High Resolution Monitoring of GLOF Vulnerable Lakes using Indian EO Data – The Paradigm Shift

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ABSTRACT

Globally in the last three decades, the number of glacial lakes and their surface area have increased by 54% and 11%, respectively. It has been noticed that the eastern Himalaya has most of these glacial lakes due to its geographical settings and climatic factors. Many of these lakes represent a GLOF hazard. In the present study, the freely available IRS LISS-IV (5.8m, multispectral) data is utilised for monitoring the selected GLOF vulnerable lakes. The temporal changes in, Chubda lake, Bhutan and Bailangcuo, Gongzhangcuo lakes, Tibet region are monitored at 1:10,000 scale using cloud-free, end-of-ablation seasons, LISS-IV (Resourcesat-2&2A) data. The results highlight the continuous expansion of these lakes. Chubda lake has inundated around 29.4 ha (21.5%) of additional area during 2015 to 2023, with the steepest change of 14.2 ha observed during 2018 to 2021. Bailangcuo lake shows expansion of 27.86 ha (13.29 %) in the period 2015-2023. Lake Gongzhangcuo though only has expanded by 17.54 ha, however, this amounts to 53.57% increase in the lake extend during the period of 8 years (2015-2023). The majority of the expansion of these lakes has come at the expense of retreating glaciers, which is also mapped in the study. The derived results are in tune with the published literature. The study highlights the potential of LISS-IV(Mx) data in high-resolution monitoring of glaciers and glacial lakes. Under the ambit of Indian Space Policy-2023, the LISS-IV(Mx) data, available since 2003, is made 'free and open' in the public domain. The free and open availability of this data reduces the financial burden from the glacier and glacial lake mapping activity. This initiative of providing free access to LISS-IV(Mx) data, by the Department of Space, Government of India, has the potential to bring the paradigm shift in the global efforts towards continuous monitoring of glacial lakes to achieve UN's SDG-11 (Disaster Risk Reduction).

Keywords: Glacial Lake, GLOF, LISS-IV, Indian Space Policy-2023, SDG-11

INTRODUCTION

Since the industrialization era glaciers all over the globe are exhibiting accelerated melting. This has led to increase in formation of glacial lakes. Many of these glacial lakes are expanding in their area and volume under the changing environment and climate. During year 2020 a total 71,508 glacial lakes were identified worldwide and it was observed that in last three decades the number of glacial lakes and their surface area have increased by 54% and 11%, respectively (Zhang, et al., 2024). Himalayan region, the third pole of the world, have about 12,828 (18%) of these glacial lakes. Many of these lakes represent a substantial natural hazard of Glacial Lake Outburst Flood (GLOF). In majority of cases forewarning of GLOF is difficult without detailed and site specific investigations of these lakes. In recent decades both the incidences of GLOF and research publication on GLOF are increasing nonlinearly (Emmer et al., 2022). However, availability of detailed, high resolution inventory of glacial lakes is limiting factor in this field of research. Making an inventory of glacial lakes and their status monitoring is tedious task due to ruggedness of terrain and inhospitable weather in these areas. To overcome these limitations remote sensing based glacial lake monitoring has gained prominence since last two decades (Kulkarni, 1991; Berither et al., 2007; Wagnon et al., 2007; Raj, 2010; Cogley et al., 2011; Pratap et al., 2016; Gupta et al., 2019, Guru et al., 2019). Though several isolated studies towards mapping of glacial lakes are available in literature, the first glacial lake inventory available in public domain was generated by International Centre for Integrated Mountain Development (ICIMOD), Nepal, for the entire Himalayan region using satellite data (Landsat- TM and IRS 1D- LISS-III). This inventory was further revised in 2018 using Landsat TM and ETM+ data (Maharjan et al., 2018). Further, Indian Space Research Organisation (ISRO) has also generated inventory of glacial lakes in the Indian Himalayan region using AWiFS and LISS-III data. However, all these datasets have limitation of scale of mapping due to spatial resolution of remote sensing data used (generally coarser that 25 m). The smallest lakes that can be identified using these datasets was >0.3 ha.

Recently, ISRO demonstrated the potential of its high resolution multispectral data from LISS-IV sensor in glacial lake mapping (>0.25 ha). Total 28,043 lakes were mapped from the Indian Himalayan region were as global glacial lake database indicates around 12,828 lakes in entire Himalayan region (NRSC, 2023). This large disparity in number of glacial lakes can be solely attributed to the high resolution of the remote sensing data used in the recent activity. The 5.8 m spatial resolution, LISS-IV data, enhances the mapping scale and identification potential of smaller lakes (>0.25ha). Under the ambit of Indian Space Policy-2023, the data dissemination guidelines have been released in November 2023. Accordingly, remote sensing data with 5 m and higher ground sample distance (GSD) is made available on 'free and open' basis to all. IRS LISS-IV (Mx) data of 5.8 m resolution is now available on 'free and open' basis in public domain. The present study is focused towards utilising IRS LISS-IV for monitoring the selected GLOF vulnerable lakes from Asia (Himalayan region). It has been noticed that eastern Himalaya has the most glacial lakes due to its geographical settings and climatic factors. The temporal changes in, Chubda lake from Bhutan and Bailangcuo, Gongzhangcuo lakes from Tibet region of Asia are monitored in the present study using LISS-IV data from Resourcesat-2 and Resourcesat-2A satellites. Along with expansion of these glacial lakes the health associated glaciers are also monitored and the glacier retreat rated are estimated. The study aims at highlighting the capabilities of LISS-IV data in monitoring glacial lakes and glacier retreat at high resolution.

STUDY AREA AND DATA USED

The technical objective of this study was to bring-out the potential and advantages of LISS-IV data in identifying and monitoring the glacial lakes in the rugged terrain of High Mountain Asia. An extensive exercise identification, mapping and preparation of inventory of glacial lakes present in Indian Himalaya is done by National Remote Sensing Centre (NRSC) of Indian Space Research Organisation (ISRO) under the project titled 'National Hydrology Project (NHP)' sponsored by Department of Water Resources, River Development and Ganga Rejuvenation (DoWR, RD&GR), Ministry of Jal Shakti, Government of India (GOI) with financial aid from the World Bank. Total of 28,043 glacial lakes have been mapped in the Indian Himalayan River basins using a total of 397 high resolution multispectral Resourcesat-2 LISS-IV images. However, due to limitations of project objective other glacial lakes present in the Himalaya (outside the Geographical boundary of India) were not take-up.

The Chubda Glacial Lake, formerly known as Churapokto Tsho GLC5 (coded by GSB, 1999) which exists in the headwater region of Chamkhar River (Chamkhar Chu basin), Central Bhutan is selected as primary study area. Chubda Tsho is one of the largest glacial lakes in the Bhutan Himalaya. Chubda Glacier drains directly in the Chubda Tsho, hence monitoring Chubda Tsho serves two purpose 1) Glacial lake Outburst Flood (GLOF) hazard assessment for the downstream and 2) Assessment of health of Chubda Glacier. Due to these reasons Chubda Tsho has received attention of local administration and global research community since last two decades. Initially, the monitoring of Chubda Glacier and Chubda Tsho was done using traditional survey techniques and it was observed that the horizontal location of the front of Chubda Glacier has not changed, at least during preceding the 35 years (1967 to 2001), and however, the surface elevation of the debris-covered part of the glacier has dropped. It was observed that during these 35 years Chubda lake has tripled its surface area (Komori et al., 2004).

Figure 1 shows the location and present status, as on 20th November 2023, of Chubda Glacier and the Chubda Tsho (Lake) using standard false color composite image generated using Resourcesat-2 LISS-IV data.

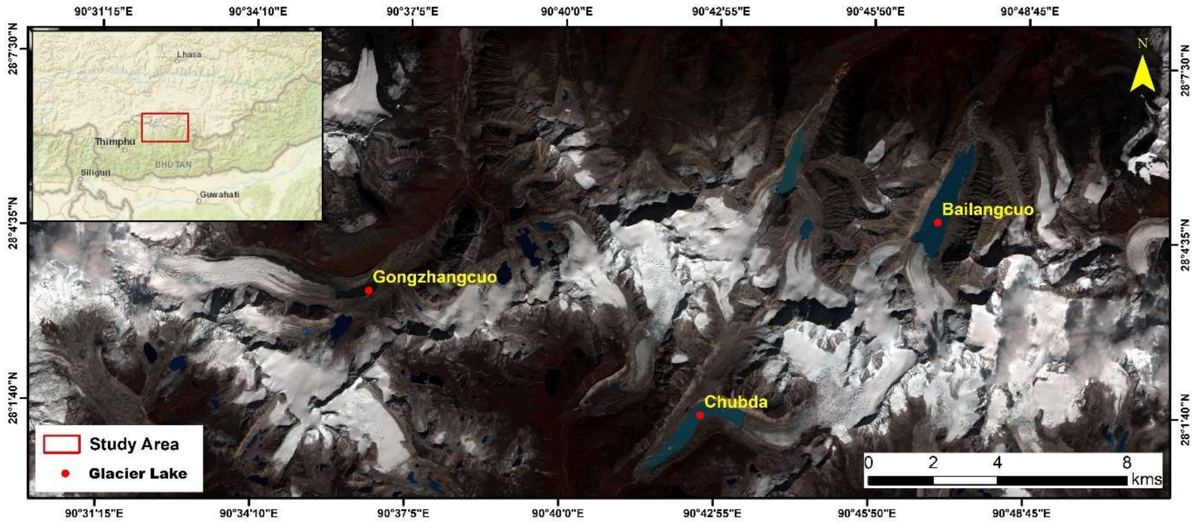

Figure 1. Location of study area (identified Glacial lakes) marked on standard FCC generated using multi-spectral data of Resourcesat-2 LISS-IV acquired on 20/11/ 2023.

LISS-IV (Linear Imaging Self-Scanning Sensor-4) multispectral high-resolution camera is one of the prime sensor onboard Resorucsat-2 and 2A satellites of Indian Remote Sensing (IRS) series. LISS-IV is a three-band push-broom camera working in Green (B2: 0.52-0.59µm), Red (B3: 0.62-0.68 µm) and Near-Infra-red (B4: 0.77-0.86 µm) region with a spatial resolution of 5.8 m and swath of 70 km. A single scene of LISS-IV sensor covering Chubda Lake also covers multiple high altitude waterbodies (small glacial lakes) and major glaciers/trunk glaciers and their tributary glaciers. As the objective of the present work was to highlight the potential of LISS-IV data in monitoring of glaciers and glacial lakes, two more glacial lakes on North-West (Gongzhangcuo Tsho) and North-East (Bailangcuo Tsho) of Chubda Lake are selected as study area. Bailangcuo Tsho, Gongzhangcuo Tsho from Tibet region are monitored using LISS-IV data from year 2015 to 2023. The heath of glaciers (Bailangcuo glacier and Gongzhangcuo glacier) terminating in these lakes were also monitored to assess/quantify the retreat of these glaciers.

Under the ambit of Indian Space Policy-2023 (ISP-2023), the data dissemination guidelines have been released in November 2023 by Department of Space, Government of India. Under these data dissemination guidelines, remote sensing data with 5 m and higher ground sample distance (GSD) is made available on ‘free and open’ basis to all. IRS LISS-IV data of 5.8 m resolution is now available on ‘free and open’ basis in public domain along with other remote sensing data of coarser spatial resolution. The data from LISS-IV sensor is available for more than two decades (since 2003) which makes it a most suitable candidate for high resolution glacier and glacial lake mapping exercise. The free and open availability of this data reduces the financial burden from this activity. These LISS-IV data can be accessed from Bhoonidhi portal (https://bhoonidhi.nrsc.gov.in). In the present study the cloud free data from the end of ablation period has been used for monitoring the spatio-temporal changes in these lakes and glacier during the period 2015 to 2023. The list of remote sensing data used in the present study is given in Table-1

Table-1. List of remote sensing data used for Glacier and Glacial lake mapping

Year	Satellite	Sensor	Spectral Resolution	Spatial Resolution	Date of Acquisition
2015	Resourcesat-2	LISS-IV	B2, B3, B4	5.8m	09/11/2025
2017	Resourcesat-2				29/10/2017
2018	Resourcesat-2A				29/11/2028
2021	Resourcesat-2				13/10/2021
2023	Resourcesat-2				20/11/2023

METHODOLOGY

A number of remote sensing based techniques have been developed for glacial lake mapping or monitoring (Kääb 2000; Mool et al., 2001; Huggel et al., 2002; Huggel et al., 2006; Ives et al., 2010). However, knowledge of the physical characteristics of the glacial lakes, and their associated features is always essential for effectively using remote sensing data for this activity. Further, glacial lakes pose many challenges in identification and mapping their water spread. National Remote Sensing Centre (NRSC), ISRO has analysed these challenges and listed the major ones as Shadows (mountain or cloud), Water quality/form (turbidity/snow cover/ frozen/ cloud cover), Size of the glacial lake, difference in illumination during different seasons/months, etc. In its suggestions the report advocates to use visual interpretation approach for accurate mapping of glacial lakes. However, many of these challenges can be overcome by careful selection of input data (remote sensing images used for mapping of glacial lakes). In the present study, since only three lakes and glaciers were selected for monitoring and remote sensing data of end of ablation period was selected with criteria of minimum cloud cover, So the challenges that discourage automatic mapping of glacial lakes were avoided.

The uniqueness of spectral signature of clean and deep water has encouraged the researchers to operationalize the use of remote sensing data for waterbody mapping, including mapping of high altitude waterbodies. With careful selection of cloud free data from October or November months for the present study the problems of cloud cover or snow cover was completely avoided. All three lakes show now mountain shadow during this season and water remains relatively clean (sediment free), So the semi-automatic approach of glacial lake mapping was adopted in the present study, for mapping and monitoring of glacial lakes. Normalized Difference Water Index (NDWI, McFeeters, 1996) was estimated using spectral reflectance of Band 2 (B2) and Band 4 (B4) of LISS-IV data as given in Eq.1

$$NDWI = (\rho_{Green} - \rho_{NIR})/= (\rho_{Green} + \rho_{NIR}) \tag{1}$$

Where, ρ_{Green} is spectral reflectance of green band (B2 of LISS-IV) and ρ_{NIR} is spectral reflectance of NIR band (B of LISS-IV)

Positive NDWI values indicate present of water in the pixel, the deep clean water tends to attend NDWI value near to 1. The NWDI image for the month of October or November shows great contrast between surrounding features and glacial lakes, however to automate the detection of water pixels the NDWI thresholding approach was implemented in the present study. The water extent of each glacial lake during all the years was mapped using this approach. The overall methodology flowchart of techniques implemented for mapping and monitoring of glacial lakes and associated glacier is shown in Figure 2.

Further the glacier boundary of all three glaciers (Chubda glacier, Bailangcuo glacier and Gongzhangcuo glacier) were taken from Global Land Ice Measurements from Space (GLIMS) database and used as reference to monitor the temporal changes in the glacier extend. In the present study the retreat of all three glaciers was estimated by monitoring the changes in the glacial front throughout the study period. The location of snout and glacier front was identified and mapped using visual interpretation technique. The retreat of glacial front was quantified using these temporal mapping results.

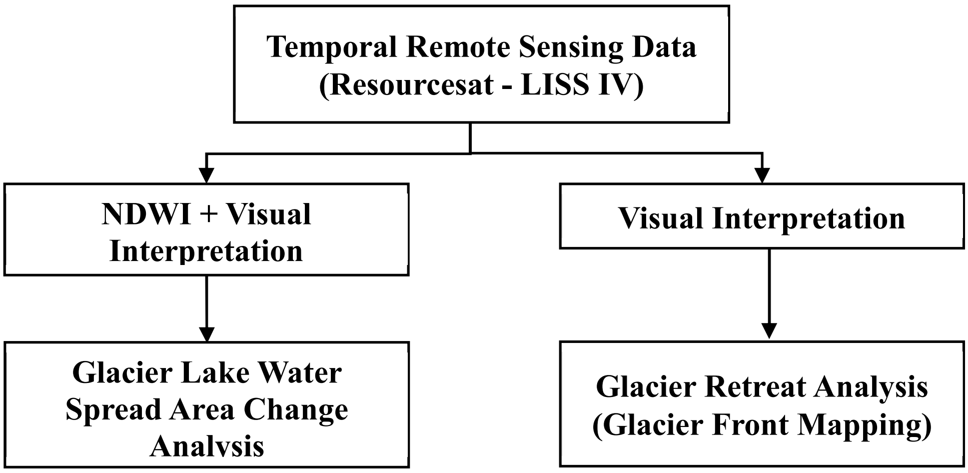

Figure 2. Methodology Flowchart

RESULTS AND DISCUSSIONS

In the present study, the temporal LISS-IV data from Resourcest-2 and 2A satellites was used for mapping and monitoring of glacial lakes in Himalayan region. The lake identification and mapping is done using semi-automatic approach where NDWI layer was as input for mapping the water spread of identified lakes. The problems of cloud cover, snow cover were nullified by careful selection of input remote sensing data from the end of ablation season. Five LISS-IV images from year 2015, 2017, 2018, 2021 and 2023 were used for mapping and quantifying the spatio-temporal dynamics of three glacial lakes. The primary target was Chubda Tsho and two adjacent lakes, Bailangcuo lake, Gongzhangcuo lake along with their contributing glaciers. Owing to high spatial resolution and radiometric resolution of LISS-IV data both glacial lake boundary and glacier boundaries were very clearly visible in the standard FCC (Figures 1, 3.a, 5.a, 6.a, 8, 9 & 10). However, the glacial lake mapping was done using NDWI thresholding approach. Clear identification of lake boundary was achieved using this approach. The delineated glacial lake boundaries were visually validated using the respective standard FCC as reference data/background at 1:10,000 scale (Hall et al., 2003).

Expansion of Chubda Tsho

The spatio-temporal changes in the Chubda Tsho (lake) mapped using LISS-IV data are shown in Figure 3.b. The water spared of Chubda Tsho during November 2015, October 2017, October 2021 and November 2023 are represented by red, blue, yellow and green color, respectively in Figure 3.b. The results clearly indicated that Chubda Tsho is continuously expanding and the major expansion is happing toward the upper part of lake which is following the retreat mechanism of the glacier. This is mainly due to the connectivity of the lake with the terminus of the glacier and accelerated retreat of Chubda glacier. Figure 3.b clearly indicates that the expansion of lake is happing in lower and middle parts also. However, it is noteworthy that the no notable expansion is observed on the entire southern bank of the lake. This is due to topography of this lake, the southern bank of the Chubda Tsho has steep sloping moraine wall. The geomorphological features (island and peninsulas) at the lower part of the lake have found to be almost submerging due to the advancement of the tail of the lake.

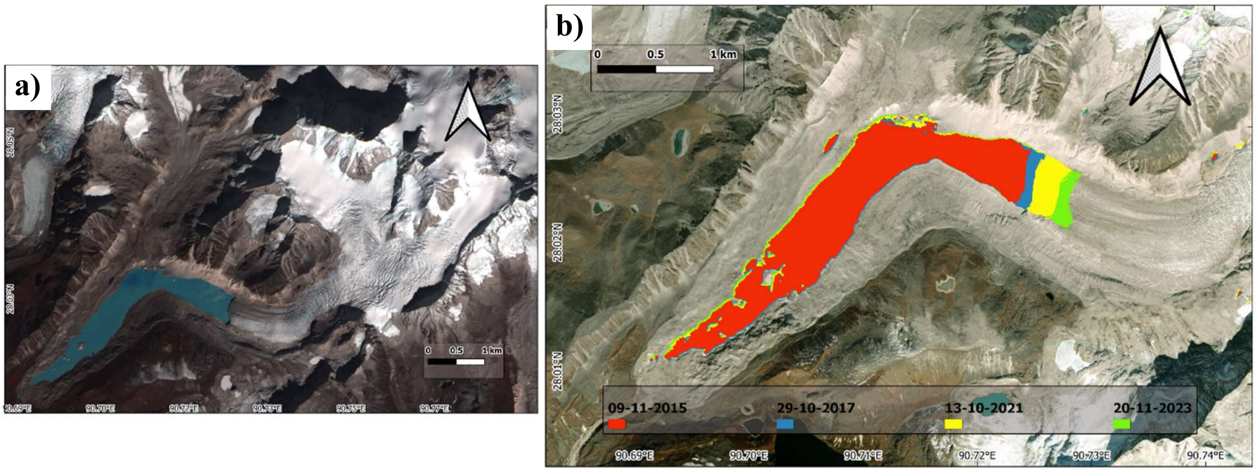

Figure 3. **a)** Chubda Tsho as seen in 20 November 2023 in the LISS-IV data, **b)** Temporal changes in Chubda Tsho mapped using temporal LISS-IV data.

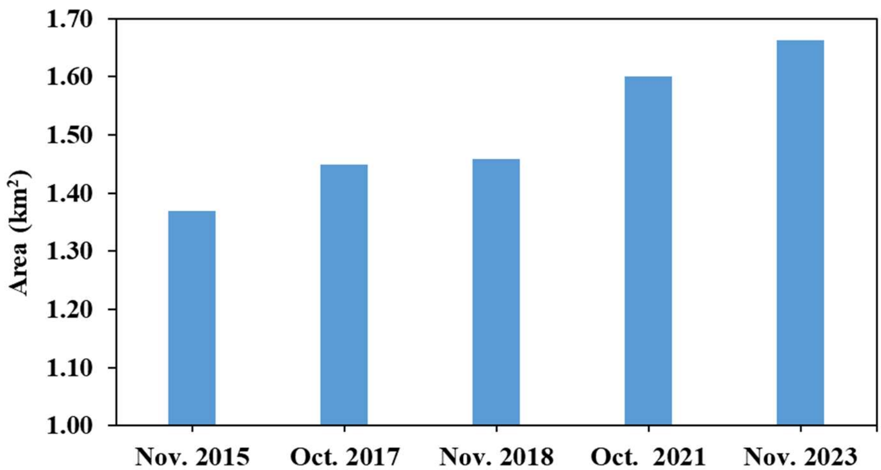

Figure 4. Expansion of Chubda Tsho from November 2015 to November 2023 mapped using Resourcesat-2/2A LISS-IV data.

Larger expansion of Chubda Tsho was observed during the period of 8 years (2015-2023). The lake was occupying 1.37 km^2 of area during November 2015 which expanded to 1.45 km^2, 1.46

km^2, 1.60 km^2 and 1.66 km^2 during the Oct-Nov. months of 2017, 2018, 2021 and 2023 respectively. Total expansion of 0.29 km^2 (21.49%) was observed in the Chubda Tsho during the period of 8 years (2015-2023). The major change in lake's water spread area was observed during 2015-2017 and 2018-2013 wherein the lake expanded by 0.08 km^2 and 0.14 km^2 respectively. The detailed changes of lake area with respect to time are depicted in Figure 3.b and Figure 4. On an average the Chubda Tsho shows the expansion rate of 0.04 km^2/year (2.69 percent per year with lake area of November 2015 as the baseline scenario). The reported value of expansion rate of Chubda Tsho upto year 2010 is in the range of 0.05 km^2/year (Jain et al., 2015). The previous studies on monitoring of Chubda Tsho were carried out using 30m or coarser resolution remote sensing data which is suitable for 1:50,000 scale mapping. The deviation of lake expansion rate of present study with previous studies can be attributed to the difference in time period and scale of mapping. However, it is noteworthy that the lake expansion rate estimated using LISS-IV data is also in close agreement with all the published values for Chubda Tsho. This highlights the advantage of LISS-IV data, which is now freely available to global research community.

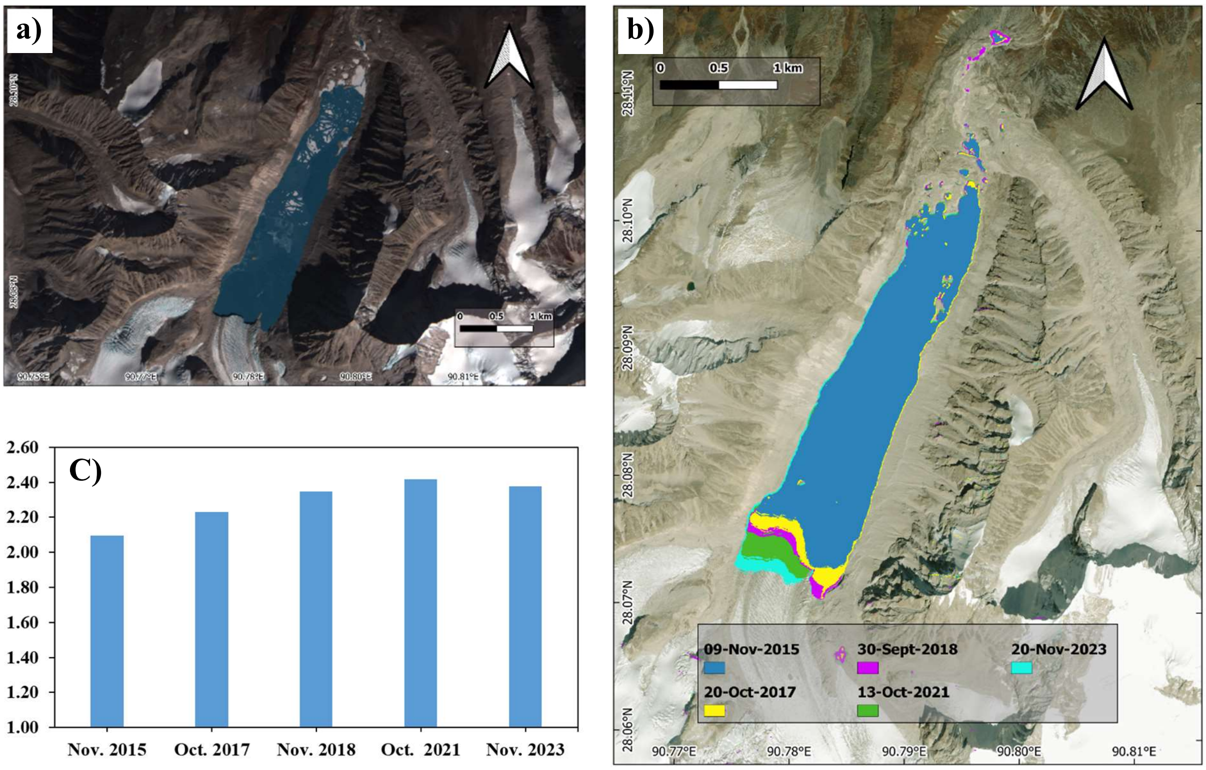

Figure 5. a) Bailangcuo glacial lake as seen in 20 November 2023 in the LISS-IV data, **b)** Temporal changes in Bailangcuo glacial lake and, **c)** Expansion of Bailangcuo glacial lake from November 2015 to November 2023 mapped using Resourcesat-2/2A LISS-IV data

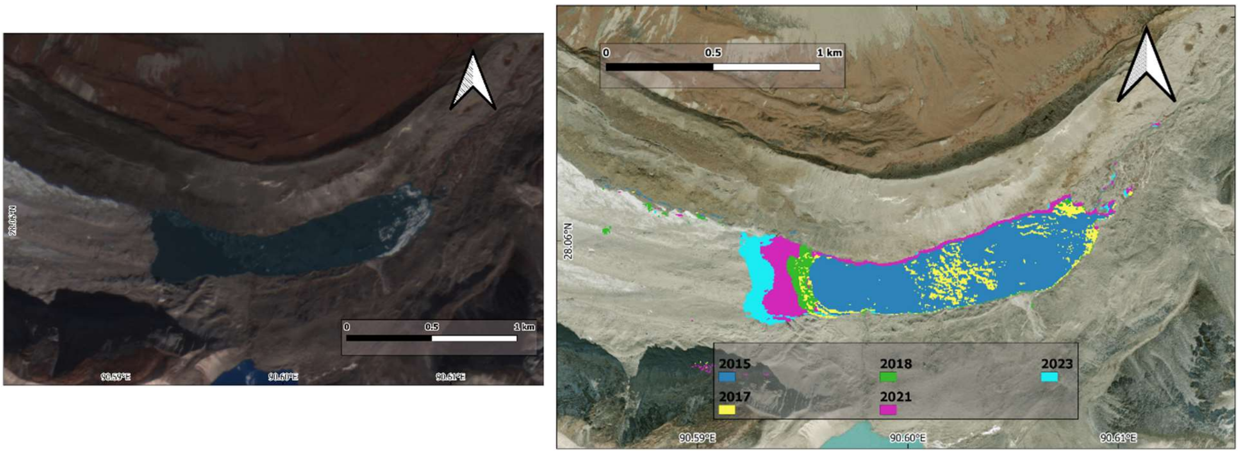

Figure 6. **a)** Gongzhangcuo glacial lake as seen in 20 November 2023 in the LISS-IV data, **b)** Temporal changes in Gongzhangcuo glacial lake mapped using temporal LISS-IV data.

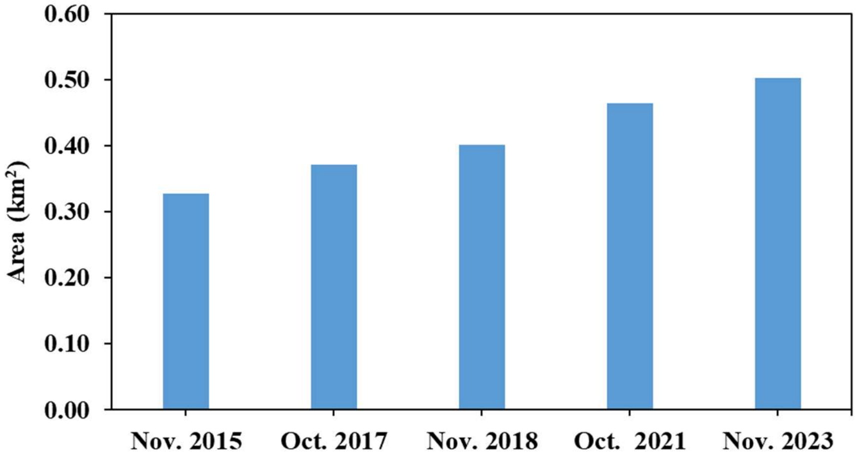

Figure 7. Expansion of Gongzhangcuo glacial lake from November 2015 to November 2023 mapped using Resourcesat-2/2A LISS-IV data.

Expansion of Bailangcuo and Gongzhangcuo glacial lakes

Similar mapping and analysis approach was implemented for assessing the spatio-temporal changes in Bailangcuo and Gongzhangcuo glacial lakes. The spatio-temporal changes of Bailangcuo glacial lake mapped using LISS-IV data are depicted in Figures 5.b and 5.c. Figure 5.b shows the temporal expansion of Gongzhangcuo glacial lake which is mainly towards the upper part of the lake due to the retreating glacier terminating in the lake. A peculiar observation of contraction of lake area is observed during 2021-2023 time period. This contraction may have happened due to reduction of snowfall during ablation period of 2023. However, over all expansion of Gongzhangcuo glacial lakes with the rate of 0.035 km^2/year

(1.66 percent per year with lake area during November 2015 as reference) was observed during 2015-2023.

Similarly, spatio-temporal changes in Gongzhangcuo glacial lake mapped using LISS-IV data of eight years (2015-2023) are shown in Figures 6.b and 7. Figure 6.b clearly indicate that Gongzhangcuo glacial lake has major expansion towards its upper part and towards its northern bank. Lake has also expanded towards its tail creating geomorphological features (island and peninsulas) at the lower part. The area of Gongzhangcuo glacial lake has increased from 0.33 km^2 during November 2015 to ~0.5 km^2 during November 2023. The Gongzhangcuo glacial lake has expanded by 0.18 km^2 with are annual expansion rate of 0.022 km^2/year. Though the absolute expansion rate of Gongzhangcuo glacial lake appears to the low, however, it is noteworthy that the lake is expanding at a rate of 6.7 % per year w.r.t. lake area during November 2015 as reference. The expansion rate of Gongzhangcuo glacial lake is very high and alarming. In just eight years the lake has expanded by 53.57%, this might be due to the sever impact of rising temperature in the region. However, detailed investigation is needed to affirm the exact causative factors for this fast rate of lake expansion.

Monitoring the Glacier Retreat using LISS-IV data

In case of all three glacial lakes selected for this study, the lakes are fed by terminus glacier and the major expansion of all three lakes was observed in the upper part of the lakes, due to the retreating glaciers. Globally, the rate of retreat of glacier is linked to the glacier health. To monitor the retreat of associated glaciers (Chubda Glacier, Bailangcuo Glacier and Gongzhangcuo Glacier) of selected glacial lakes, the LISS-IV data of end of ablation period, the most preferred period of mapping the glacier boundary, was used. In the present study, the front of all three glaciers were mapped using visual interpretation technique. The temporal change in front of each glacier are shown in Figures 8, 9 and 10. It is clear from these figures and the results of glacial lake mapping that all three glaciers are retreating. To estimate the rate of retreat of each glacier the change in glacier front with respect to time was estimated. Three points were identified on the front of each glacier and the change in position of these points on the glacier front along the major axis of glacier were measured from their position during November 2015 to November 2023. The results of this analysis are presented in Table 2.

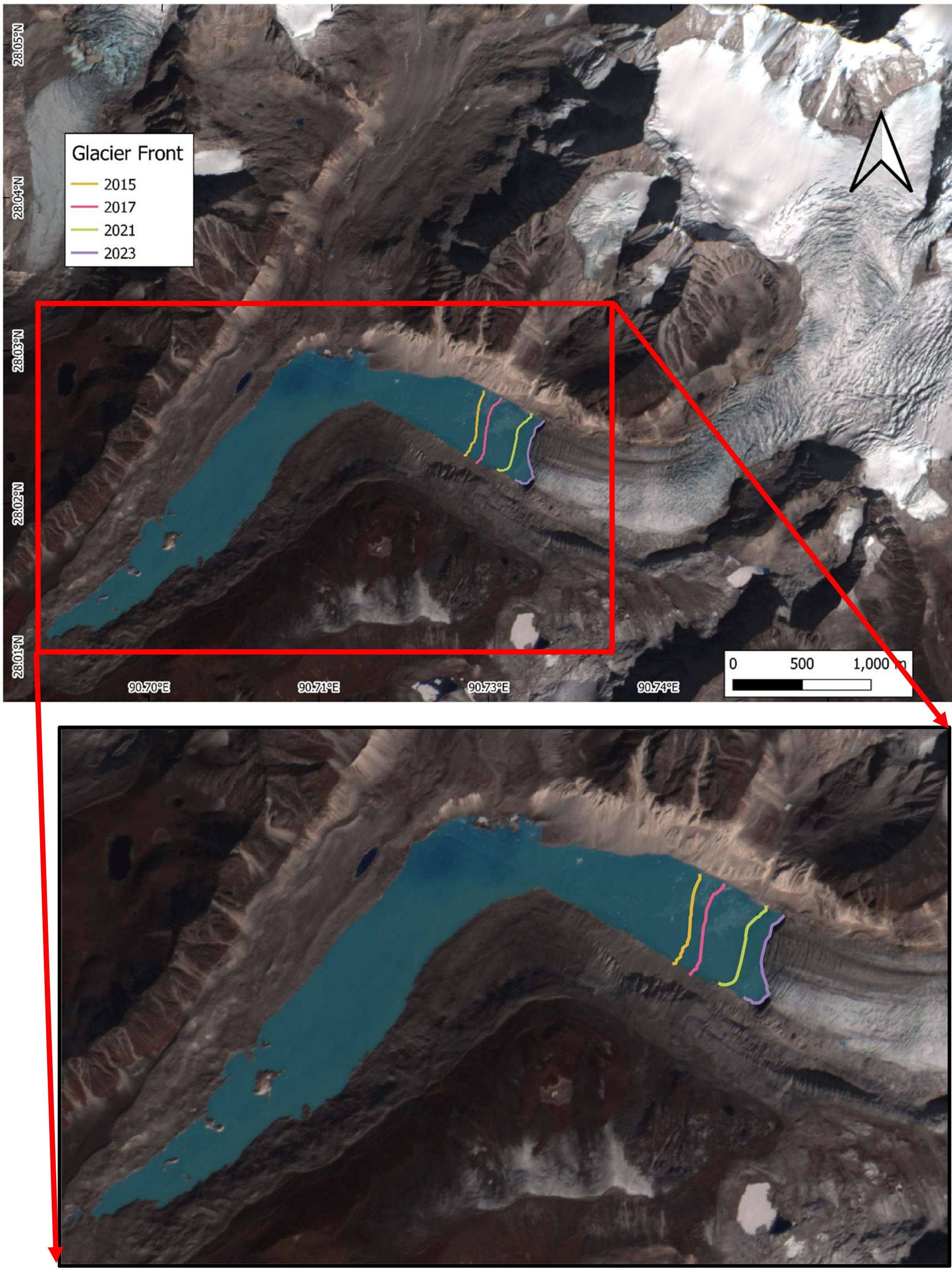

Figure 8. Retreat of Chubda Glacier front mapped using LISS-IV data from November 2015 to November 2023

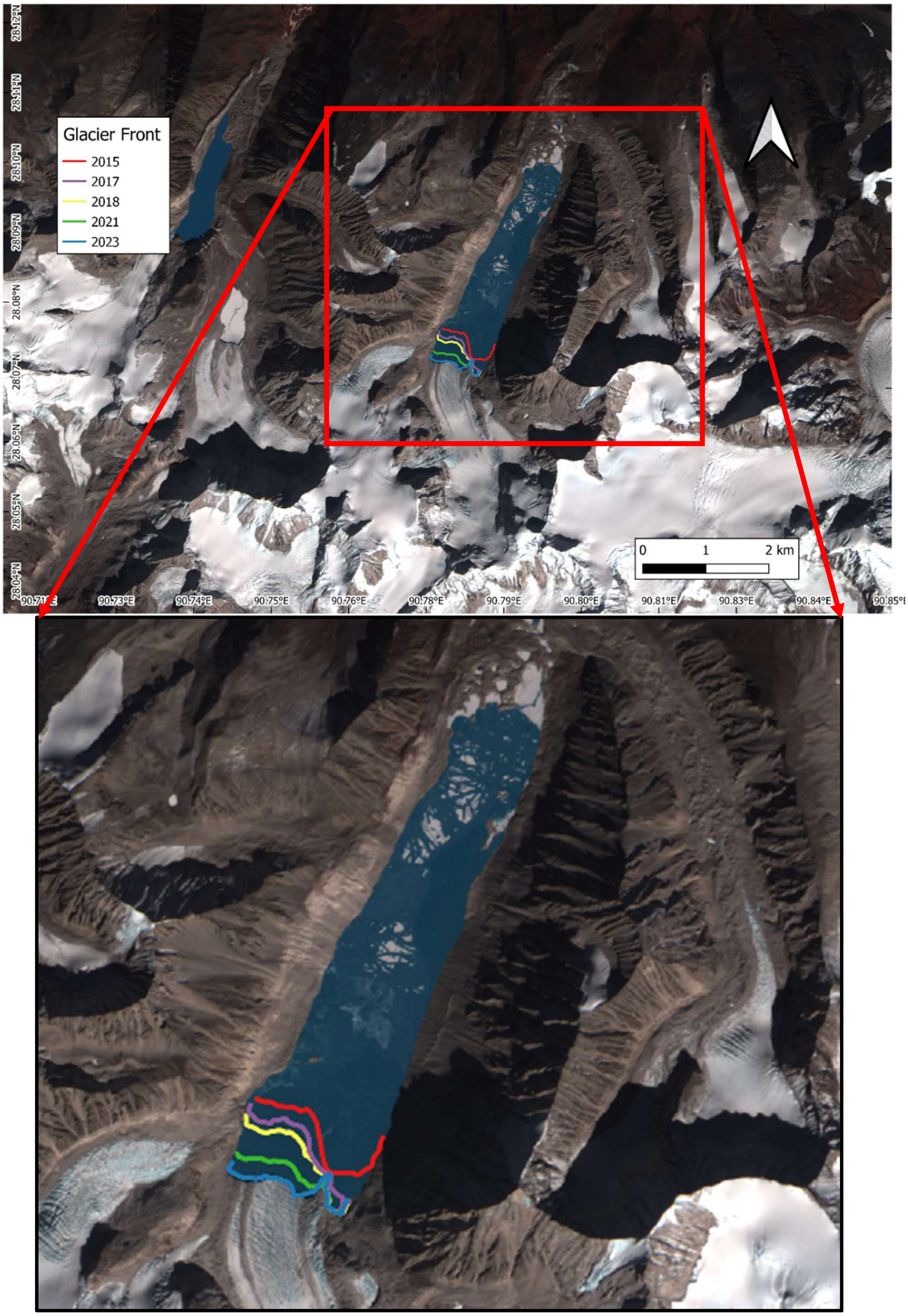

Figure 9. Retreat of Bailangcuo Glacier front mapped using LISS-IV data from November 2015 to November 2023

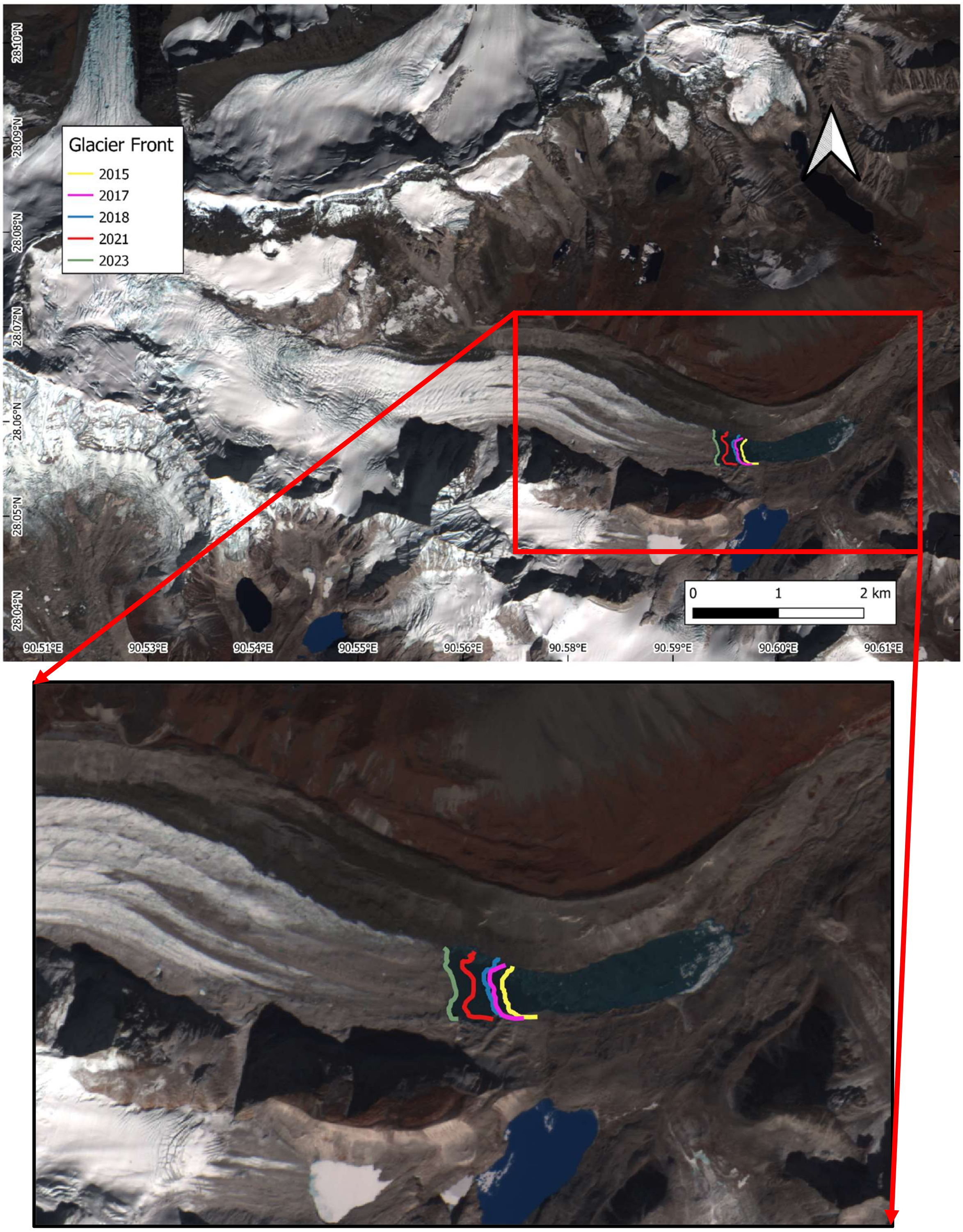

Figure 10. Retreat of Gongzhangcuo Glacier front mapped using LISS-IV data from November 2015 to November 2023

Table 2: Retreat of Glacier Front measured using LISS-IV data and estimated annual rate of retreat.

Glacier Front	Remote sensing based measured retreat 2015-2023 (m)				Rate of Retreat (m/year)
	L-1	L- 2	L- 3	Average	
Chubda Glacier	469	420	495	461.33	57.67
Bailangcuo Glacier	522	420	272	404.67	50.58
Gongzhangcuo Glacier	345	292	349	328.67	41.08

It can be observed from Figures 8, 9 & 10 and Table 2 that Chubda Glacier front has retreated by around 460 m in November 2023 with respect to its position during November 2015. The average rate of retreat of Chubda Glacier front was observed to be 57.67 m/year. This rate is in close agreement with previous results published for this glacier. Similarly, the fronts of Bailangcuo and Gongzhangcuo glaciers have retreated with 50.68m/year and 41.08m/year in these eight years. These retreat rates are much higher than the average rate of Himalayan glaciers, which is in the range of 20-30m/year. This accelerated rate of glacier retreats and expansion of glacial lakes needs immediate attention of global community.

CONCLUSIONS

The spatio-temporal changes in three Himalayan glacial lakes and their terminus glaciers was mapped using Resourcesat 2/ 2A LISS-IV data. This data is first of its kind (5.8m spatial resolution, multispectral data, having more than two decades of legacy) made freely available for global community. The objective of this study was to highlight the potential of LISS-IV data in mapping and monitoring glacial lakes and glacier health. The long-term and systematic availability of LISS-IV data helped us to overcome the major challenges researchers face in glacial lake and glacier mapping e.g. the cloud cover, cloud shadow, snow cover, frozen lake, etc. The most preferred time for mapping glacial lakes and glacier boundaries is the end-of-ablation period. The LISS-IV scenes were selected from end-of-ablation period from 2015-2023. The semi-automatic approach was implemented for temporal mapping of glacial lakes and visual analysis based approach was followed for mapping the temporal changes in glacier fronts of Chubda, Bailangcuo and Gongzhangcuo Glaciers. The temporal changes in glacial lakes (Chubda Tsho, Bailangcuo and Gongzhangcuo lakes) were mapped at 1:10,000 scale. It was observed that all three lakes have highest expansion towards their upper part. The Chubda Tsho has expanded by 0.29 km^2 in eight years (2015-2023) with average rate of 0.04 km^2/year, which is in tune with previously published results for this lake. The high resolution mapping of glacial lake expansion also has highlighted the topographical control over the expansion of lake, which have no significant expansion towards its southern-bank. This analysis was only made possible by the high resolution mapping of lake, courtesy high resolution of LISS-IV data. Similarly, results were observed in Bailangcuo and Gongzhangcuo lakes which have shown expansion with rate of 0.035 km^2/year and 0.022 km^2/year, respectively. It is noteworthy that though the absolute rate of expansion of Gongzhangcuo lakes is least of all three however, the lake has expanded by 53.57% in last eight years.

These lakes have expanded mainly at expense of retreating glaciers terminating in these lakes. The retreat of these associated glaciers was mapped and quantified using the LISS-IV data. The temporal change in the glacier front was mapped and analyzed over the period of eight years. It was observed that these three glaciers are retreating at rate of 51.67m/year, 50.83 m/year and 41.08m/year, respectively. The highest among these was Chubda glacier (51.67m/year). However, all three glaciers are retreating at much faster rate than the Himalayan average rate of 20-30m/year. This accelerated retreat of the glaciers is contributing to fast expansion of lakes in which these glaciers are terminating. This fast expansion may cause the acceleration of GLOF hazard in the downstream areas.

The study highlights the potential of LISS-IV data in mapping and monitoring of glacial lakes and glacier retreat. The high resolution of LISS-IV data also offers the possibility of in-depth analysis of spatio-temporal changes in glaciers and glacial lakes. Since, 2023 the LISS-IV data is made free for all. The LISS-IV data is available for more than two decades (since 2003) which makes it a most suitable candidate for high resolution glacial lake mapping exercise. The free and open availability of this data also reduces the financial burden from this activity. This initiative of providing free access to high resolution multispectral remote sensing data, by Department of Space, Government of India supports the global efforts towards continuous monitoring of glacial lakes to achieve UN's SDG – 11: Disaster Risk Reduction.

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