Report on the Rapid Assessment of Thorthormi Lake and the Restoration of Automatic Water Level Sensors for the GLOF Early Warning System

NATIONAL CENTER FOR HYDROLOGY AND METEOROLOGY
ROYAL GOVERNMENT OF BHUTAN

2019

Executive Summary

On the evening of the 20th June 2019, the main lake of Thorthormi partially breached causing the subsidiary lake II to drain out. Over the course of 4 days, water level in the main lake at Thorthormi got lowered by 0.80 m which roughly translates to 2.73 million m^3 of water.

Temperature data from the Thanza Automatic Weather Station (AWS) revealed that the months of April, May and June 2019 were the warmest compared to the last 8 years. Information from the satellite images indicates that excessive melting occurred on Thorthormi glacier in the months of May and June 2019. Such extent of melting on the glacier correlates well with the warmer months observed from the temperature data. Analysis of RADAR images shows that Thorthormi glacier had been very active in terms of movements and displacement had taken place on the main glacier prior to the breaching. Other physical based indications of movement/displacement on the glacier such as highly fractured and disintegrated ice bergs were found to be floating around in the lake. Huge ice bergs were found to have been displaced more than a meter on the shorelines of Thorthormi indicating that there was a sudden rise in the water level in the lake. Therefore, it is possible that the excess melt water due to the higher temperature could have triggered and accelerated the movement (forward) within the glacier itself which resulted in rising of the water level in the main lake. The higher hydrostatic pressure ultimately could have impacted the weakest point at the outlet of the main lake which breached, giving way to the new outlet at Thorthormi main lake.

The high flow during this incident the Automatic Water Level Sensors (AWLS) for the GLOF Early System installed at Thorthormi Subsidiary lake II was exposed and the terminal block of the water level sensor at Thanza gauging station was also damaged. A team from the National Center for Hydrology & Meteorology (NCHM) visited the lake from 23rd to 28th June 2019. The team carried out a rapid assessment of the breach and relocated the AWLS at Thorthormi from subsidiary lake II to subsidiary lake I. The damaged terminal block at Thanza was also repaired and restored.

ACKNOWLEDGEMENT

The National Center for Hydrology and Meteorology would like to acknowledge the following individuals and institutions for enabling the team to complete the rapid assessment, relocation of damaged AWLS at Thorthormi and restoration of AWLS at Thanza station within 5 days (23-28 June 2019).

The Center would like to thank the Cabinet Secretary, Secretary of the Ministry of Home and Cultural Affairs, Dasho Zimpon of the His Majesty's Secretariat and officials of the Department of Disaster Management (DDM) for facilitating timely deputation of the team to Lunana through arrangement of the helicopter.

The Center remains very grateful to the Principal and teachers of Lhedi Community School, Lunana who helped and assisted the team for timely completion of the works at the lake site. The Center is very thankful to the Health Assistant, Basic Health Unit (BHU) and Livestock officer in Lunana for their unwavering assistance provided to the Flood Warning staffs stationed in Lunana during the time of emergency for the physical monitoring of Thorthormi lake.

NCHM would also like to express sincere thanks to Sentinel Asia team and Mr. Sonam Wangchu, PhD candidate at the University of Zurich, Switzerland for their support in providing the analyzed product of various satellite images.

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

Table of Content

Photos

Figures

1 Introduction

1.1 Background

Bhutan has more than 700 glaciers as per the revised Bhutan Glacier Inventory, 2018 (NCHM, 2018) and 2674 glacier lakes (ICIMOD & DGM, 2001) in the head waters of Bhutan. As per the revised Assessment of Potentially Dangerous Glacier Lakes (PDGL) in Bhutan 2018 (NCHM, 2018), 17 lakes have been identified as potentially dangerous lakes. Out of the 17, 11 PDGL are located within the Punatsangchhu basin i.e. 9 in the Phochhu head water and remaining 2 in Mochu sub-basin. All the four lakes in Lunana- Lugge, Thorthormi, Rapstreng and Baytsho falls under the PDGL of Bhutan

Due to the high risks of GLOF in this basin, the Government through the National Adaption Programme of Action (NAPA-I) project implemented the Thorthomri Lake mitigation work and Installed Glacier lake Outburst Flood (GLOF) Early Warning System (EWS) along the Punatsangchhu basin (2008-2013) to reduce the risks and timely dissemination of GLOF information downstream, in the event of a GLOF.

1.2 Thorthormi Flood Incident

On the 20th June 2019, there was a sudden unusual rise of water level followed by a sharp drop in the water level at Subsidiary lake II of Thorthormi glacial lake in Lunana. The rise in water level was detected by the remote water level sensors installed at subsidiary lake II of Thorthormi lake at 6.55 PM on 20th June 2019. On ground verification by the staffs of the National Center for Hydrology and Meteorology (NCHM) who are stationed in Lunana as part of redundancy for Flood Warning System on the same night, it was found that subsidiary lake II had breached and almost completely drained out. It was also reported that the channel between subsidiary lake I and subsidiary lake II had undergone bed scouring. The next day (21st June 2019), NCHM staffs visited the lake site in the first hour of the morning and took photos and sent to NCHM HQ. On scrutiny it was observed that there was also a partial breach at the main lake which had created a new outlet. The sequence of event is documented in the action taken report (Annexure 1).

An emergency meeting to update the status on the incident was held at DDM on the evening of 21st June 2019. The meeting was chaired by the Cabinet Secretary and attended by the Secretary of the Ministry of Home and Cultural Affairs and Dasho Zimpon, His Majesty's Secretariat. NCHM made a presentation on the situation on Thorthormi lake. One of the decisions from the meeting was to send a rapid assessment team from NCHM to the lake site.

Accordingly, a four-member team from NCHM was formed who visited the lake site from 23rd to 27th June 2019. The following assessment team were deputed based on the expert's requirement for the assignment and officials who have earlier travelled to Lunana .

a. Mr. Karma, Specialist, Cryosphere Services Division, NCHM – Team Leader/ Glaciologist;
b. Mr. Sangay Tenzin, Engineer, Hydrology and Water Resources Services Division (HWRSD), NCHM – Operational Hydrology and EWS Expert;

c. Mr. Pema Wangyel, Engineer, Hydro-met Operation and Infrastructure Division (HOID), NCHM as Instrument and ICT Expert; and,
d. Mr. Sonam Tashi, Technician, NCHM as additional Technicians to Thanza Flood Warning Station, Lunana.

2 Objectives

The objectives for the visit were as follows:

a. To carry out a rapid assessment on the situation at the lake site;
b. Relocate Automatic water level sensor from subsidiary lake II to a more appropriate site; and,
c. Restore the automatic water level sensor at Thanza which was damaged during the breach.

3 Assessment of Thorthomi Lake

3.1 Observations

For the assessment purpose a detail observation was carried out on each vulnerable sections of Thorthormi lake as detailed below:

Photo 1: Location of Thorthormi lake

Thorthormi glacier/Thorthormi lake lies at the base of the famous Table Mountain (Photo 1). It lies to the left of Rapstreng tso and to the upstream lies Lugge Tso which outburst in 1994. To the far right (downstream) lies Baychung glacier which is associated with Baytso.

Photo 2: Surface of Thorthormi glacier as observed on 23rd June 2019

On the 23rd June 2019, the team carried out an aerial survey on the Thorthormi lake and the surrounding areas. The whole glacier was observed to have undergone drastic disturbances resulting in breaking down of the mother glacier into pieces which floated on the water bodies as ice bergs (Photo 2).

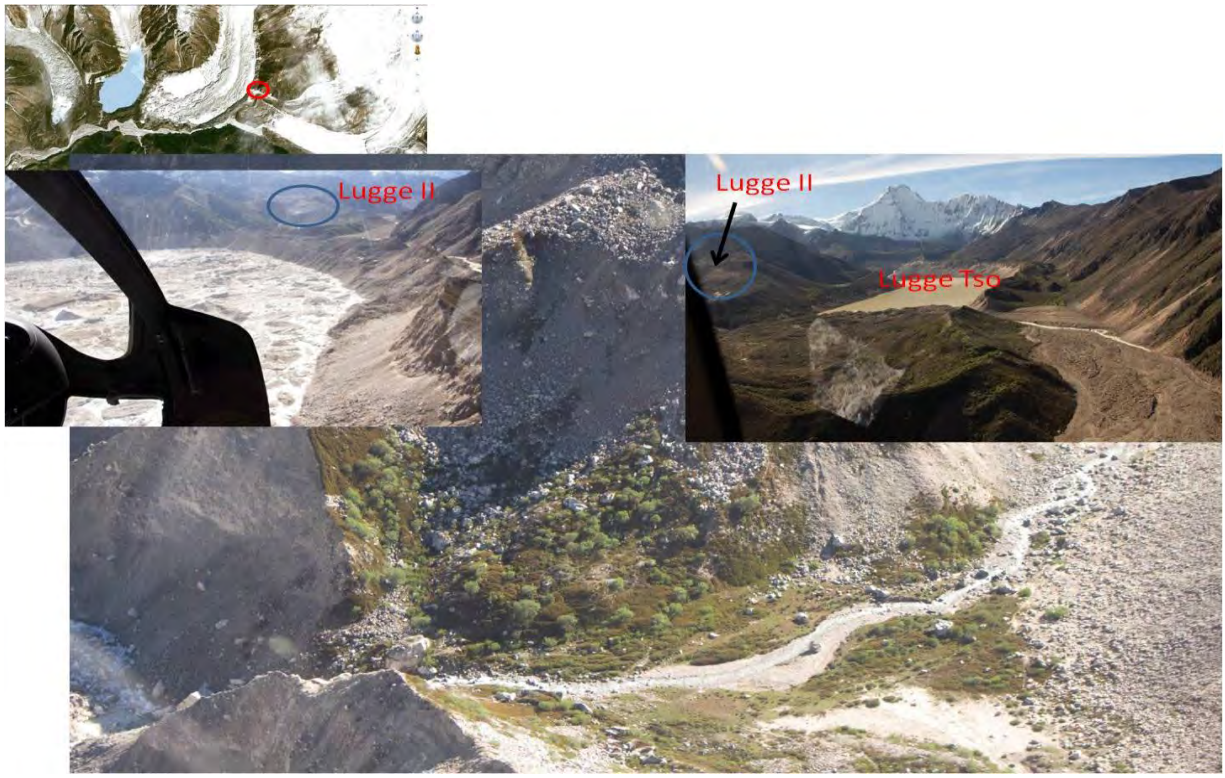


Photo 3: Lugge II glacier with Thorthormi and inlet area into Thorthormi tso

The melt water from Lugge II glacier (photo 3) drains into Thorthormi lake. Therefore, it was important to first check the status of the flow from Lugge II glacier into Thorthomi lake. During the aerial survey, based on the water marks at the inlet area it was found that no unusual flow originated from Lugge II glacier which drains into Thorthomi lake in the recent days (Photo 3).

3.1.1 Subsidiary lake II and its outlet.

The natural channel at the outlet of subsidiary lake II was found to have undergone huge erosion both at the bed as well as on the side. As a result, the new channel bed lies at approximately 9 m lower than the original channel before the breach. (Photo 4). The vertical height of water level in subsidiary lake II got lowered by 3.1 m (photo 4) due to the breach on the 20th June 2019. The new channel width is about 10 to 12 meters and length more than 100 meters with an average gradient of 13 – 15 degrees. Due to the breach the subsidiary lake II appears to be almost empty now.

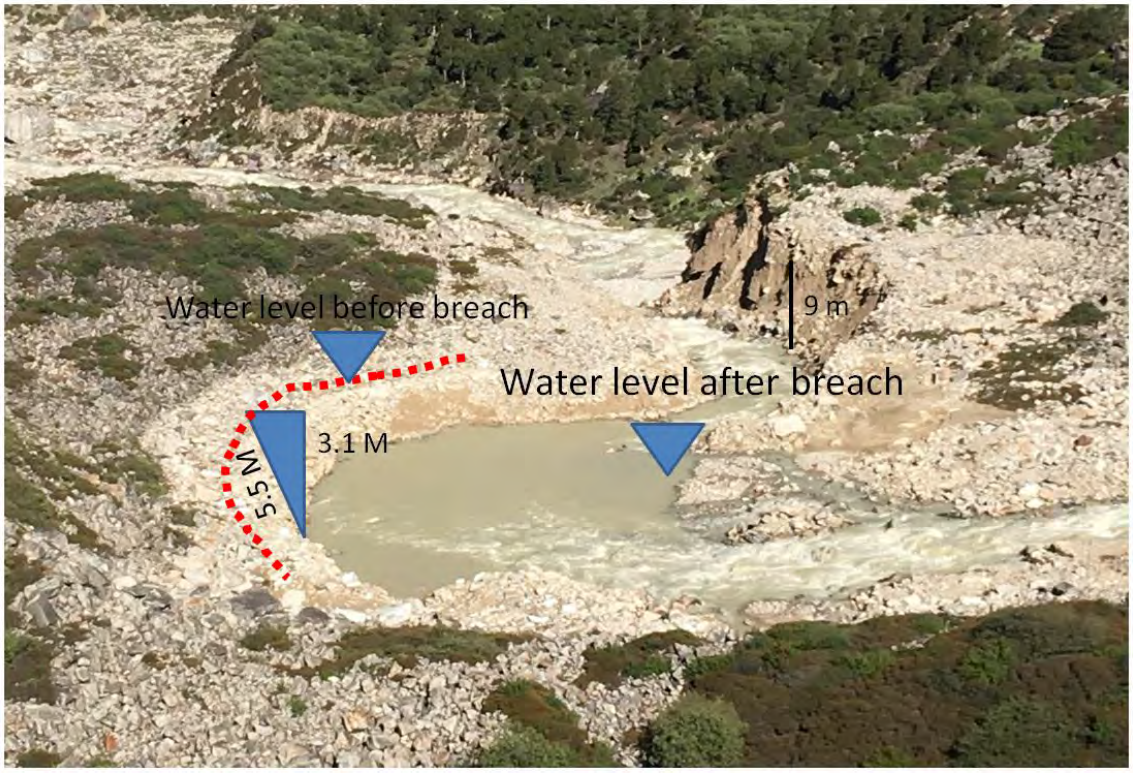


Photo 4: Subsidiary lake II after the breach

3.1.2 Channel between subsidiary I and Subsidiary lake I

Photo 5 : (A) Lower part of channel between Subsidiary lake I (B) Subsidiary II along with the outlet of subsidiary lake I

The channel between subsidiary lake I and subsidiary lake II has undergone some degree of erosion due to the excess water spilling over from the main lake. However, except for some erosion in the downstream part of this channel the outlet area of subsidiary lake I appeared to be normal. Based on the erosional marks, the lower part of this channel (near subsidiary lake II, Photo 5 (A) was eroded and lowered by 1.2 m on average. The average gradient of this channel length between subsidiary lake I and subsidiary lake II was found to be 11 – 13 degrees.

3.1.3 Subsidiary lake I

Photo 6 : Condition of subsidiary lake I

Photo 7 : Displaced ice berg on the shore of subsidiary lake I

Subsidiary lake I on the whole appears to be undisturbed by the incident on 20th June 2019. However, due to large volume of water from the main lake there were remnants of minor mass movement taken place on the side. (Photo 6). There were ice berg displaced at a height of more than a meter was observed on the shoreline of subsidiary lake I (Photo 7).

3.1.4 Main Lake

The main glacier (Thorthormi glacier) was observed to have undergone massive changes. The glacier was observed to have disintegrated and broken into smaller pieces of ice (ice berg) which were found to be floating around. Similar to subsidiary lake I, huge ice bergs were observed to have displaced on the shoreline about more than a meter's height from the present water level (Photo 8).

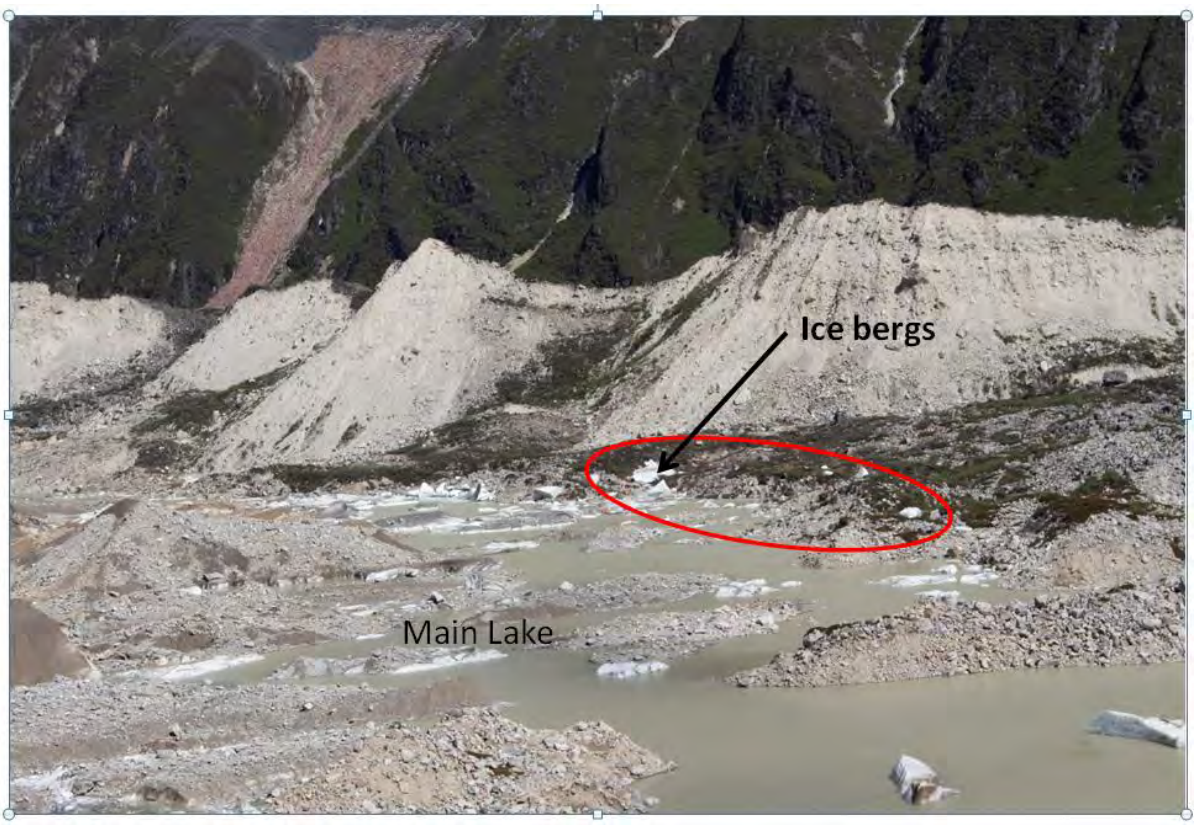


Photo 8 : Displaced ice bergs on the left shoreline of main lake Thorthormi

The team also found that a new outlet channel was created during the incident of 20th June 2019 which now lies at the right side of the original outlet channel (Photo 9). The formation of this new outlet channel indicates that a partial breach of the main lake had occurred. The point through which the main lake breached (new outlet channel) was a weaker zone with presence of seepage observed during the mitigation work on Thorthormi lake from 2008 to 2012. The length of the new channel is 25 m long and 12 m wide with an average gradient of 15 -17 degrees. (Photo 9).

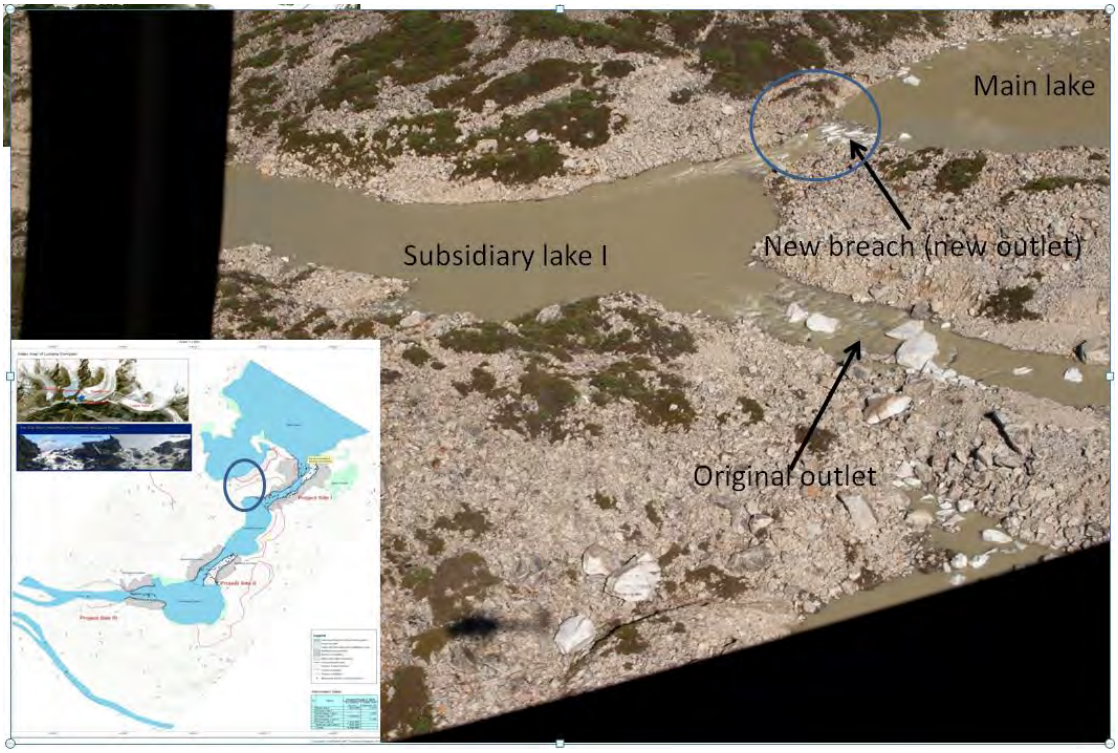


Photo 9 : Outlet area of main lake Thorthormi glacier

4 Data Analysis

4.1 Temperature Trend

It is important to establish few basic scientific facts before discussing the causes of triggering the breaching scenario of subsidiary lake II and partial breach of main lake on Thorthormi glacier. In this context, temperature data collected at Thanza automatic weather station was analyzed to see the trend of temperature.

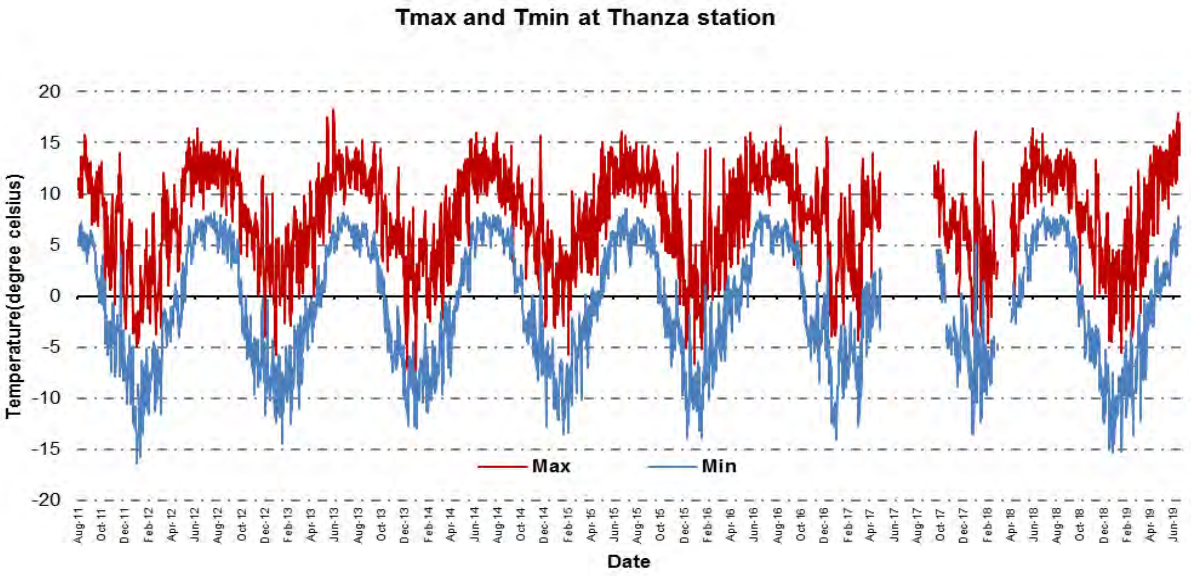


Figure 1 : Daily Tmax and Tmin from Thanza station

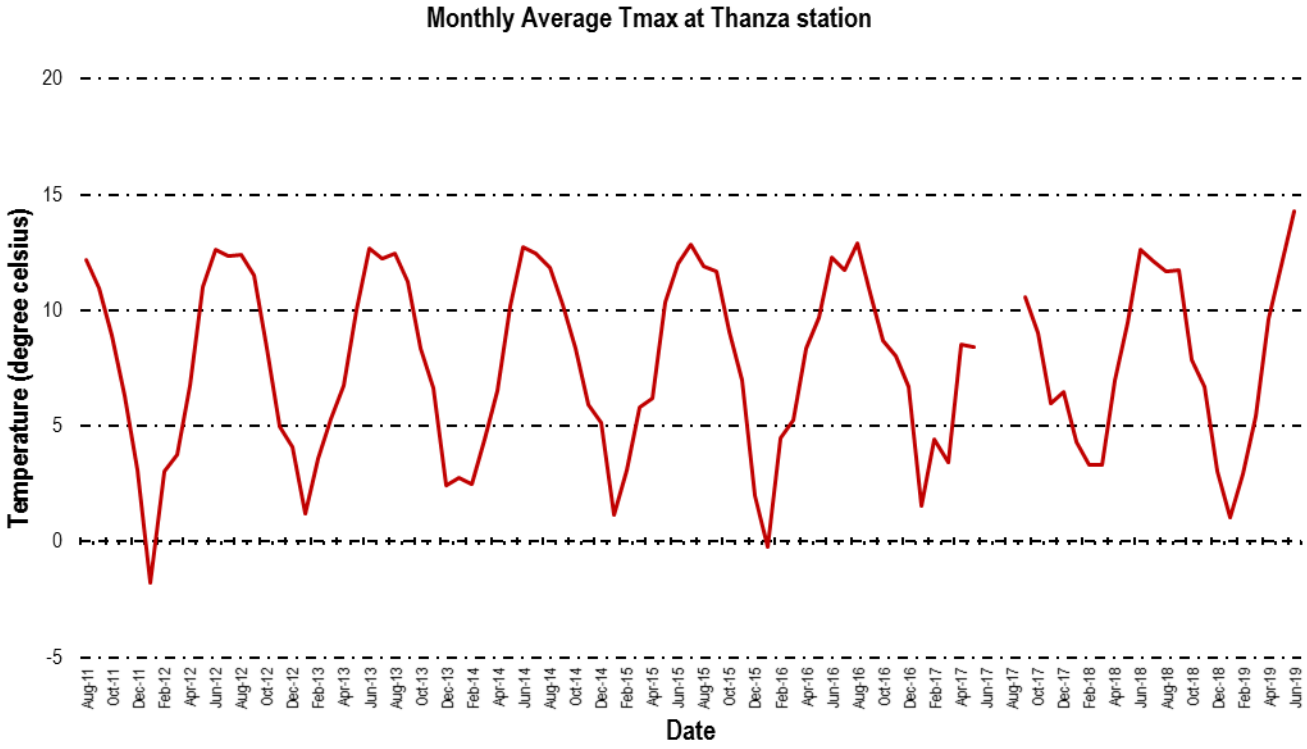


Figure 2 : Monthly average Tmax from Thanza station

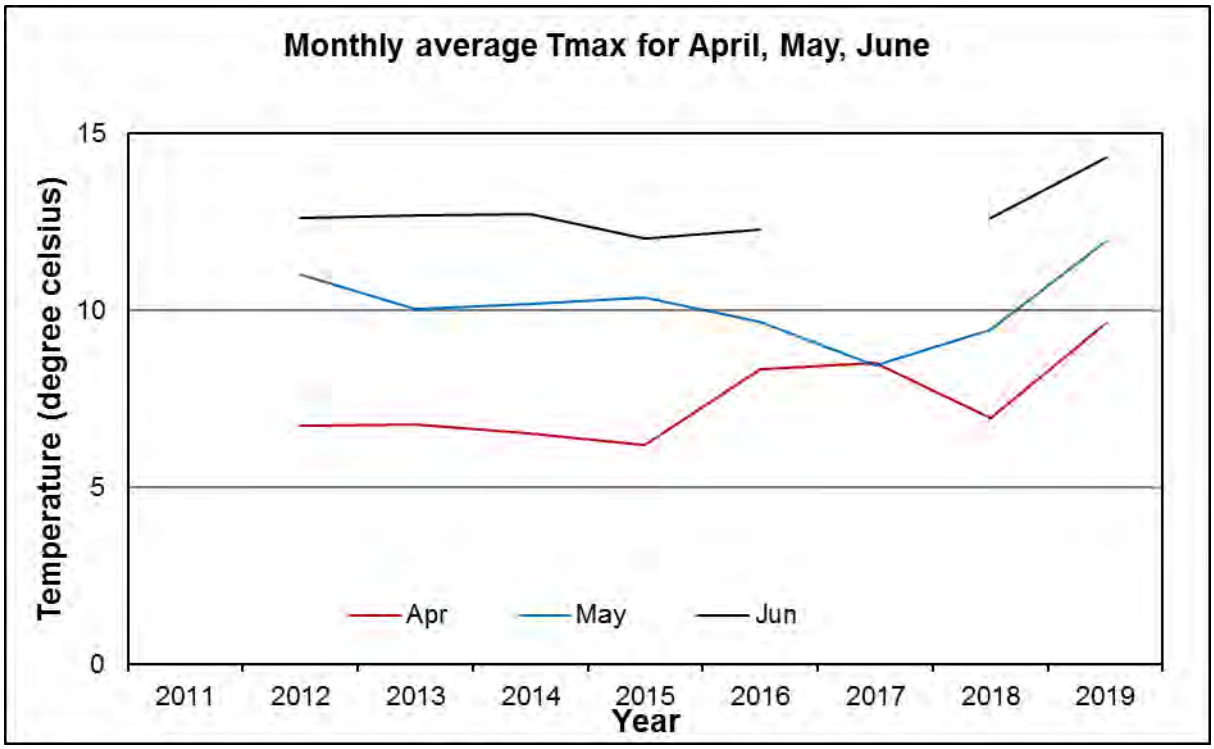


Figure 3 : Comparison of monthly average Tmax for the month of April, May, June from 2011 to 2019.

The months of April, May and June 2019 had recorded the highest maximum temperature over Thanza (Figure 3) compared to the past 8 years (after the installation of GLOF EWS). The maximum daily temperature reached 17°C in June 2019 (Figure 1).

There has been records of abrupt increase of maximum temperature in the past which is followed by cooling phase. This year the record shows a greater number of days with frequent higher temperature during the months of April, May and June. The monthly average maximum temperature showed a consistent warming over the months of April, May an June (Figure 2 and Figure 3)

The figure 2 shows the monthly variation of the average monthly maximum temperature for Thanza station. Compared to the past years the temperature trend has been increasing since the April month. Overall, there has been warming by more than 1°C during the last three months (AMJ).

4.2 Glacier Displacement

Sentiniel-1 images were used to analyze displacement on Thorthormi glacier in the month of May and June 2019. The same images were also used to detect the extent and severity of melting corresponding to the same time of the recent Thorthomi incident.

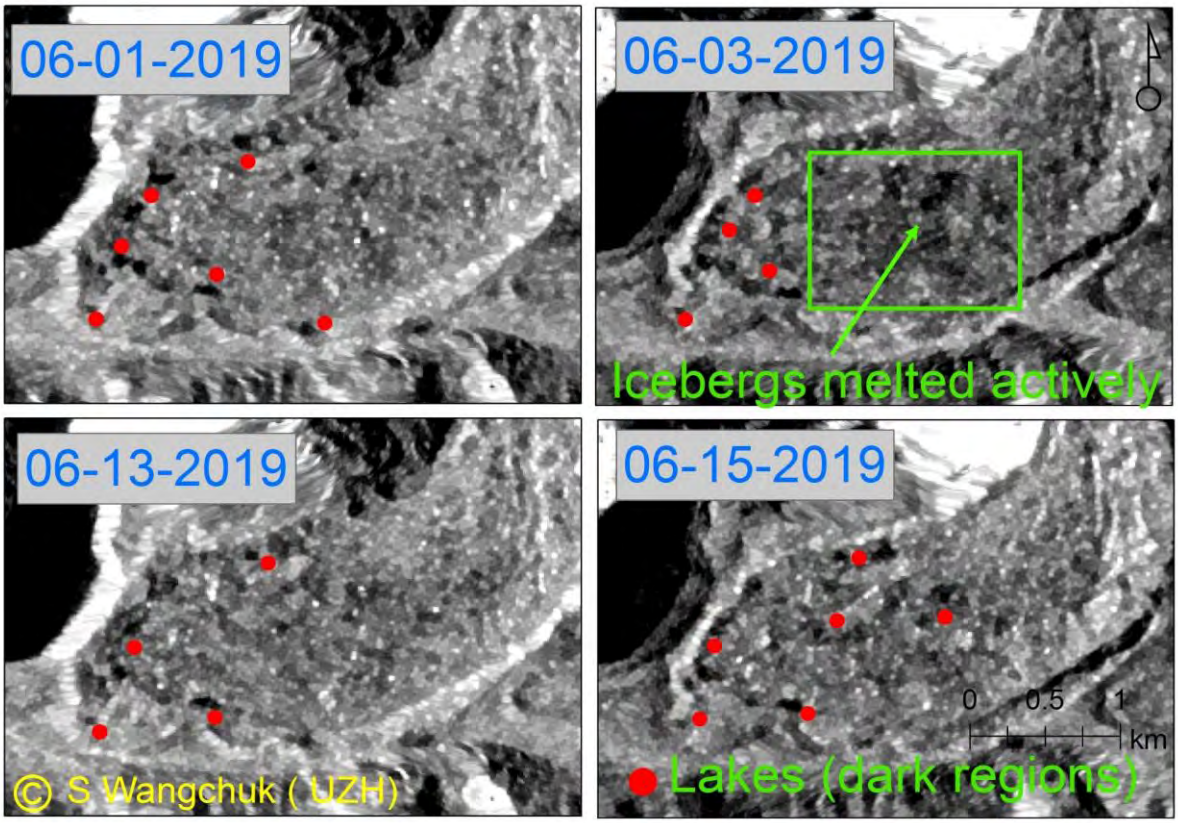


Figure 4 : Sentinial 1 image showing extensive melting taking place on Thorthormi glacier in the month of June 2019.

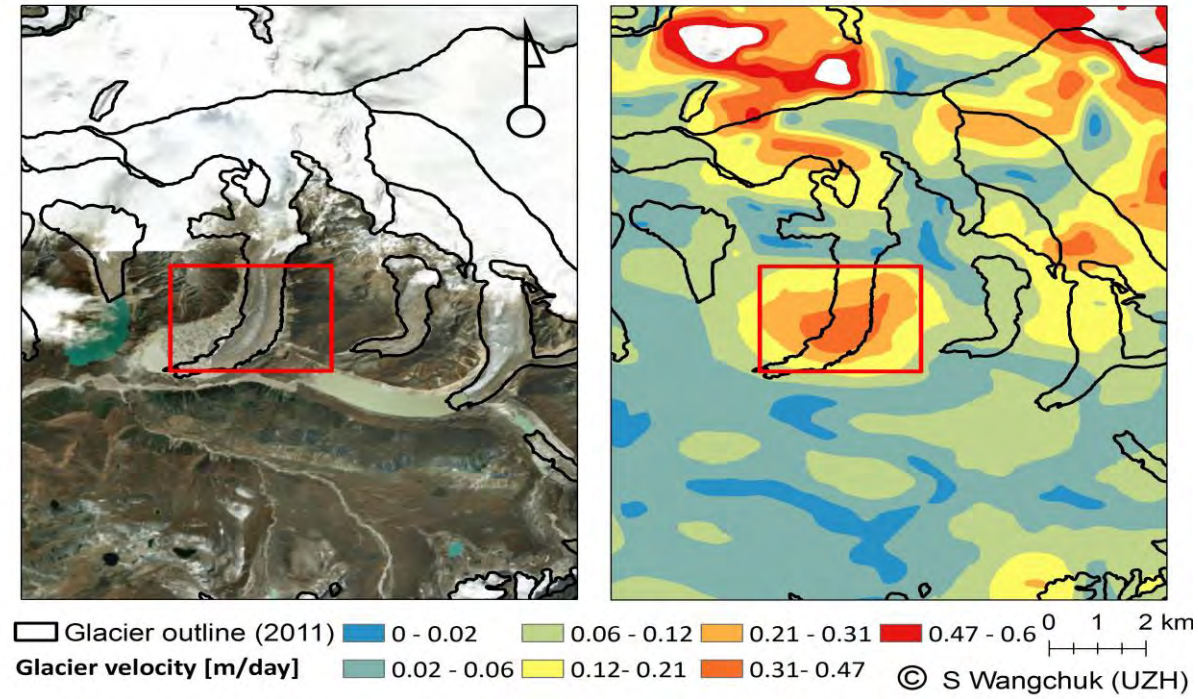


Figure 5 : Radar image showing displacement taken place on Thorthormi glacier on 13th June w.r.t 1st June 2019 *(Courtesy: Sonam Wangchuk, University of Zurich, Switzerland)*

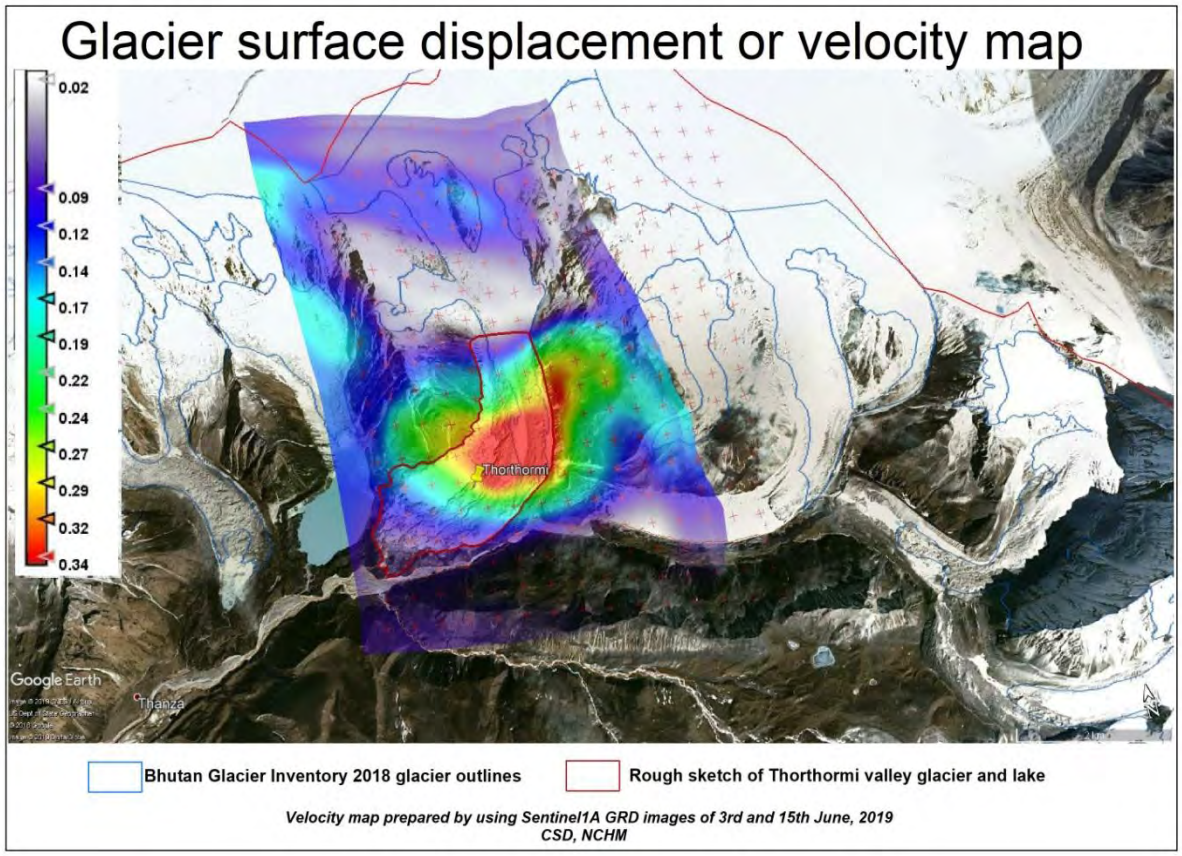


Figure 6 : Image showing displacement on Thorthormi glacier between 3rd and 15th June 2019.

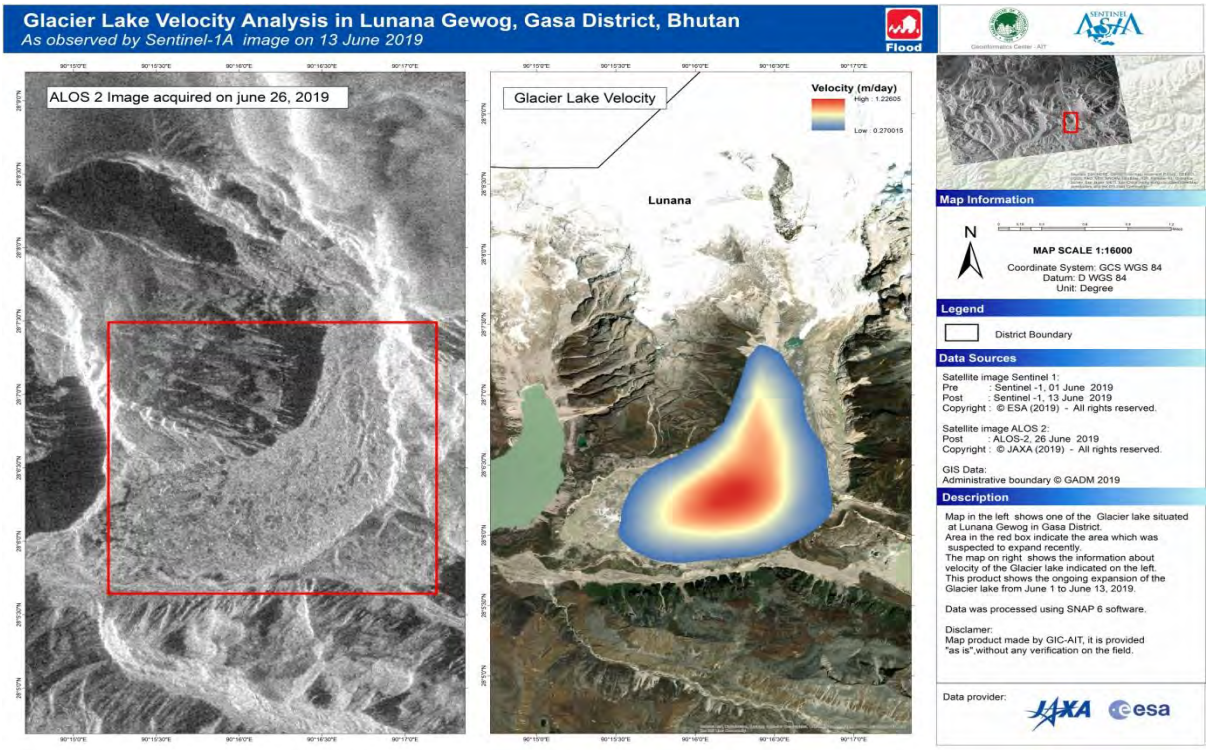


Figure 7 : Image showing displacement taking place on Thorthormi glacier from 1st to 13th June 2019. *(Courtesy: Sentinel Asia Team)*

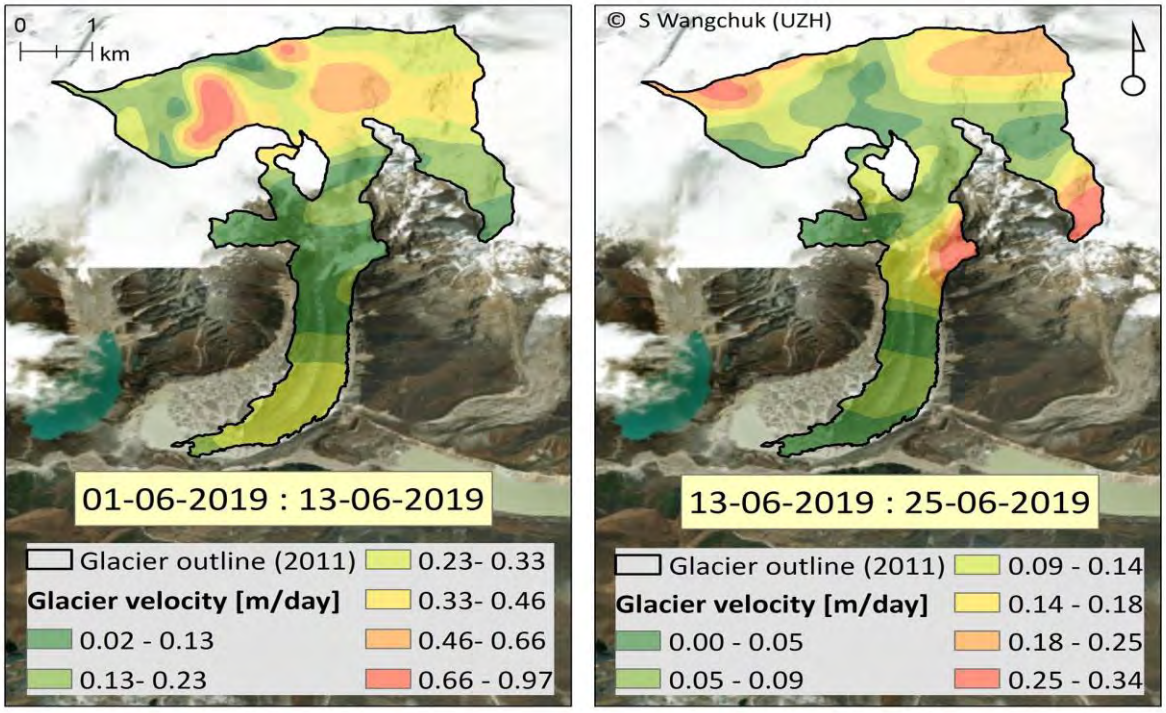


Figure 8 : Comparison of displacement on Thorthormi glacier between 1st June, 13th June and 25th June 2019 *(Courtesy: Sonam Wangchuk, University of Zurich, Switzerland).*

Figure 9 : Time series Sentinel 2 image the status of Thorthormi glacier.

Figure 4 shows a RADAR image of Sentinel 1 where dark spots denotes water bodies. It is clear from the images that there was extensive melting taking place on Thorthormi glacier in the month of June 2019.

Figure 5, 6 and 7 shows movement on Thorthormi glacier before breaching occurred (before 20th June 2019). It is evident from these images that there was active displacement measuring between as low as 0.34 to as high as 1.2 meters per day on Thorthormi glacier in the early part of June 2019. However, after 20th June 2019, such displacement on Thorthormi glacier subsided (right image of figure 8). The velocity measurement in the late 1990s on Thorthormi glacier showed 90 m per year in the upper region and 40 m in the lower region (Joint Japan – Bhutan research report, 2003) which roughly translates into 0.25 m per day and 0.11 m per day which is lower than the movement observed in the month of June 2019..

Figure 9 and 10 shows time series Sentinel 1 and Sentinel 2 images of 25th May, 4th June, 19th June and 24th June 2019. The bright white part on the Thorthormi glacier (figure 9 & 10) which is visible on the last image of 24th June 2019 is not present on the previous images. This bright part is the exposed fresh glacier ice of Thorthormi glacier which is a result of breaking and disintegration of the glacier due to movement taking place within the glacier. As a result of all these disturbances taking place on Thorthormi glacier, the small pond (yellow circle) in the upstream part of the glacier disappeared (Figure 9). Evidence of the increased melting is also visible in the disintegrated area (red circle part in figure 10).

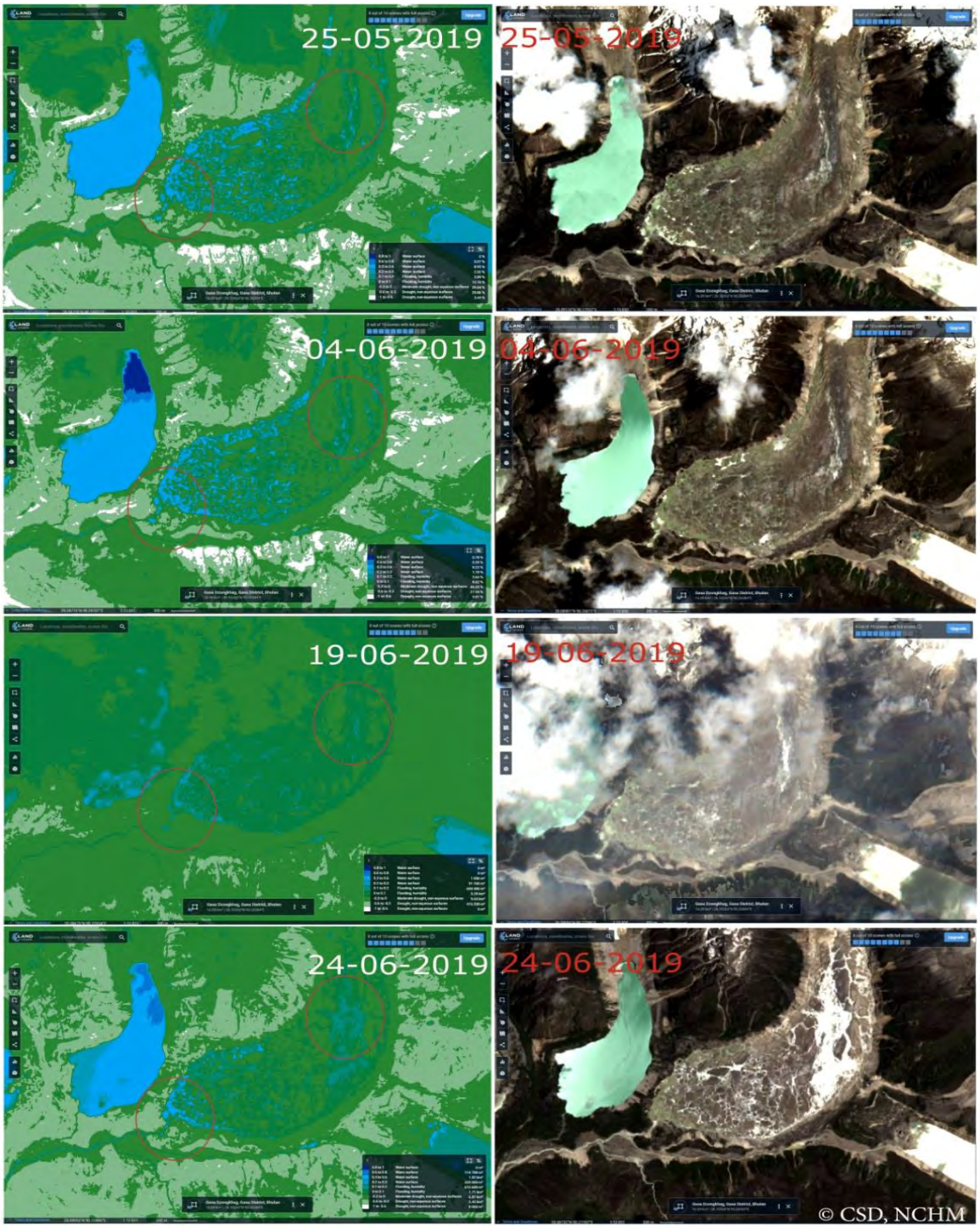


Figure 10 : Time series Sentinel 1 and Sentinel 2 images analyzed with NWDI

5 Discussion

Based on the results of all the above analysis, it is clear that there had been extensive melting taking place on Thorthormi glacier prior to the incident of 20th June 2019. As indicated by the temperature data (figure 1, 2 and 3), the temperature recorded for the months of April, May and June 2019 at Thanza Automatic Weather Station was the highest in the last nine years.

Therefore, it is possible that the higher temperature to have triggered extensive melting on Thorthormi glacier (Figure 4). The information from analyzed RADAR data from sentinel 1 image shows occurrence of vigorous movements (displacement) on Thorthomi glacier prior to the breaching incident on 20th June 2019 (Figure. 5,6,7,8 and 9). The presence of melt water within the glacier might have accelerated such displacement (through accelerated basal sliding process). As a result, displacement occurred on the whole glacier (most probably forward).

Such sudden forward movement of glacier (surging) might have resulted in the pushing of the water in the lake forward (figure 11) and raising the water level in the lake over 1 m. The displaced iceberg on the shore of Thorthormi lake clearly indicates the possibility of the occurrence of such a process. As the hydrostatic pressure increased in the main lake of Thorthomi, the weakest point on the moraine damming the main lake on Thorthormi glacier failed giving way to a new outlet resulting in a partial breach of the main lake. The excess water which got over spilled into subsidiary lake I further spilling into subsidiary lake II (figure 11). The thickness of moraine wall at the outlet of subsidiary lake II after the mitigation work in 2012 was measured only about 40 m thick at the crest. Therefore, due to increased water volume in subsidiary lake II, the moraine at the outlet fail and resulting in the complete draining of the subsidiary lake II (figure 11 & Photo 4).

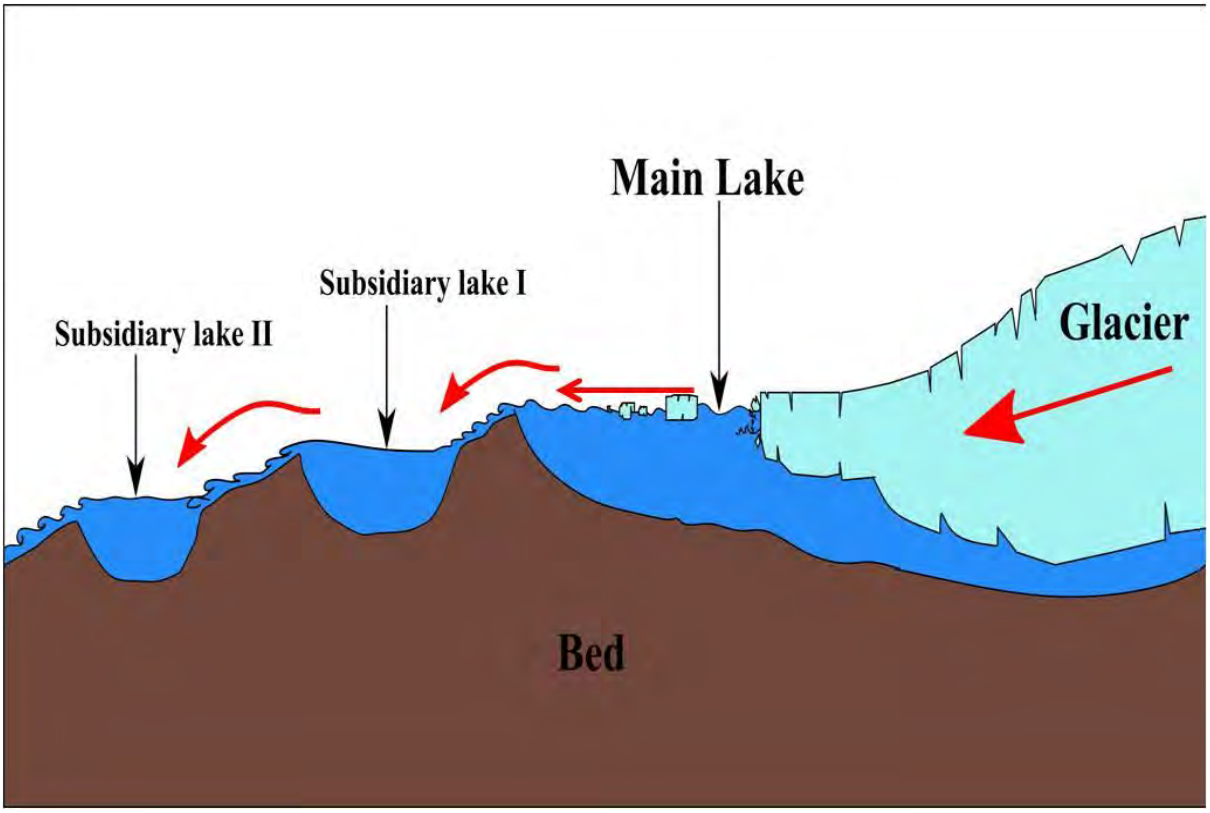


Figure 11 : Schematic diagram showing the process of breaching at Thorthormi lake

6 Relocation and Restoration of Automatic Water Level Sensors at Thorthormi lake and Thanza Gauging Station

As a part of the GLOF Early Warning System Remote Automatic Water Level Station (AWLS) were installed in all the four lakes (Baytso, Rapstreng, Thorthormi and Lugge) in Lunana and also at Thanza gauging station in 2011. The function of these sensors AWLS are to regularly monitor and transmit the water level at sub-hourly basis and to detect any abnormalities in the water level and transmit data to GLOF Early Warning Control Room at Wangdi and National Weather and Flood Warning Center (NWFWC), Thimphu that are operational for 24/7.

6.1 Relocation of Thorthormi AWLS

The AWLS on Thorthormi lake was installed in subsidiary lake II in 2011 to detect any abnormalities in the Thorthormi lake. Since subsidiary lake II was completely drained out on the 20th June 2019 due to partial breaching of the main lake, the water level sensor termination block was exposed above the water level and the monitoring station was rendered unserviceable. Therefore, it had become essential for the Center to relocate the AWLS to a new site to resume and enable continuous monitoring of water level in Thorthormi lake.

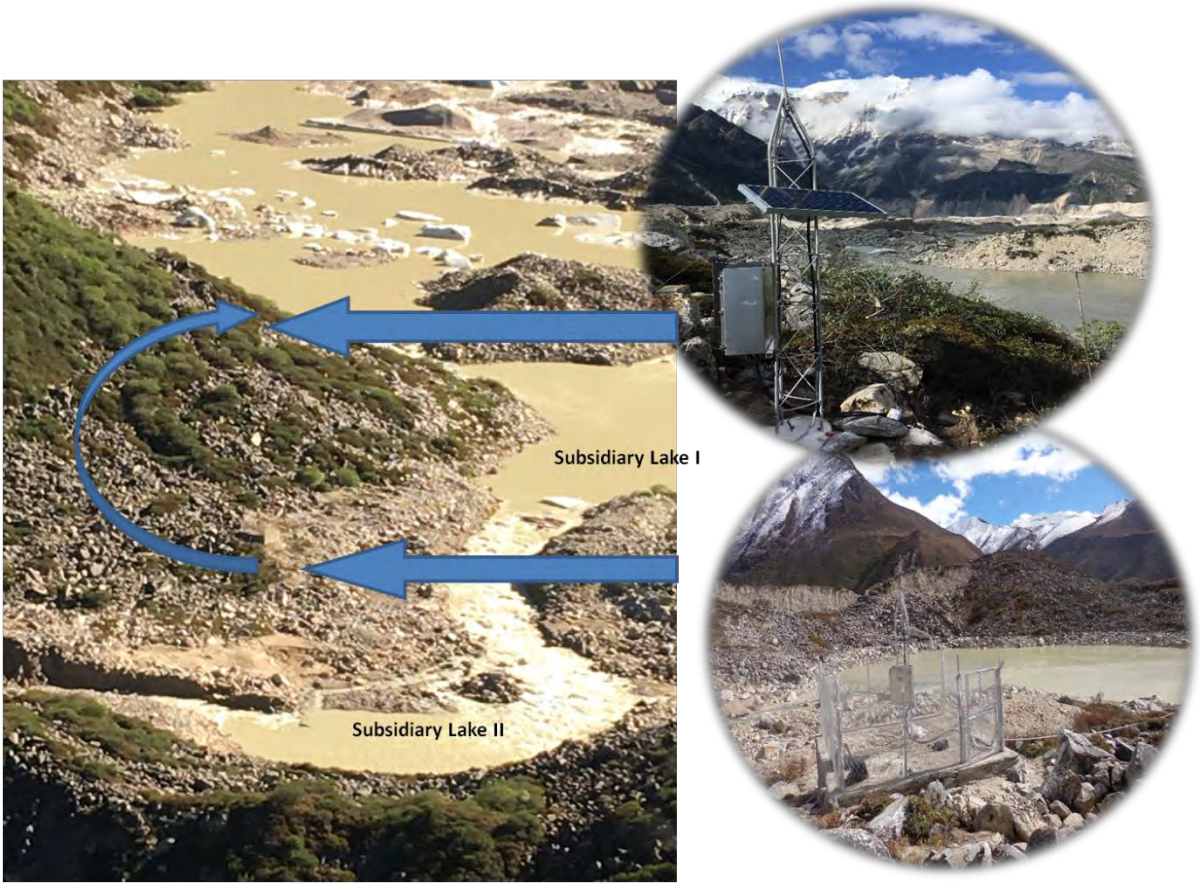


Photo 10 : Relocation of AWLS at Thorthormi Tso

Initial plan was to relocate the AWLS from subsidiary lake II to the main lake. However, after inspecting the site, it was found that a more appropriate site for the relocation was at

subsidiary lake I (photo 10). Thorthormi main lake has two outlets now flowing into subsidiary lake I. By installing the AWLS at subsidiary lake I, the instrument can detect any abnormalities in the flow from both these outlets. The original plan to shift the AWLS to the main lake will not be able to detect any high flow from the original outlet which is located to the left side of new breached outlet channel. The entire work of relocation the AWLS was completed on 24th June 2019 and the station is operational and functioning currently.

6.2 Restoration of terminal block at Thanza AWLS

During the high flow on 20th June 2019, the terminal block at Thanza AWLS was damaged completely (Photo 11).

Photo 11 : Showing damaged sensors part of Thanza AWLS

The work on the restoration of Thanza AWLS commenced on 25th June 2019. In the next 3 days the team completed the entire work which consisted of repairing the terminal block and changing bubbler pressure pipe. The station is operational and running at present but the communication is not stable. The communication system at Thanza station may take little more time to stabilize.

7 Conclusion

Based on the information and data collected from the site as well as other scientific data available with the Center and also information generated and provided by individuals and

institutions with whom National Center for Hydrology & Meteorology has close linkages, the following conclusion can be drawn:

7.1 Triggering of the breach at the main lake:

a. The months of April, May and June in 2019 had experienced higher temperature as recorded by Thanza automatic weather station
b. Extensive melting occurred on Thorthormi glacier in May and June 2019 as seen on satellite images which can be attributed to the higher temperature.
c. Presence of excessive melt water within the glacier might have triggered sudden displacement on the glacier which in combination with forward movement had resulted in abrupt rise in water level in the main lake.
d. The increased hydrostatic pressure from the rising water level caused the partial breach of the main lake through the weakest point at the outlet area.
e. The excess water which spilled over to subsidiary lake I and there onto subsidiary lake II eroded and the outlet of subsidiary lake II and drained out the same lake.
f. Based on the bathymetry map prepared in 2015 for subsidiary lake II, the total volume of water stored was only 18,160 m^3. But when it breached on 20th June 2019, the volume could have been little more than this due to excess water from the main lake.
g. The water level in the main lake of Thorthormi Tso was measured to be about 0.8 m lower than the original water level (from the fresh water marks) on 24th June 2019. Based on this lowering, it is estimated that a water volume of approximately 2.73 million m^3 was drained out from the main lake over the course of 4 days.

7.2 Relocation and restoration of Automatic water level sensors:

a. The AWLS at Thorthormi lake is relocated from subsidiary lake II to subsidiary lake Iand the station is up and running normally at present.
b. The damaged terminal block of Thanza AWLS has been repaired and restored. The pressure pipe of the instrument was also replaced. The station is up and running currently. However, the communication line is erratic and might take some time to normalize.

8 Recommendations:

Based on the findings and experience of the team in the field, the Center recommends the following:

a. Relocation of Community households settled immediate downstream of lakes
   Based on the fact that the vulnerable communities in Lunana (Thanza and Tenchoe) get very short lead time in case of major GLOF, the Center recommends for relocation of those households falling within the red zone to a safer area. Considering that relocation would not only incur huge burden to the Government and is a sensitive issue, the relevant sectors must fully engage the communities, local government during the planning and implementation. There were 2 households in Thanza and 13 houesholds in Tenchoe villages identified as high risk (Austrian report,2002). The exact number of houses to be relocated need to be reassessed since the communities

had undergone many recent changes such as reconstruction of houses in new places and also considering the study was done 17 years back.

b. Enhancing the existing GLOF early warning system

Glacier Lake Outburst Flood Early Warning System (GLOF EWS) along the Phochhu basin was installed in 2011 and the same system was later expanded to Mochhu in 2013 under the NAPA-I project "**Reducing Climate Change-Induced Risks and Vulnerabilities from Glacier Lake Outburst Flood in the Punakha-Wangdu and Chamkhar Valley",** funded by LDCF through GEF/UNDP**.** The system consists of 10 remote monitoring Water Level and Weather stations and 18 Sirens (3 in Lunana region, 1 on Mochhu and remaining along the Phochhu and downstream Punatsangchhu basin). The system monitors water level and weather conditions upstream on real time from the GLOF EWS Control Room Wangdi and Flood Monitoring and Command Room (FMCR), Thimphu. Data are transmitted from the remote Automatic Water level Station (AWLS) installed on outlet of lakes and upstream through satellite (Iridium) communication. Since the current GLOF Warning is based on flood detection by the just water level sensors of the remote monitoring stations, warning cannot be issued in advance before two or three days. In order to detect the change and abnormalities of lakes and surrounding areas team recommends to enhance the existing GLOF EWS by installing additional sensors like ground motion sensors and visual sensors (CCTV cameras). Moreover, the existing GLOF EWS is more than 8 years old and life of most of the components (water level, weather monitoring Stations and control room softwares) have expired and team recommends to upgrade and replacement of the existing components of GLOF EWS as life of most of sensors are just around 5 years.

Robustness is the key requirement for the Early Warning Systems. The current software and hardware used in the control room has aged and never been serviced or upgraded mainly due to proprietary rights and lack of fund. To enhance the robustness of the EWS, the system requires software and hardware upgradation with add-on components which are listed below:

1. River flow forecasting
2. Dam breach model
3. Enhanced capacity for web application
4. Alert messaging system to last mile and stakeholders
5. Enhanced capacity for basic data analysis tools.
6. Enhancing the onsite data base back up.
7. Adding Decision Support System (DSS) with robust information dissemination system.

c. Establishment of High-Altitude Long-Term Climate Monitoring Station

The IPCC reports and Climate Projection studies show that impact of climate change will be more in the high altitudes. The recent Thorthomi Lake breached event shows direct correlation to increased temperature of high altitude. Since Bhutan has no or limited climate data and information, the team recommends to establish long term

climate monitoring station in high altitude. Climate data and information would be not only useful for understating the change and causes of the glacier melting but temperature threshold can be useful in providing early warning for the downstream communities to be prepared for such event in the future.

d. Based on the experience this time by the team, it is recommended that concern gewog administration should play a proactive role in assisting such team in the future.

e. Relocation of the Thanza station house

Currently the station house in Thanza that accommodates office and the accommodation of NCHM staffs posted to Lunana is located on pasture land opposite and overlooking the Tenchoe village. The staffs on duty have to walk more than 1 Km to have a visual verification during emergencies and even during regular monitoring of the river. The Thanza station house is also the only government structure in upper Lunana (Thanza and Tenchoe village) as of now. In the past this station house was used as very important facility during VVIP's visit and other official visits. Thus, the Center proposes to relocate the current station house to a location where it has the direct visibility of river but at a safe zone with additional facilities. The Center initially identified the location close to S15 siren station. The budgetary requirement for this relocation and construction is estimated at Nu.4.5 million which also includes a compound fencing and water supply.

References

CSD, NCHM, 2018 : Bhutan Glacier Inventory 2018 (BGI 2018)

CSD, NCHM 2018 :Re-assessment of Potentially Dangerous Glacial Lakes in Bhutan

Joint Japan _ Bhutan Research Report (2003)

Leber, D; Hausler,H; Brauner, M & Dorji,W (2002): Glacier lake Outburst Flood (GLOF) Mitigation Project, Pho CHhu – Eastern Branch (Thanza – Lhedi,2000 -2002), Lunana, Bhutan.

ANNEXURE

Annexure 1: Action taken report for the 20th June 2019 incident from Thorthormi lake based on the existing SOP of the GLOF Early Warning System in Puna Tsang Chu sub basin.

Thorthormi Flood Incident Action Taken Report

1. Background

There are four lakes in Lunana area. All four lakes (Luggye, Thorthormi, Rapstreng and Baytso) are identified as the potentially dangerous lake out of 9 potentially dangerous lakes in the head water of Phochhu.

Glacier Lake Outburst Flood Early Warning System(GLOF EWS) installed in 2011along the Punatsancghhu basin with the **Reducing Climate Change-Induced Risks and Vulnerabilities from Glacier Lake Outburst Flood in the Punakha-Wangdu and Chamkhar Valleys, funded by GEF/UNDP.**The system transmits data on realtime from all 10 monitoring stations including all the four lake's water level and are monitored on real time from the GLOF EWS Control Room Wangdi and Flood Monitoring and Command Room (FMCR), Thimphu. Data are transmitted from the remote Automatic Water level Station (AWLS) installed on outlet of lakes through satellite communication (Iridium).

As a manual back to Automatic GLOF EWS, the Flood Warning Office at Thanza, Lunana as two regular staff posted on a special duty, who monitors the lakes physically from time to time ad inform HQ, and Control Room. Thanza Flood Warning Office is equipped with HF Wireless and Satellite phone beside the mobile.

2. GLOF Detection

On the evening of 20th June 2019 at 7:00Pm the remote monitoring station of the GLOF EWS on Thorthomi Lake detected a sudden rise in water level from 6.55 meters to 8.04 meters with the rise of 1.49 meters within approximately 25 minutes. The sub-basin control room at Wangdue and the Flood Monitoring and Command Room, Thimphu, HQ had observed the rise of Water Level which has asserted the GLOF Early Warning System in Punakha-Wangdue Valley into ALERT Condition. The Water Level started to recede from 7:20 PM and was back to normal by 9:30 PM. The Water Level further receded from normal which was an indication of emptying of the lake as per GLOF EWS system logic.

River	Site Name	Update Time	Water Level	Alert	Alarm
PHOCHU	Luggy-AWLS	Jun 20, 2019 7:05 PM	6.53	7.9	10.0
PHOCHU	Thorthormi-AWLS	Jun 20, 2019 7:05 PM	7.75	7.5	9.4
PHOCHU	Rapstreng-AWLS	Jun 20, 2019 7:05 PM	6.2	7.4	9.3
PHOCHU	Bay-Tsho-AWLS	Jun 20, 2019 7:00 PM	6.27	7.4	9.3
PHOCHU	Thanza-AWS	Jun 20, 2019 7:00 PM	6.49	7.2	9.1

Figure 1: Exceeded Alert threshold of water level at Thorthomi Station

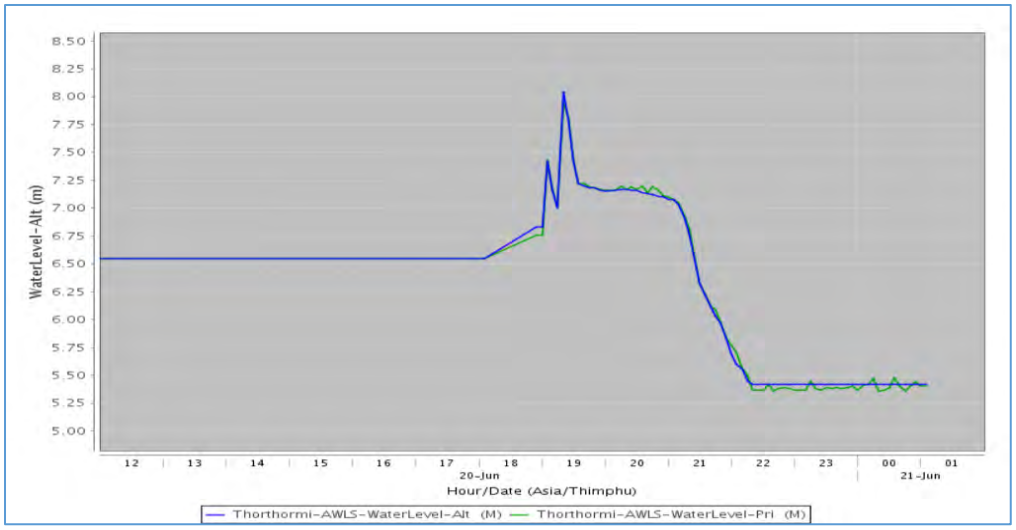


Figure 2: Detection of the rise and fall of water level at Thorthomi Station

The rise of water level was also detected by GLOF EWS monitoring station at Thanza, that is located approximately 4.60 KM along the river channel downstream of Thorthomi lake.

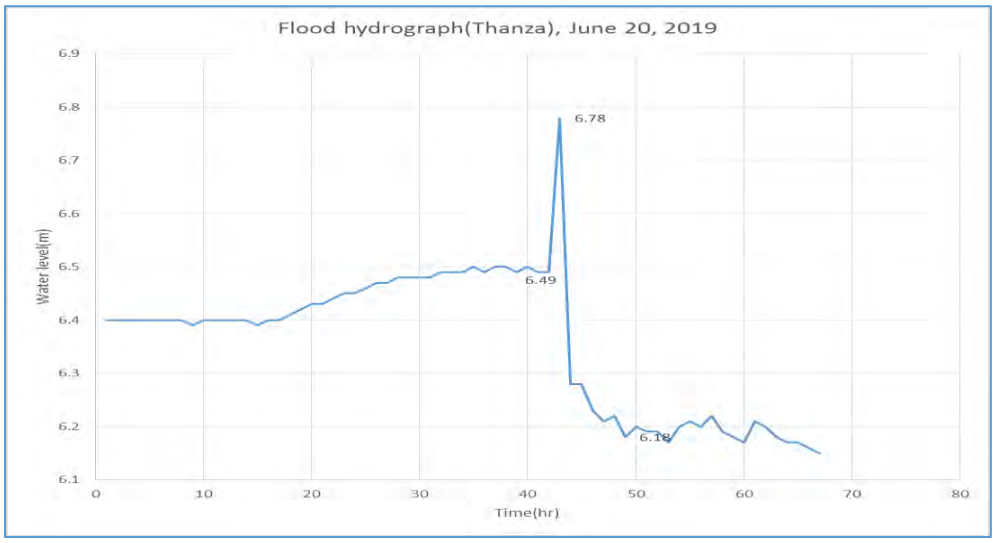


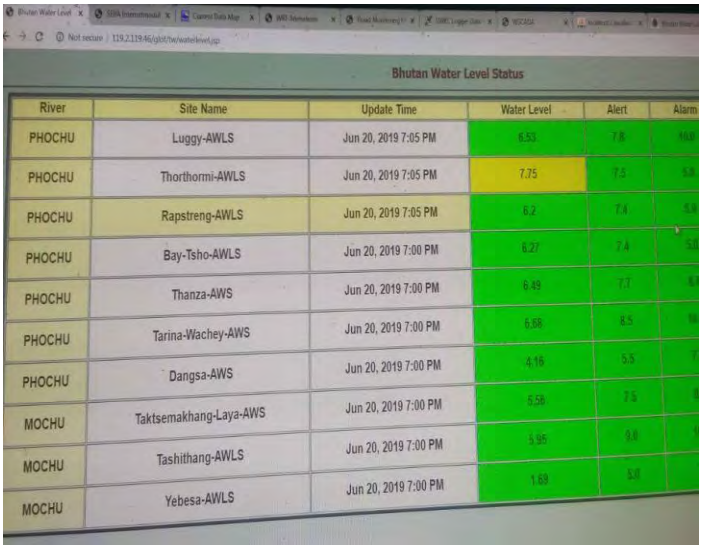
Figure 3: Detection of the rise and fall of water level at Thanza Station

3. Emergency Meeting

As per the Standard Operating Procedure (SOP) of the GLOF EWS installed along the Punakha-Wangdue Valley, an emergency meeting was called for by HWRSD, Offtg Chief. The following members of NCHM management group attended the meeting in the FMCR room by 7:10 PM:

1. Mr. Karma, Specialist, (chief, CSD), Offtg, Director, NCHM
2. Mr. Sangay Tenzin, Offtg Chief, HWRSD
3. Mr. Pema Wangyel, Dy Ex. Engineer, HOID

4. Mr. Tandin Wangchuk, Engineer, HWRSD
5. Mr. Jamyang Zangpo, Engineer, HWRSD
6. Mr. Pema Dorji, Technician, FMCR, HWRSD



Bhutan Water Level Status

River	Site Name	Update Time	Water Level	Alert	Alarm
PHOCHU	Luggy-AWLS	Jun 20, 2019 7:05 PM	6.53	7.8	
PHOCHU	Thorthormi-AWLS	Jun 20, 2019 7:05 PM	7.75	7.5	
PHOCHU	Rapstreng-AWLS	Jun 20, 2019 7:05 PM	6.2	7.4	
PHOCHU	Bay-Tsho-AWLS	Jun 20, 2019 7:00 PM	6.27	7.4	
PHOCHU	Thanza-AWS	Jun 20, 2019 7:00 PM	6.49	7.7	
PHOCHU	Tarina-Wachey-AWS	Jun 20, 2019 7:00 PM	6.58	8.5	
PHOCHU	Dangsa-AWS	Jun 20, 2019 7:00 PM	4.16	5.5	
MOCHU	Taktsemakhang-Laya-AWS	Jun 20, 2019 7:00 PM	5.58	7.5	
MOCHU	Tashithang-AWLS	Jun 20, 2019 7:00 PM	5.95	8.8	
MOCHU	Yebesa-AWLS	Jun 20, 2019 7:00 PM	1.69	5.0	

Figure 4: Emergency meeting at FMCR

The Chief, HOID and WCSD actively participated in communication online throughout the night.

4. Information Sharing

4.1.Flood Monitoring and Command Room (FMCR), Thimphu

FMCR shared the information regarding the rising water level with the immediate officials of Hydrology and Water Resources Services Division (HWRSD). Subsequently, according to the Standard Operation Protocol, the situation was informed to relevant stakeholders like Department of Disaster Management (DDM), Ministry of Home and Cultural Affairs (MoHCA), Director and Chiefs of NCHM. The information was shared to alert the relevant people and stakeholders of the situation.

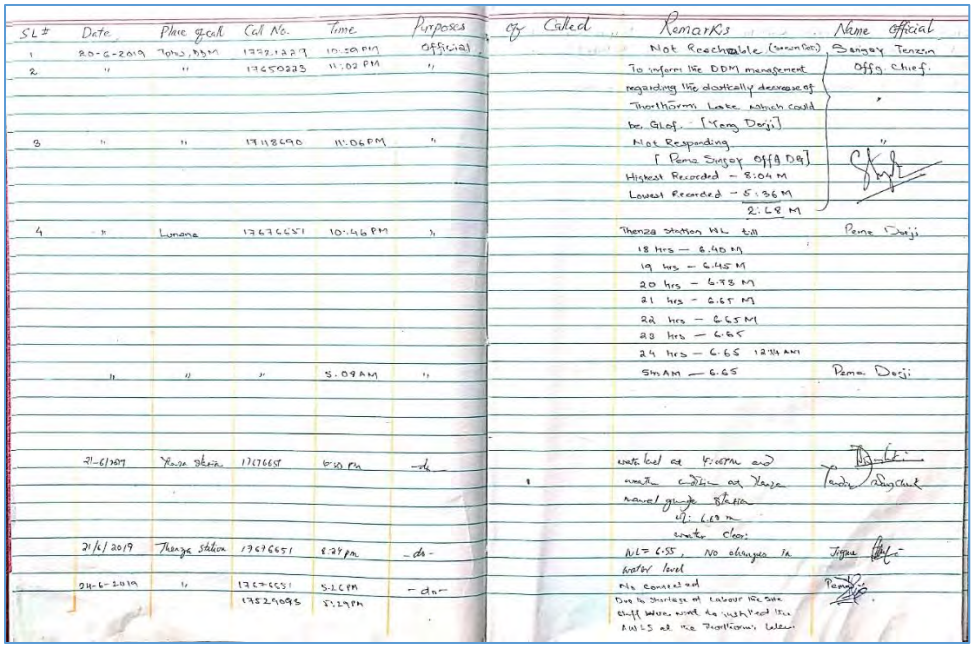


Figure 5: Information sharing log book at FMCR, HQ

4.2.Wangdue Control Room

Wangdue Control Room also informed agencies and the relevant stakeholders in line such as the DDMO (Wangdue Phodrang and Punakha), Punatsangchu Hydroelectric Project Authorities (PHPA I&II), Basochu Hydropower Plant (BHPA) and FMCR, Thimphu as per the standard operating procedure.

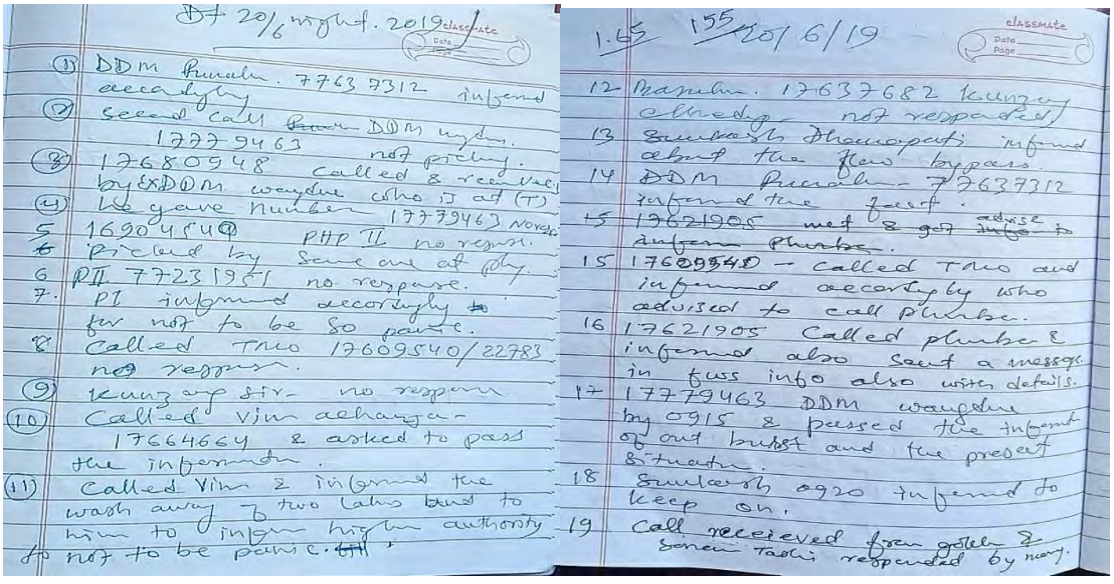


Figure 6: Information sharing log book at Wangdue CR

4.3.Thanza(Lunana) Site Staff

Two site staff of NCHM stationed at Thanza(Lunana) informed about the breach of subsidiary lake II of Thorthormi glacier lake to concern people and agencies. As mandated, the information was shared to control rooms at Wangdue and Thimphu, Director and the Chiefs of NCHM, Gup of Lunana Gewog,Principal of Lunana Primary School, Member of Parliament(Lunana) and Bhutan Braodcasting Service reported Wangdue.

Figure 7: Information sharing log book at Thanza site office and monitoring process supported by one of the Teachers of Lunana.

5. GLOF Monitoring and Follow-up Updates

5.1.Flood Monitoring and Command Room (FMCR), Thimphu

Since the detection of the rise in water level at Thorthormi AWLS, FMCR as the Control Room in Head Quarter which is operated 24/7 intensified the monitoring. The site staff at Thanza were contacted and asked for immediate field verification through manual gauge reading and reported that the water level had risen. As the water level struck ALERT level, information was shared as per SOP to the relevant stakeholders. Soon after, it started to fall below normal but stopped when it was just above ALERM level no siren was triggered. Immediately, flood advisory was prepared and first issued at 12:00 mid-night. Every detail was noted without fail.

Daily flood advisory with latest updates from the field (Thorthormi lake and Thanza) were issued and the intensive monitoring continued until the situation was stabilized back to normal.

5.2. Wangdue Control Room

Puntsangchu basin control room at Wangdue also intensified the monitoring. Staff kept in contact with the Thanza site staff for field updates and reported to FMCR. Necessary information was duly shared as per SOP. A small meeting was called for by the in-charge asking for continued vigilance and monitoring.

Figure 8: Emergency meeting at Wangdue CR

5.3.Thanza(Lunana) Site Staff

The field staff stationed at Thanza were deputed for field verification soon after detection. Despite harsh weather condition, the two-site staff immediately initiated the action. One stayed at Thanza AWLS reporting the situation while the other continued to the Thorthormi Lake. It was reported at 12:08 AM, 21st June that the subsidiary lake II of the main Thorthomi lake had fully drained out. Since it was dark, no site photo could be sent to CRs but at the very early hours of the day when it became visible, site information through photos was shared. They informed the Head Quarter about the Thorthormi AWLS which was rendered functionless was due to water being fully drained out exposing the sensors. Similar problem at Thanza AWLS was also reported.

Figure 9: First photos of the site update in the early morning of June 21

Figure 10: Thanza AWLS rendered non-functional after June 20

Since then, they manually monitored the site situation but due to lack of additional man power, assistance from the school teachers and health workers of Thanza was sought as ordered from the HQ. Site situation were frequently updated to CRs in all possible ways. On June 21st by afternoon, the Thorthormi AWLS was manually put off as the sensor termination block was exposed and for as we doubting that it might cause a false alarm.

6. Lunana Trip

On the night of the 22nd July, our Center informed that government has made a decision to depute a team from NCHM to conduct a "Rapid assessment of Thorthormi lake status and to restore the damaged monitoring stations of EWS in Lunana Region.

The rapid assessment team had relocated the sensor station to SL-I and the station started monitoring and reporting toward the evening of 24rth June and the team recommended the manual 24/7 monitoring on the lake be discontinued mainly due to extremely harsh weather at site and logistic problems.

After the restoration and relocation by rapid assessment team, the GLOF EWS has been fully operational

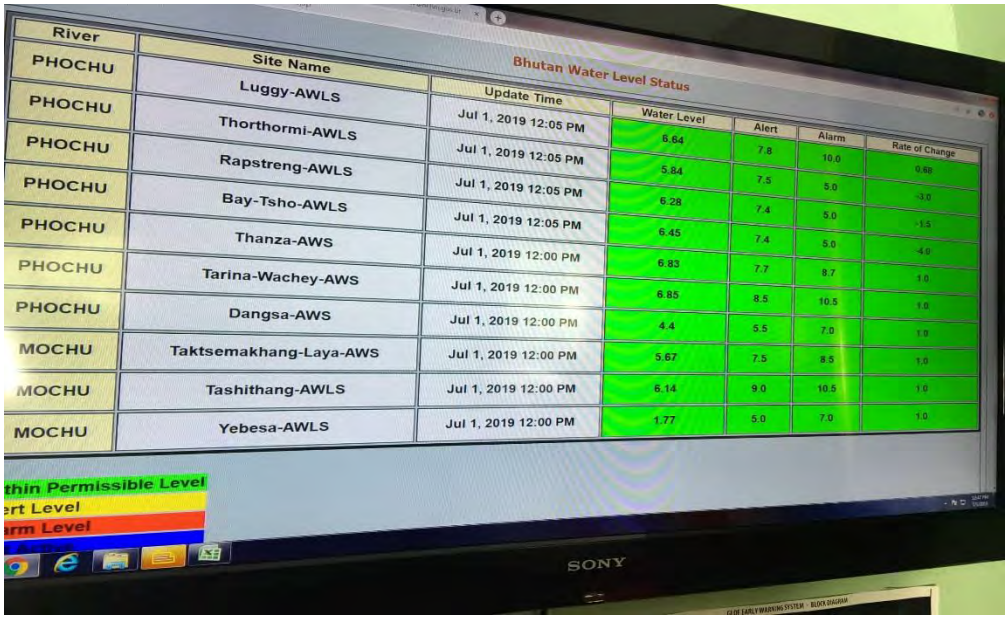


Figure 9: Puna-Wangdue GLOF EWS status since June 24

NATIONAL CENTER FOR HYDROLOGY AND METEOROLOGY
ROYAL GOVERNMENT OF BHUTAN
www.nchm.gov.bt