial lakes in Bhutan
3. NCHM (2019); Report on the Rapid Assessment of Thorthormi lake and the Restoration of Automatic Water Level Sensor for the GLOF Early Warning System.
4. NCHM (2021); Bhutan Glacial Lake Inventory 2021

NATIONAL CENTRE FOR HYDROLOGY AND METEOROLOGY
ROYAL GOVERNMENT OF BHUTAN
THIMPHU: BHUTAN

Contact Us
Tel. No: +975-2-327202
Fax No: +975-2-327202
Website: www.nchm.gov.bt
Facebook Page: www.facebook.com/NationalCentreforHydrologyandMeteorology