Modeling glacial lake outburst flood process chains in Sikkim Himalaya: A EWS framework for two potentially dangerous lakes, India

Presented by:

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Presented at:

Conference of Cryosphere and related hazards in High Mountain Asia in a changing climate
Almaty, Kazakhstan

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Overview of the presentation

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GEOTEST GEOLOGY / GEOTECHNICS / GEOPHYSICS / ENVIRONMENT

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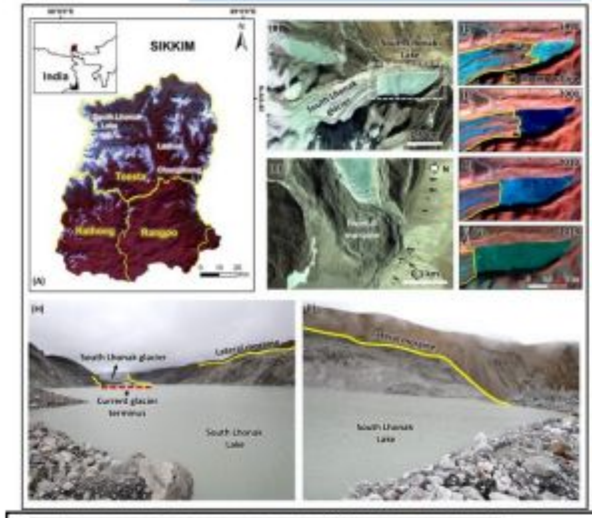
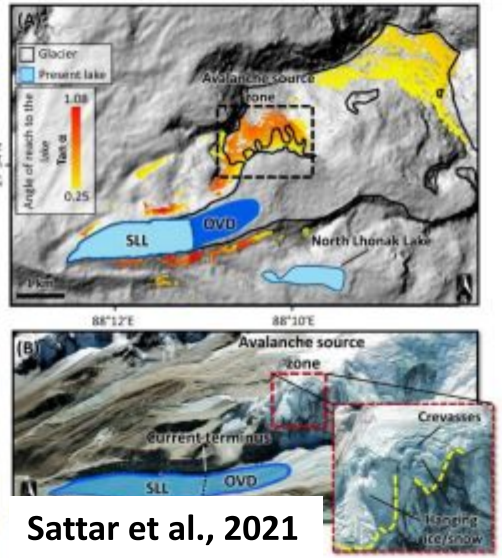
Study area

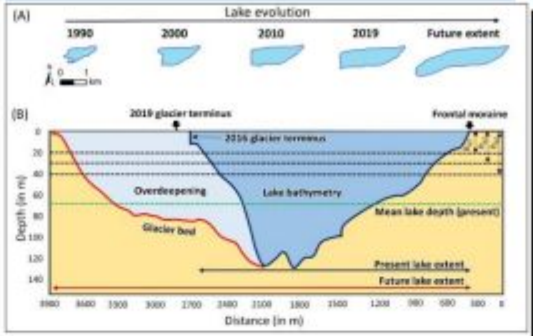


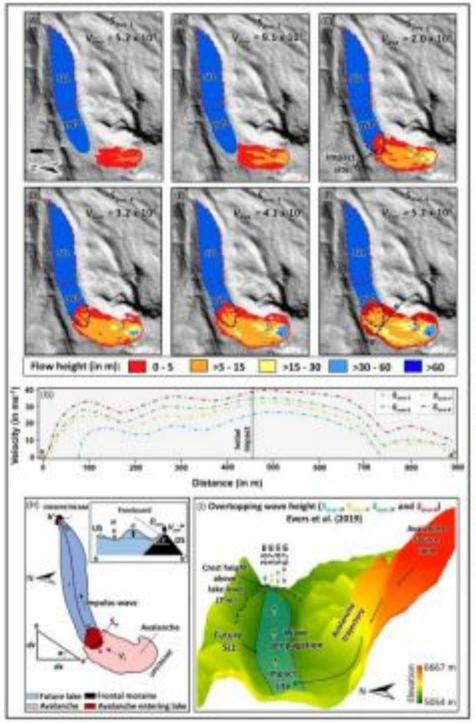


Topographic potential for mass movements shown for the surrounding slopes

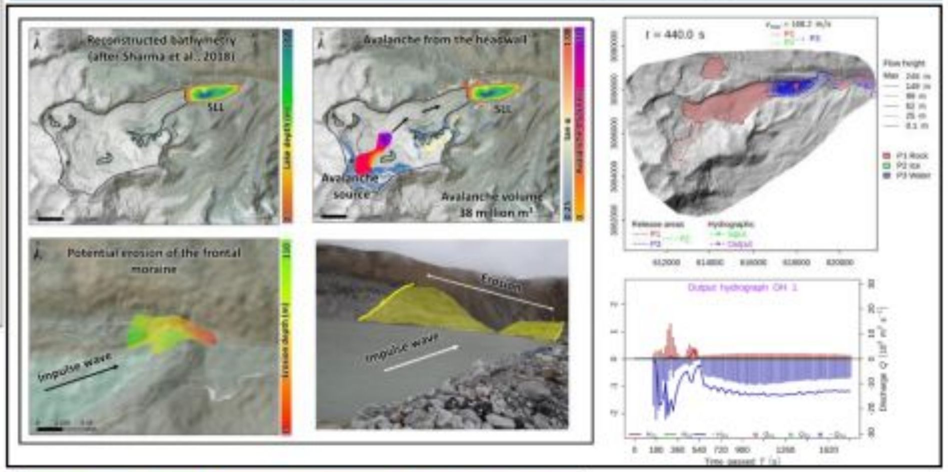
Sattar et al., 2021

Bathymetry

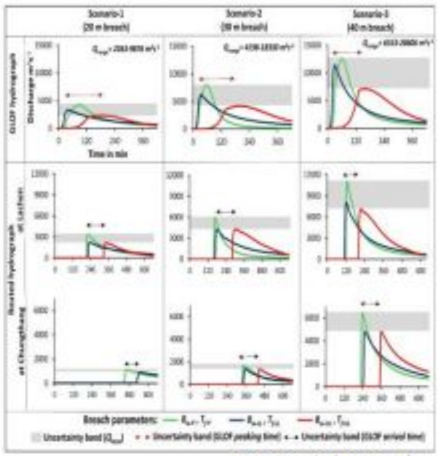




GLOF process chain modeling (r.ava flow)

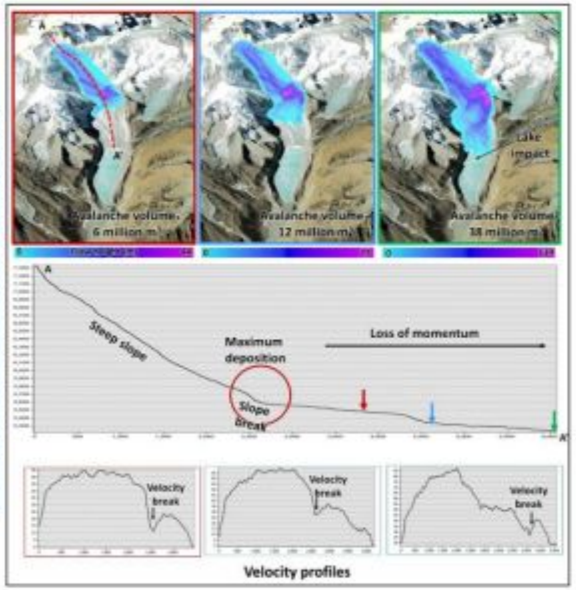


Flood routing (HEC-RAS)

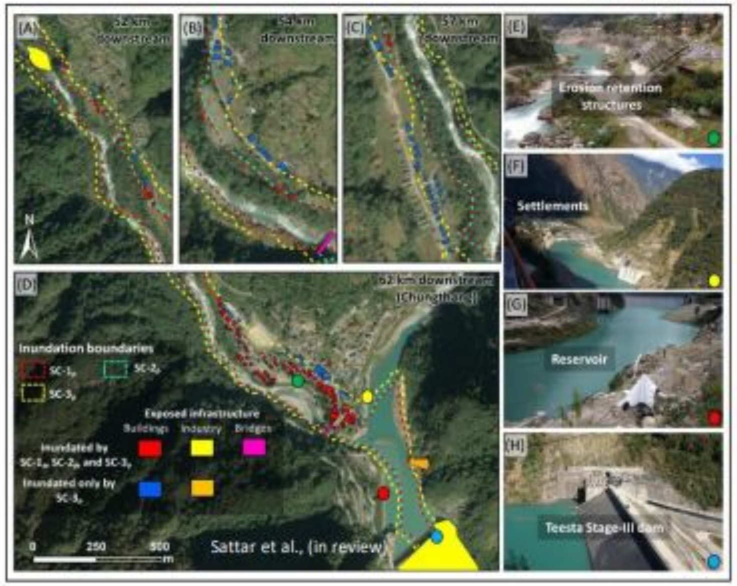


Sattar et al., (in review)

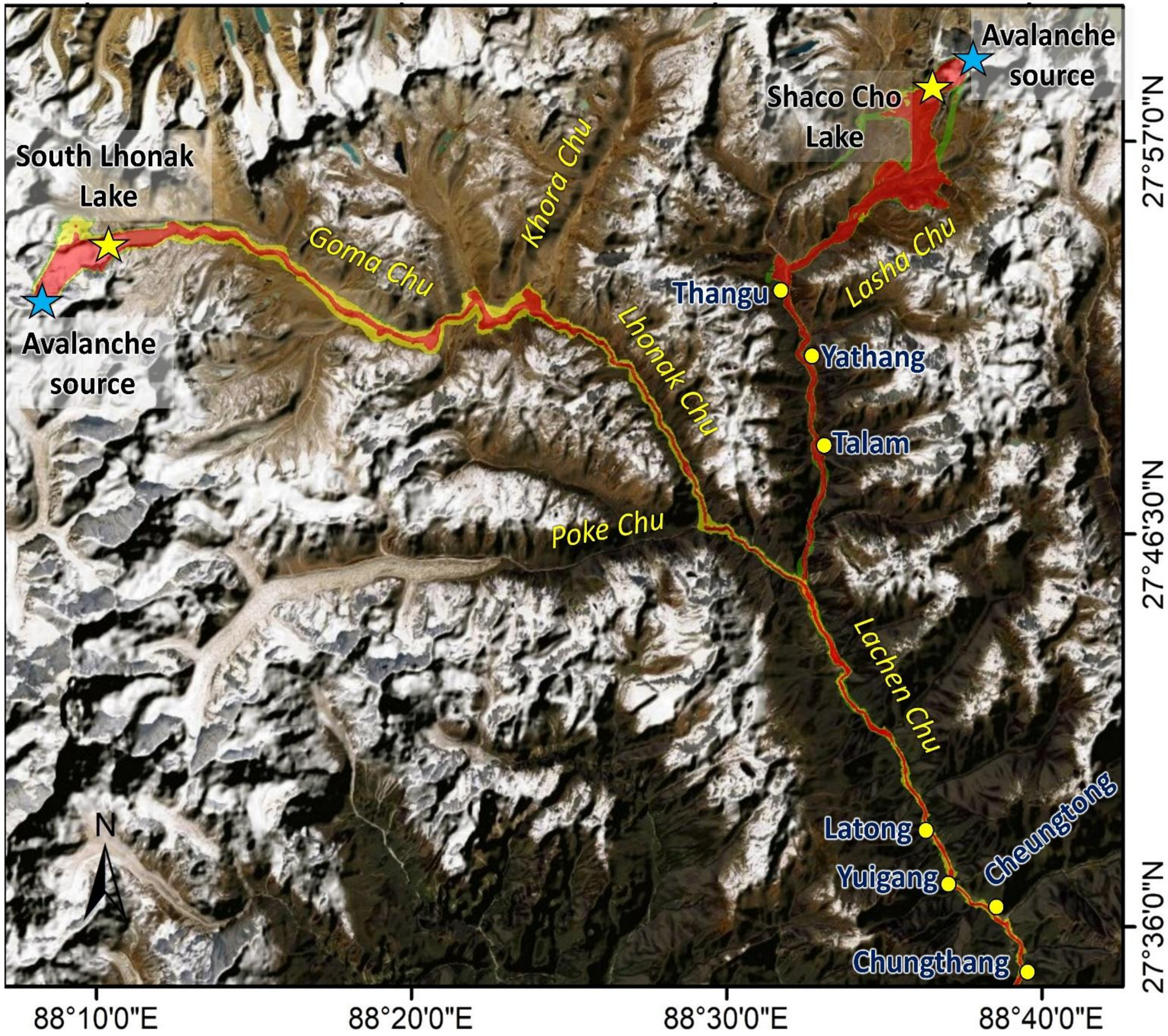
Avalanche modeling (RAMMS)

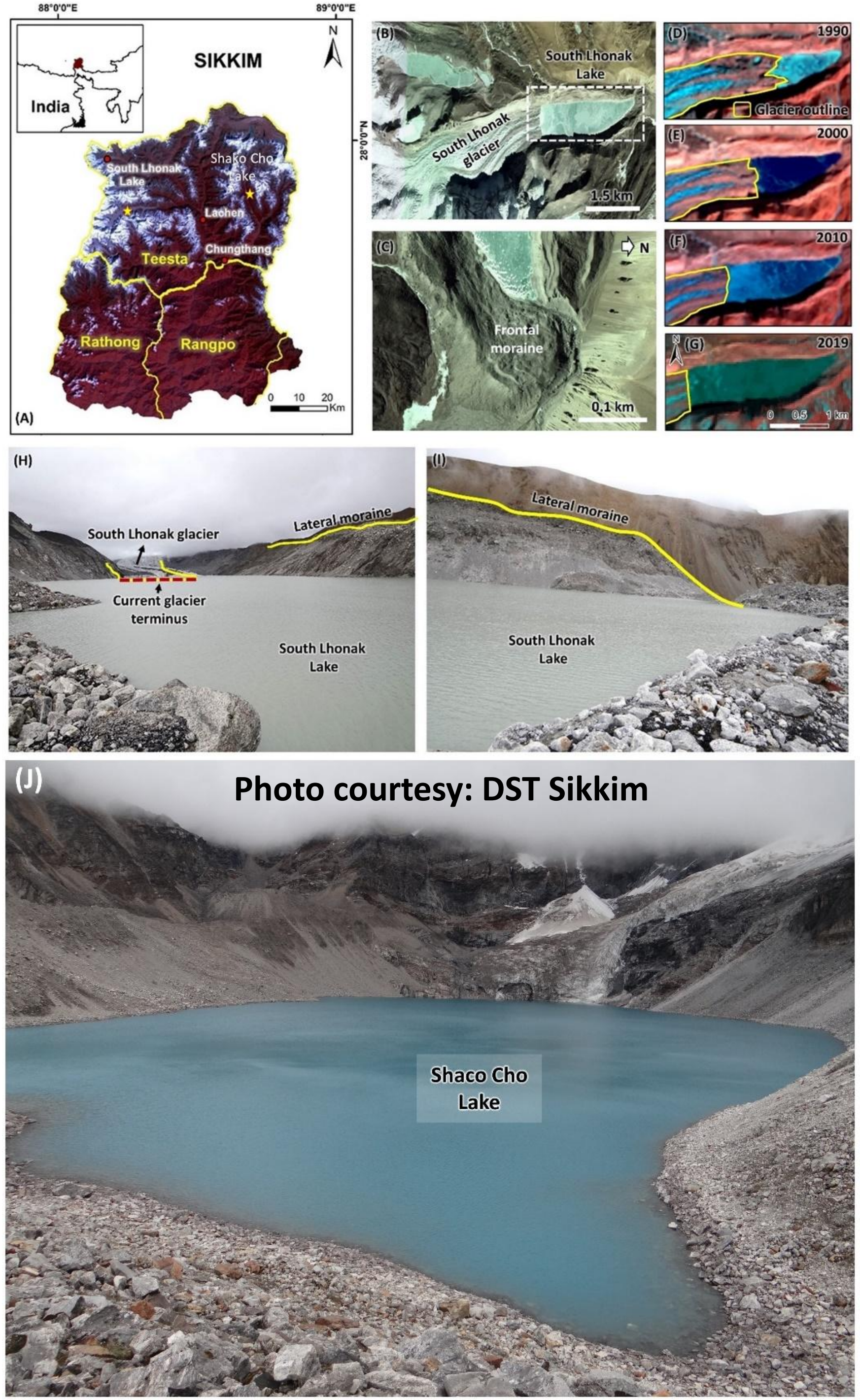


Potential downstream exposure



South Lhonak and the Shako Cho Lake





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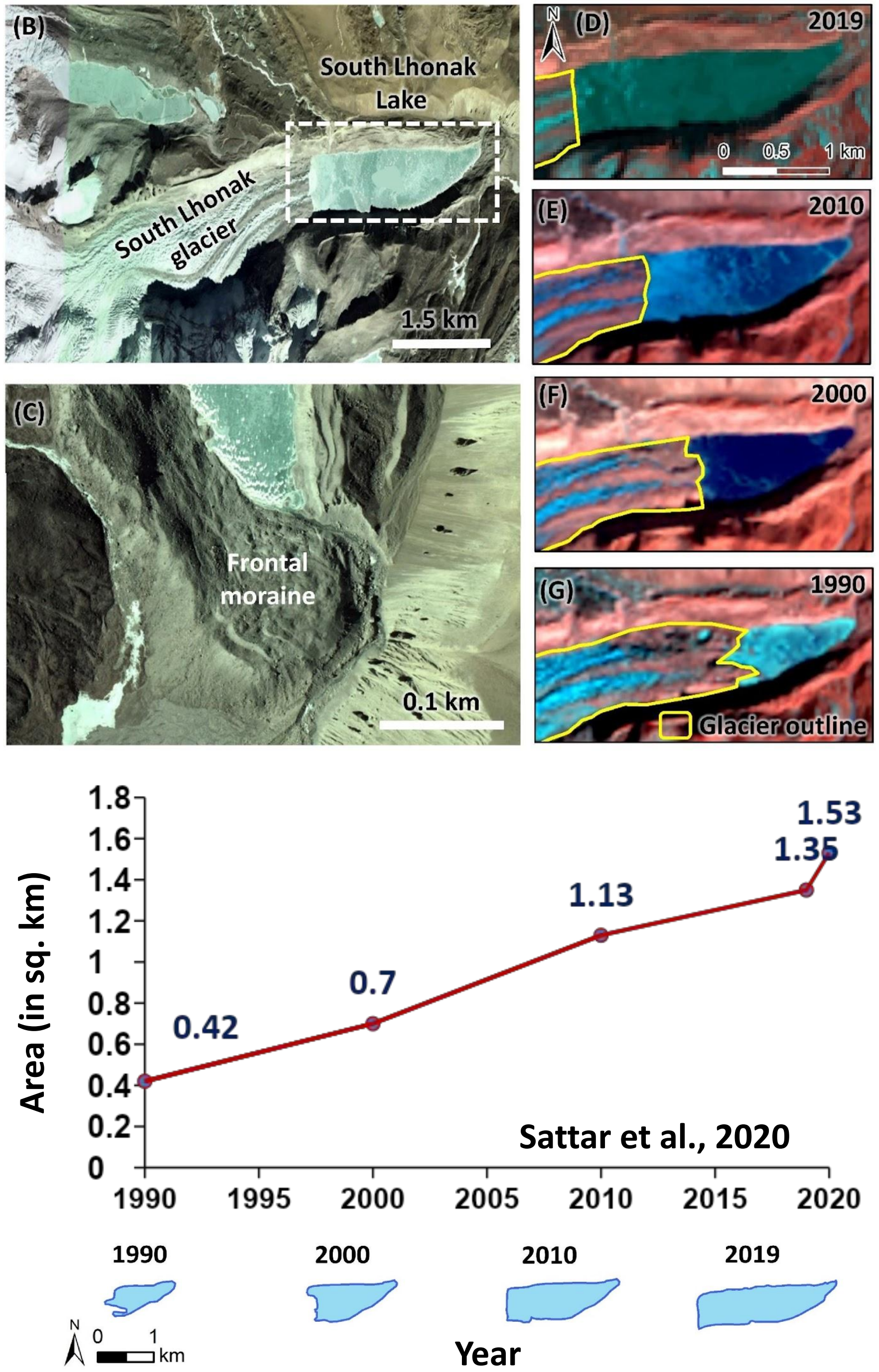
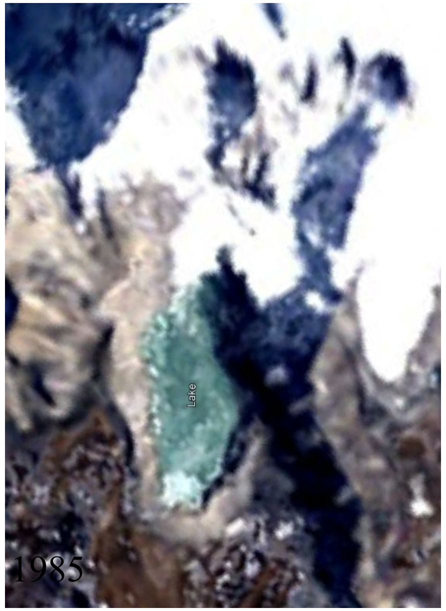
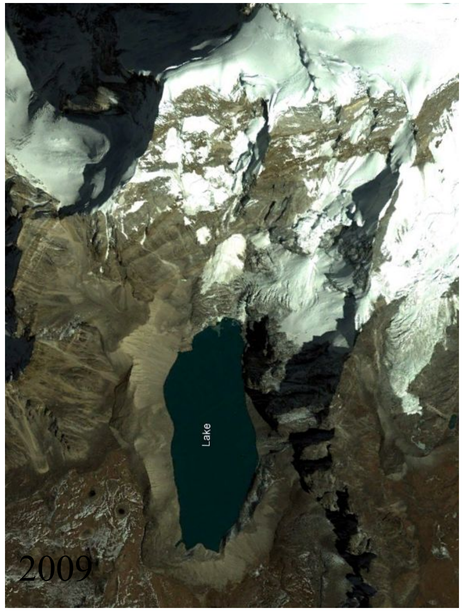
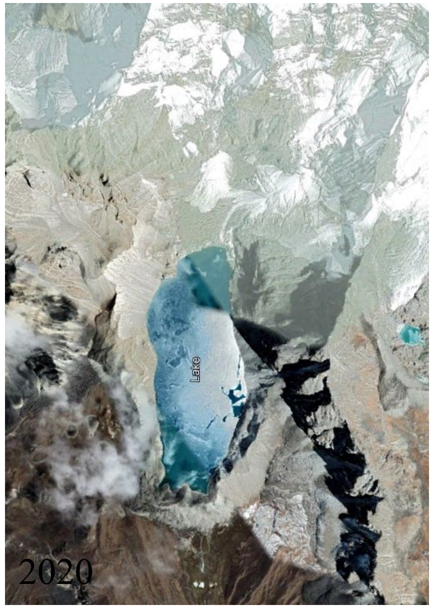


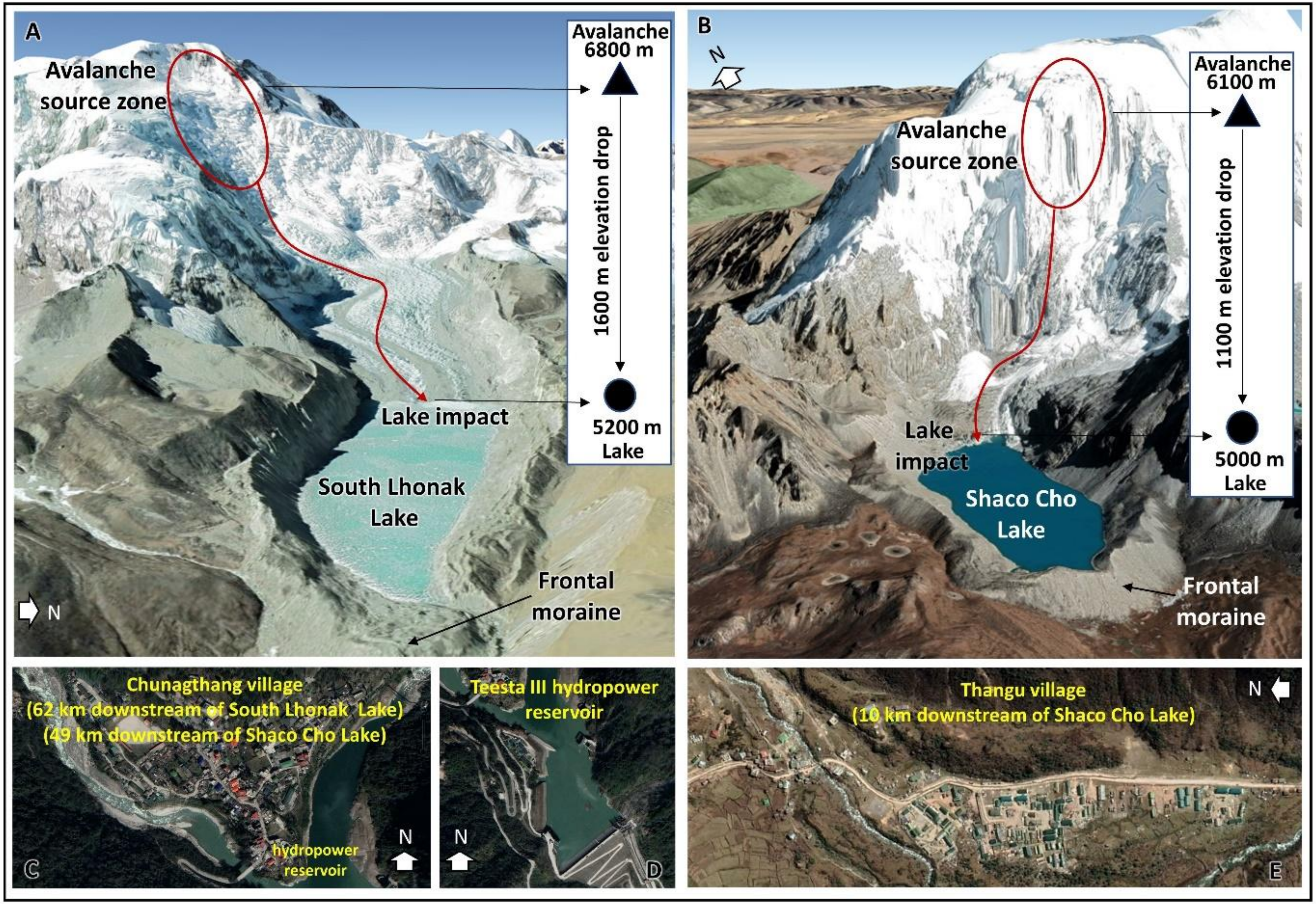
Shako Cho Lake







Why are these lakes dangerous?
Potential GLOF triggers?



South Lhonak Lake- Government advisory and press releases

Science

Glacial lake flood keeps disaster managers on toes in Sikkim

Jyoti Singh | Updated on September 26, 2018

Disasters managers and scientists in Sikkim are keeping a close watch on a lake formed due to melting of glaciers to see how successful is an experiment they began two years back to siphon off excess water from the lake to prevent it from bursting.

TOPICS

- Sikkim
- lakes
- rivers

Central Water Commission

Ministry of Water Resources,

River Development & Ganga Rejuvenation

Advisory Sheet

Glacial Lake Outburst Flood –South Lhonak System in Teesta River Basin

Planning and Development Organisation

March 2015

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Press Release Details

Press Release from Science and Technology Department, Government of Sikkim

Information & Public Relations Department

Date: 13-May-2022

Consultation Workshop on Glacial Lake Outburst Flood Risk for South Lhonak and Shako Cho Lakes in Sikkim

A Consultation Workshop on Glacial Lake Outburst Flood Risk for South Lhonak and Shako Cho Lakes in Sikkim was organised by the Department of Science and Technology (DST), the Government of Sikkim and the Swiss Agency for Development and Cooperation (SDC) on 13 May 2022 at Hotel Yangthang Heritage, Gangtok.

The workshop was conducted in the frame of the project Strengthening Climate Change Adaptation in the Himalayas (SCA-Himalayas) under the chairmanship and co-chairmanship of Ms Sarala Rai, IAS, State Relief Commissioner-cum-Secretary, Land Revenue and Disaster Management Department (LR&DMD) and Shri Bhuwan Pradhan, IFS, Secretary, DST.

The workshop was participated by representatives from Mangan District Administration, State Departments (Sikkim State Disaster Management Authority, LR&DMD, DST, Power, Forest, Mines and Geology, Water Resources), Central organisations (GSI, CWC), ITBP, and Hydel power developers (Teesta Urja, NHPC, Lanco).

Shri. B.P Pradhan outlined the work carried out by the Department of Science and Technology, particularly in glacier and climate studies. He sought the active support and participation of the stakeholders to achieve a successful and exemplary GLOF EWS.

Ms Divya Sharma, Deputy Head of Cooperation, SDC India briefed on the evolution of the SCA Himalayas project. She thanked the stakeholders for their participation and cooperation. She informed me that the project outcomes would be shared with National Disaster Management Authority for further course of action.

Ms Eveline Studer, Senior Regional Advisor on DRR and RR in South Asia, presented the SDC initiatives and projects in India. She also elaborated on the SCA Himalayas project.

Shri D.G Shrestha, Director, DST welcomed the participants and presented the activities carried out by the Department in the South Lhonak Lake and Sakho Cho lakes in Sikkim. He highlighted the South Lhonak lake's increasing size and the urgent need for an Early Warning System (EWS) for these glacial lakes in Sikkim.

Shri. Prabhakar Rai, Director, SSDMA, Government of Sikkim outlined the roles of different stakeholders in the Glacial Lake Outburst Flood (GLOF) and the need for community involvement in such activities.

Mr Christoph Haemmig, Geotest, presented the first-order assessment of GLOF risk for Sikkim and preliminary detailed hazard modelling of South Lhonak lake. He also gave the proposed and planned activities of GLOF risk assessment and EWS for both lakes. This was followed by an open discussion amongst the participants. All stakeholders actively participated and raised their comments, queries and suggestions.

The consultation concluded with a vote of thanks by Ms Ada Lawrence, Technical Expert, Disaster Risk Management, SCA Himalayas.

SIKKIM EXPRESS

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Early warning system to be installed in South Lhonak Lake

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Lhonak Glacier (Sikkim Region, India)

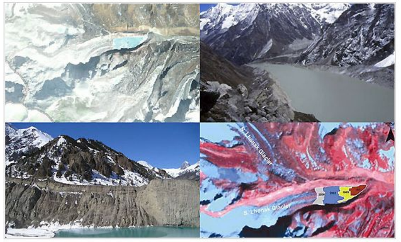
Quit

Lhonak Glacier (Sikkim Region, India)

« Back

Bangalore, February 2013 (From: Zee News) - A satellite-based study has indicated that a huge glacial lake has formed atop the Himalayas in Sikkim with a "very high" potential for it to burst and create devastation downstream. Analysis of satellite data has revealed that the lake has formed at the snout of South Lhonak glacier that is about 7,000 meters high on the mountain in the north-eastern state. The lake, bounded only by loose soil and debris, could cause havoc downstream if it ruptures, according to scientists at the National Remote Sensing Centre (NRSC) in Hyderabad. In a report published in the latest issue of the journal Current Science, NRSC researchers Babu Govindha Raj and co-workers say the glacial lake is about 630 meters wide and 20 meters deep. It covers an area of 98.7 hectares and contains 19.7 billion litres of water. A sudden outburst "can create devastating floods downstream," they warn, adding that the probability of this happening "is very high". They however note this is only their preliminary assessment and more field studies are required to confirm the hazardous potential of this high altitude lake. Data from the American Landsat satellite were used to estimate the size of the shrinking Lhonak glacier and the growth of the glacial lake at different times between 1962 and 2008. Based on this study the scientists estimate that the Lhonak glacier had receded 1.9 km between 1962 and 2008. The glacial lake that was initially a small body of water in 1962 grew in size with accumulation of melt water. The NRSC scientists say that the lake is still attached to the snout of the glacier but is expanding in area due to the glacier retreat. "The rate of growth of the lake indicates possible developments of the hazard situation," the report says. As Himalayan glaciers are retreating fast, it is necessary to make an inventory of glacial lakes and set up an early warning system for lake outburst floods in vulnerable areas, they say.

Area of interest



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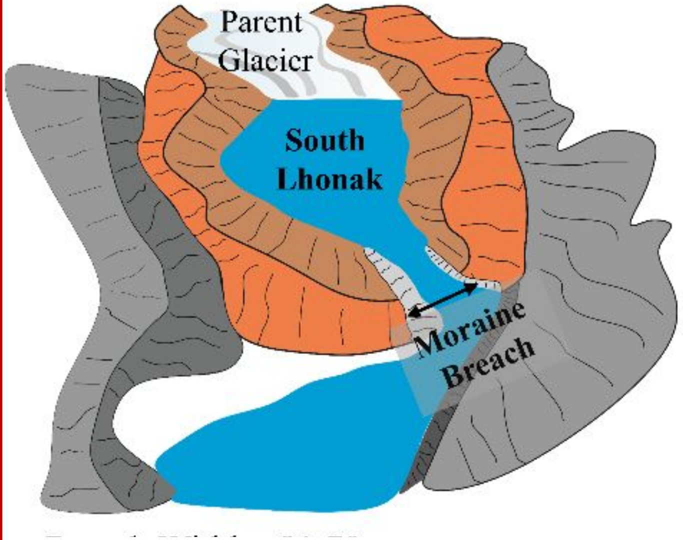
1. Overtopping and piping failure of the frontal moraine-Present GLOF hazard-GLOF exposure



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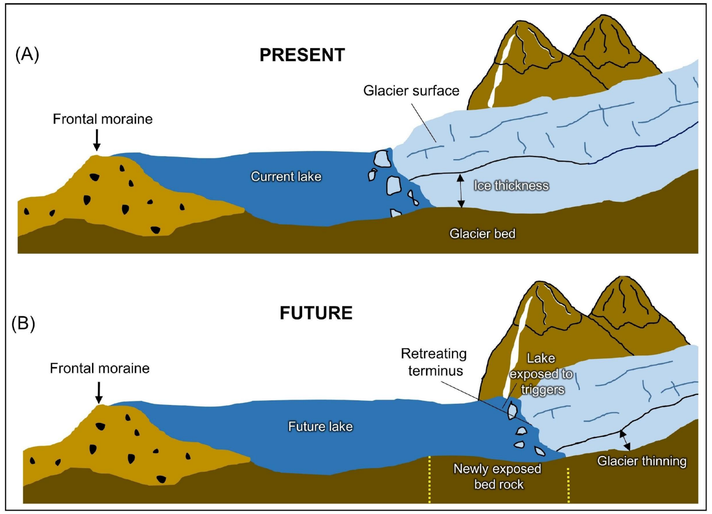
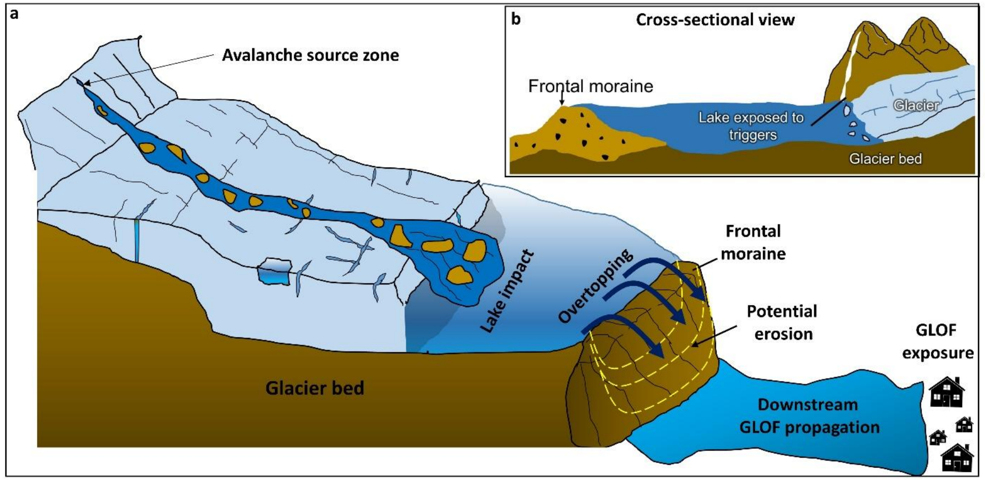
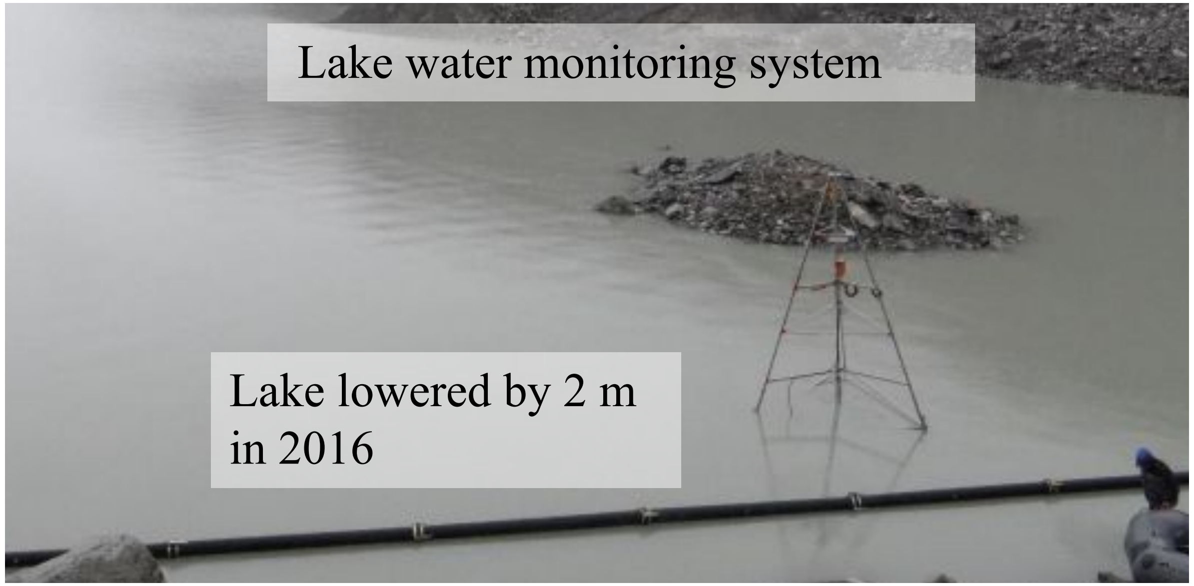
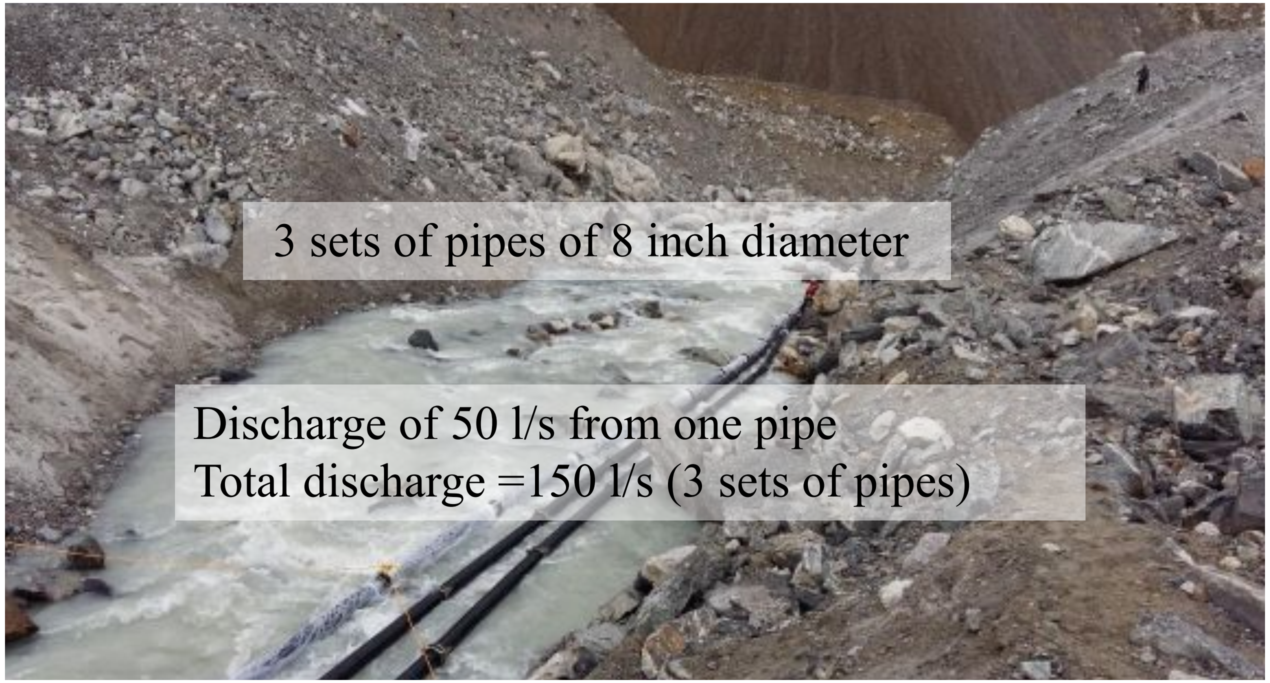


3. GLOF process chain-GLOF triggers-GLOF exposure



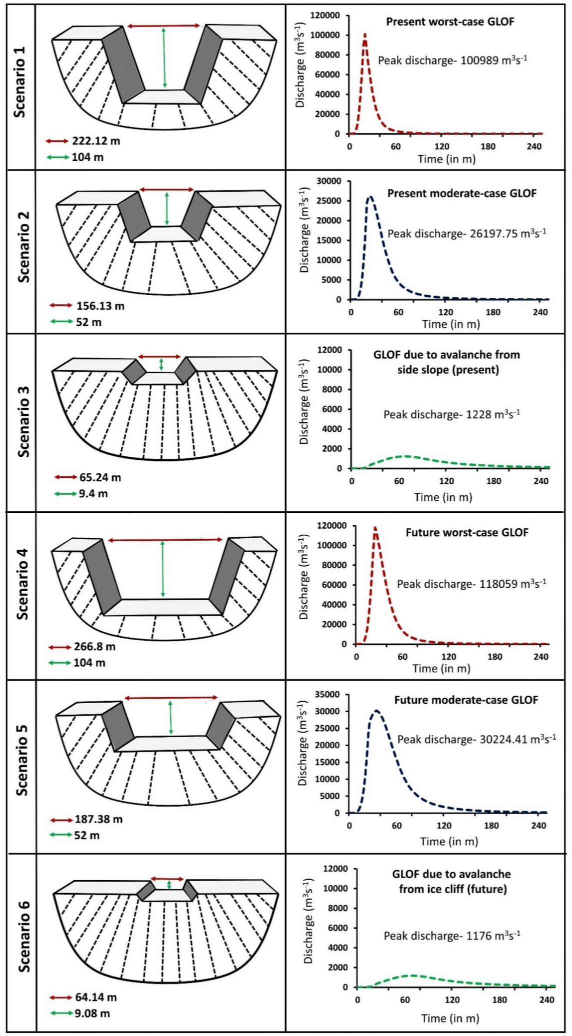
Previous work by DST Sikkim to reduce the hazard potential of SLL



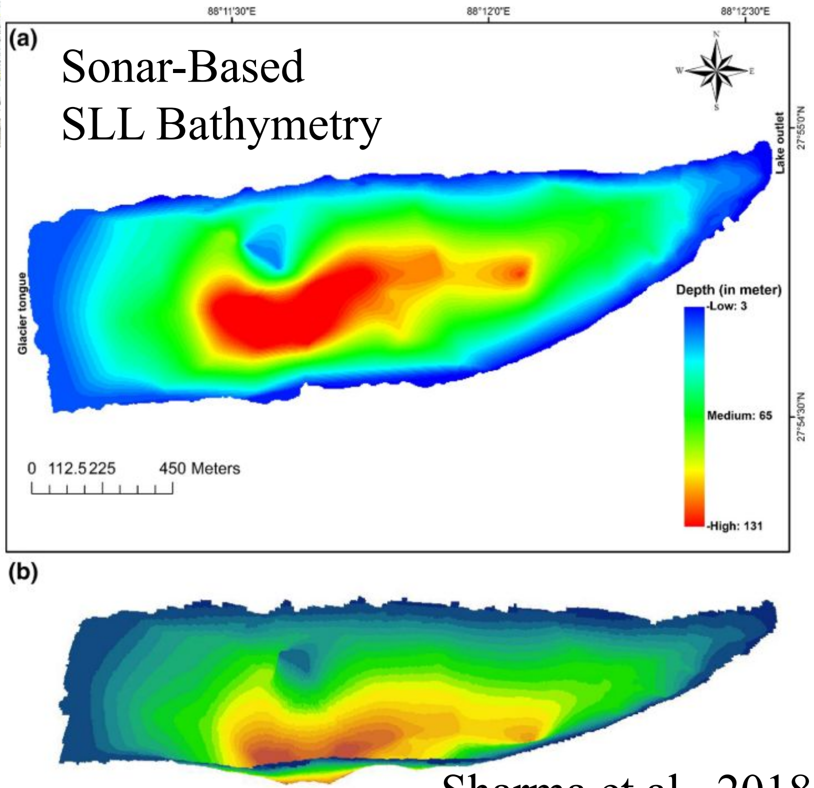


Source: http://dstsikkim.gov.in/Adv/South%20Lhonak%20Lake%20expedition_tech%20report.pdf

GLOF HAZARD OF THE SOUTH LHONAK LAKE

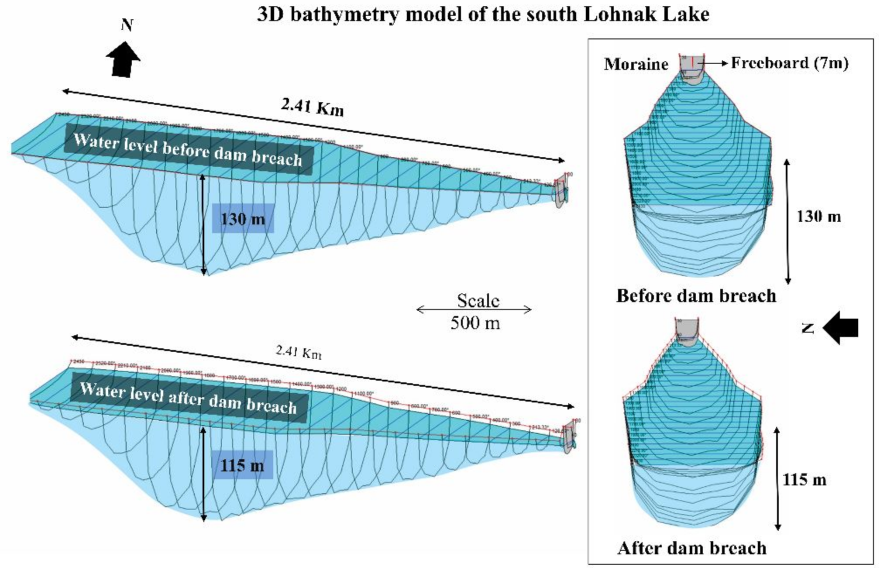


Sattar et al., 2021
Journal of Hydrology



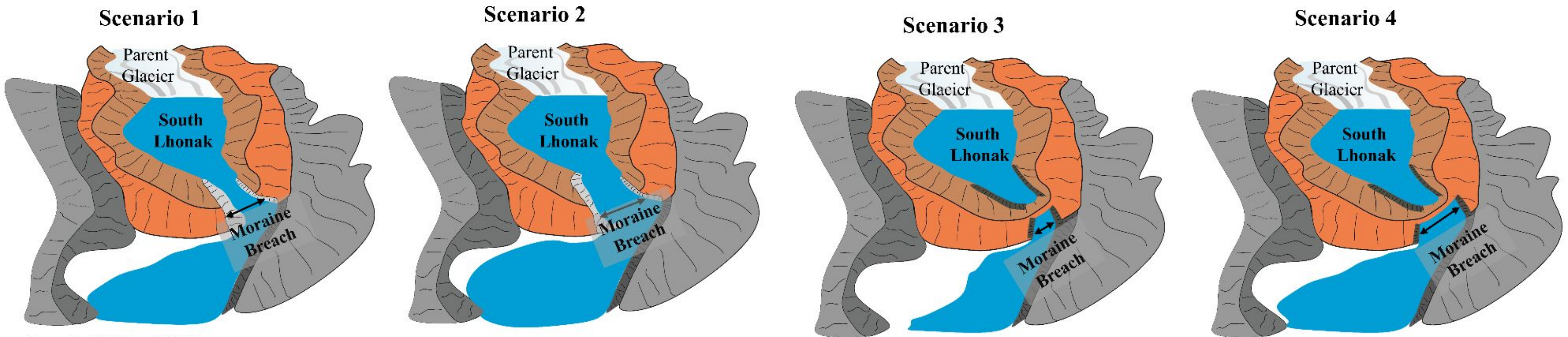
Sharma et al., 2018

3D GIS based South Lhonak lake model



Total Volume=65.81 ± 2.5 million m^3

BREACH SCENERIOS



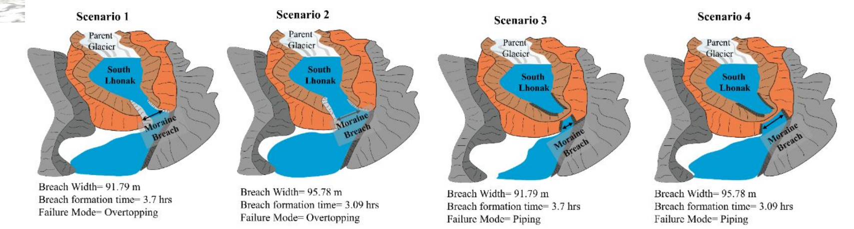
Scenario 1: Breach Width= 91.79 m
Breach formation time= 3.7 hrs
Failure Mode= Overtopping

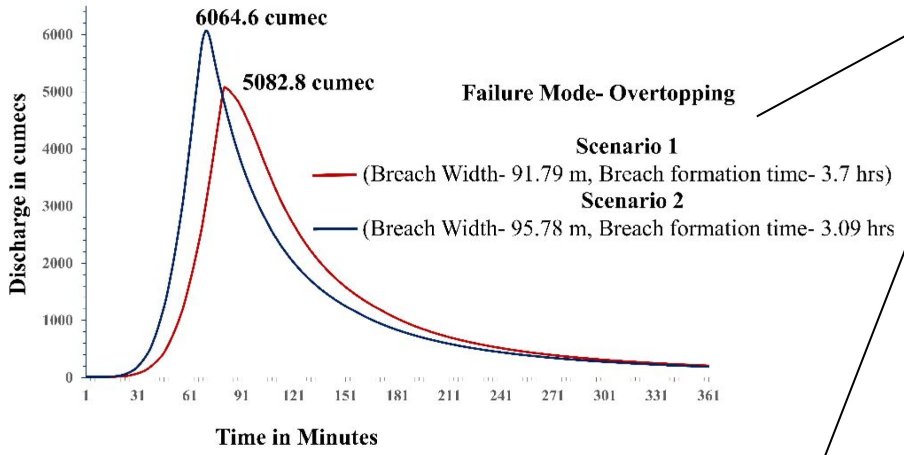
Scenario 2: Breach Width= 95.78 m
Breach formation time= 3.09 hrs
Failure Mode= Overtopping

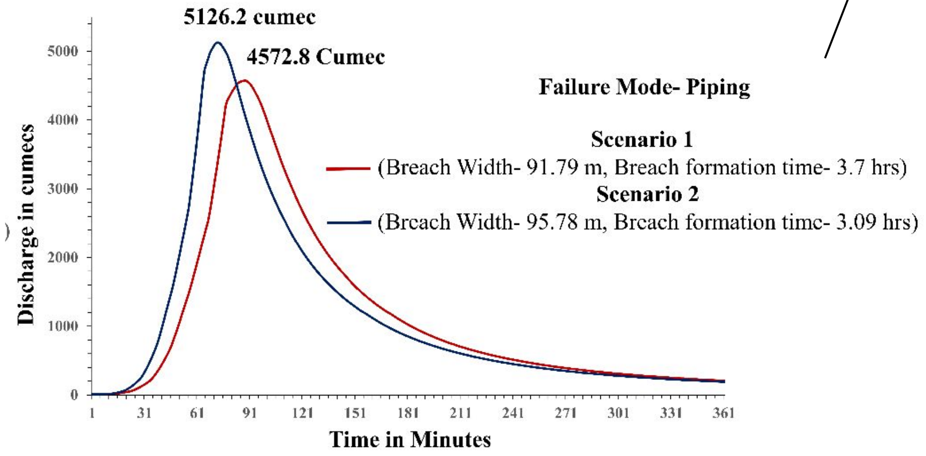
Scenario 3: Breach Width= 91.79 m
Breach formation time= 3.7 hrs
Failure Mode= Piping

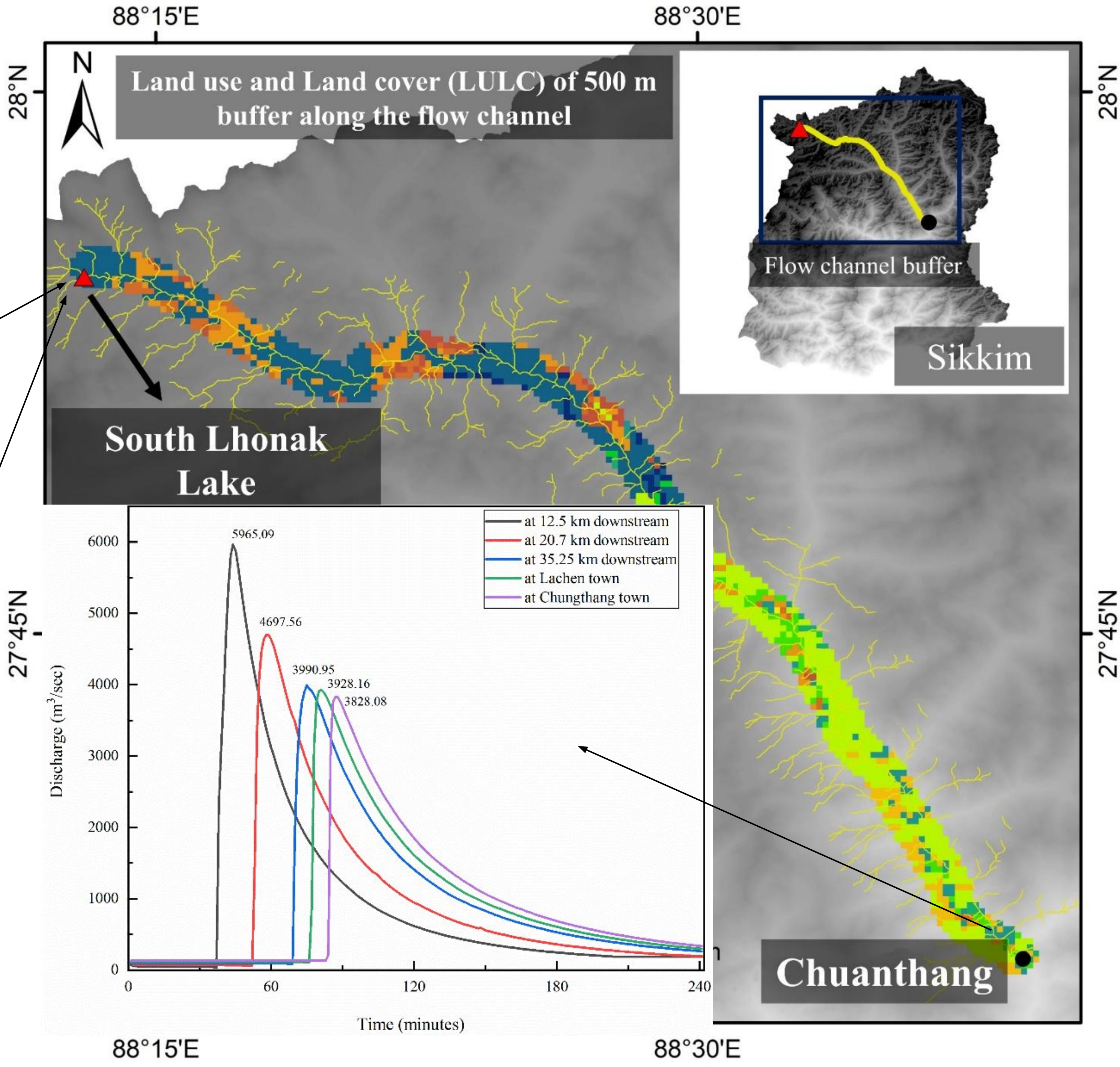
Scenario 4: Breach Width= 95.78 m
Breach formation time= 3.09 hrs
Failure Mode= Piping

1-D hydraulic routing of the SLL GLOF









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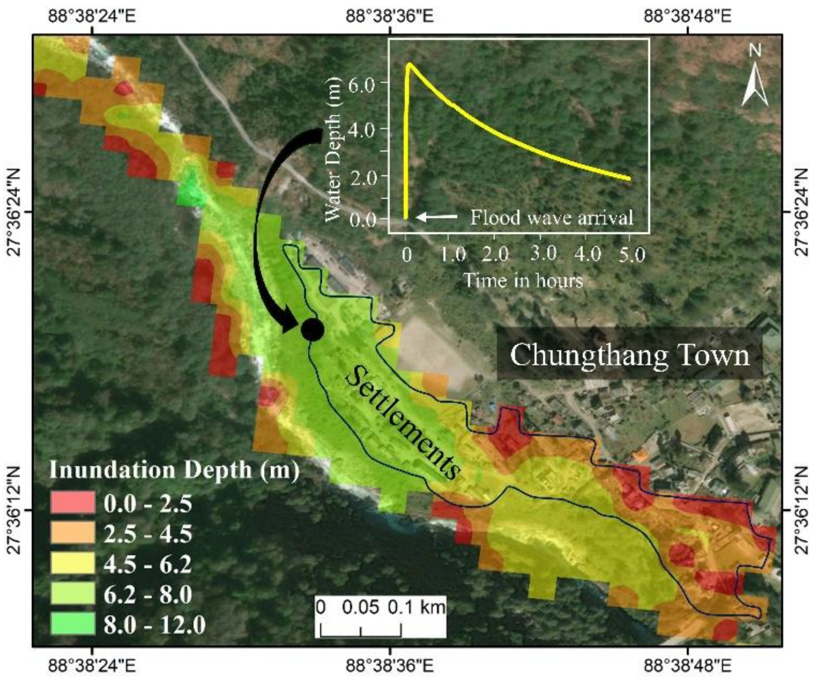
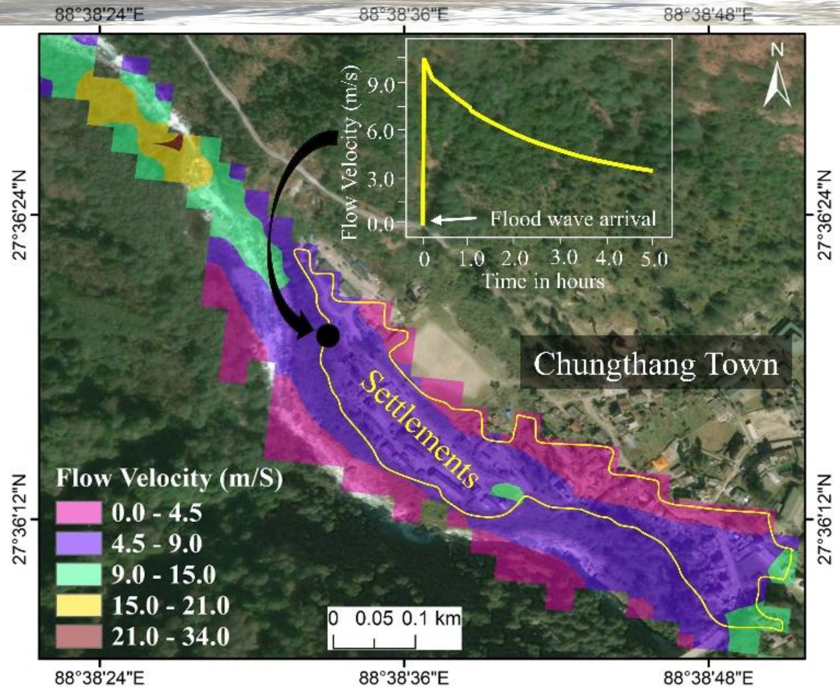
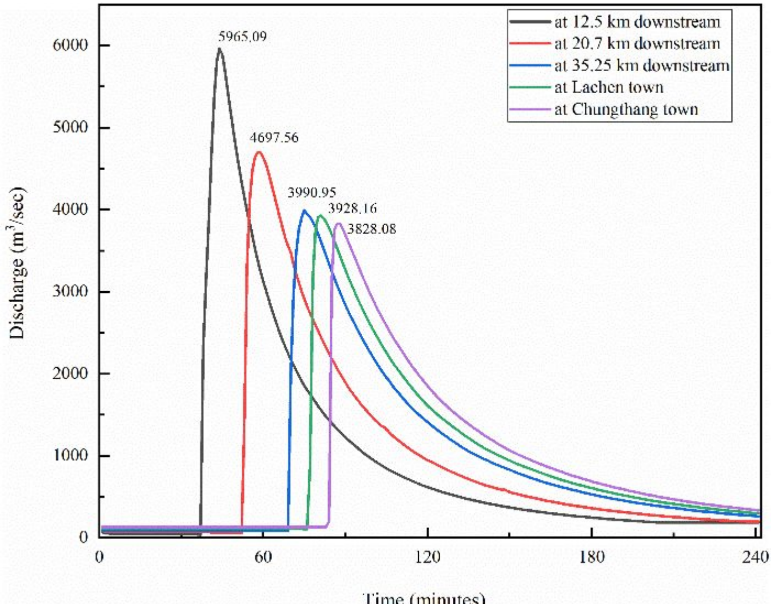
IMPACT OF THE SLL GLOF AT ‘CHUNGTHANG and TEESTA III HYDROPOWER STATION







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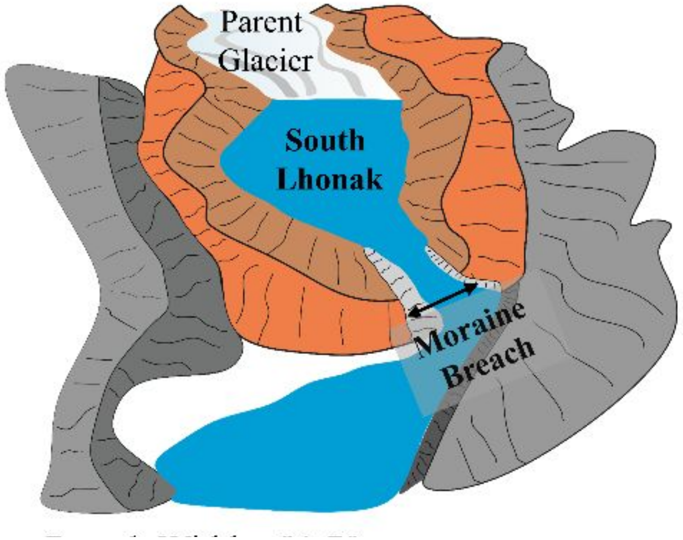

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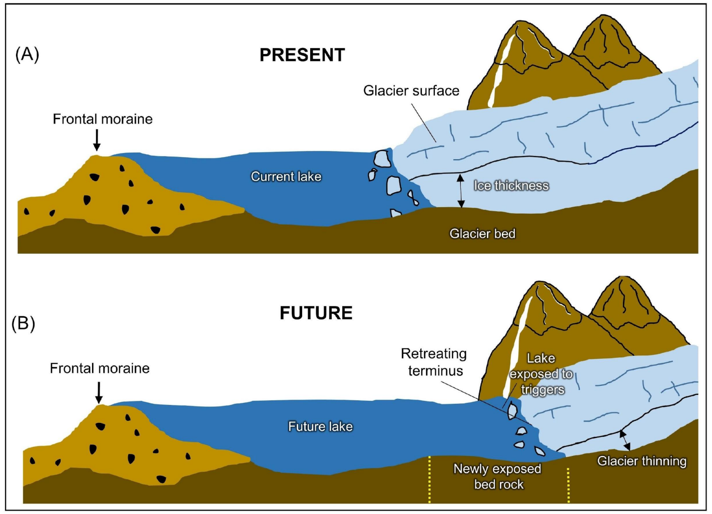
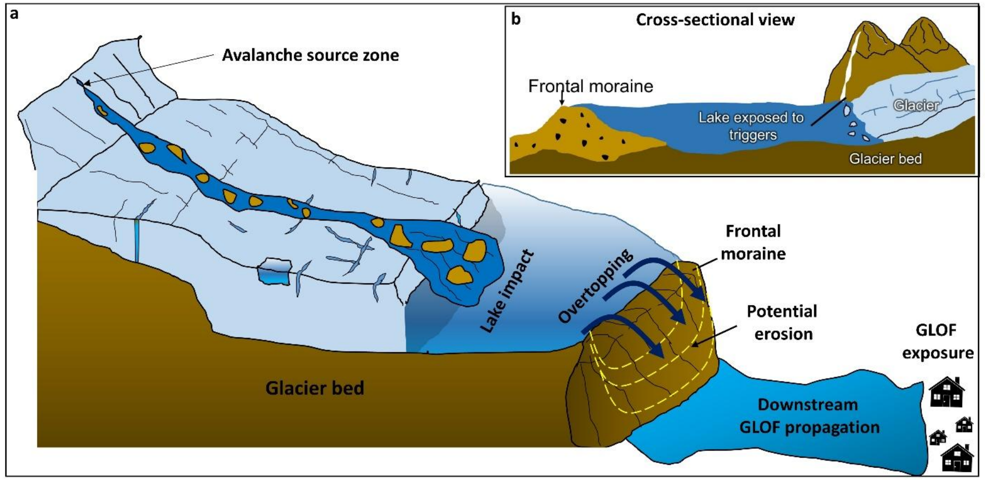
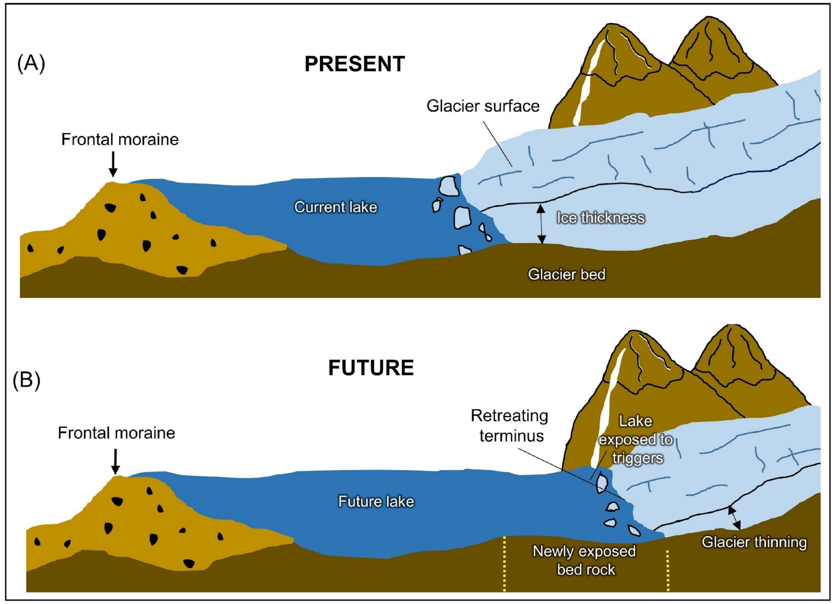


3. GLOF process chain-GLOF triggers-GLOF exposure

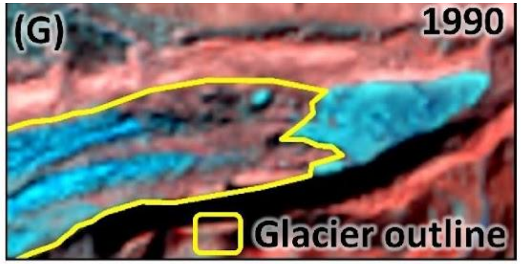


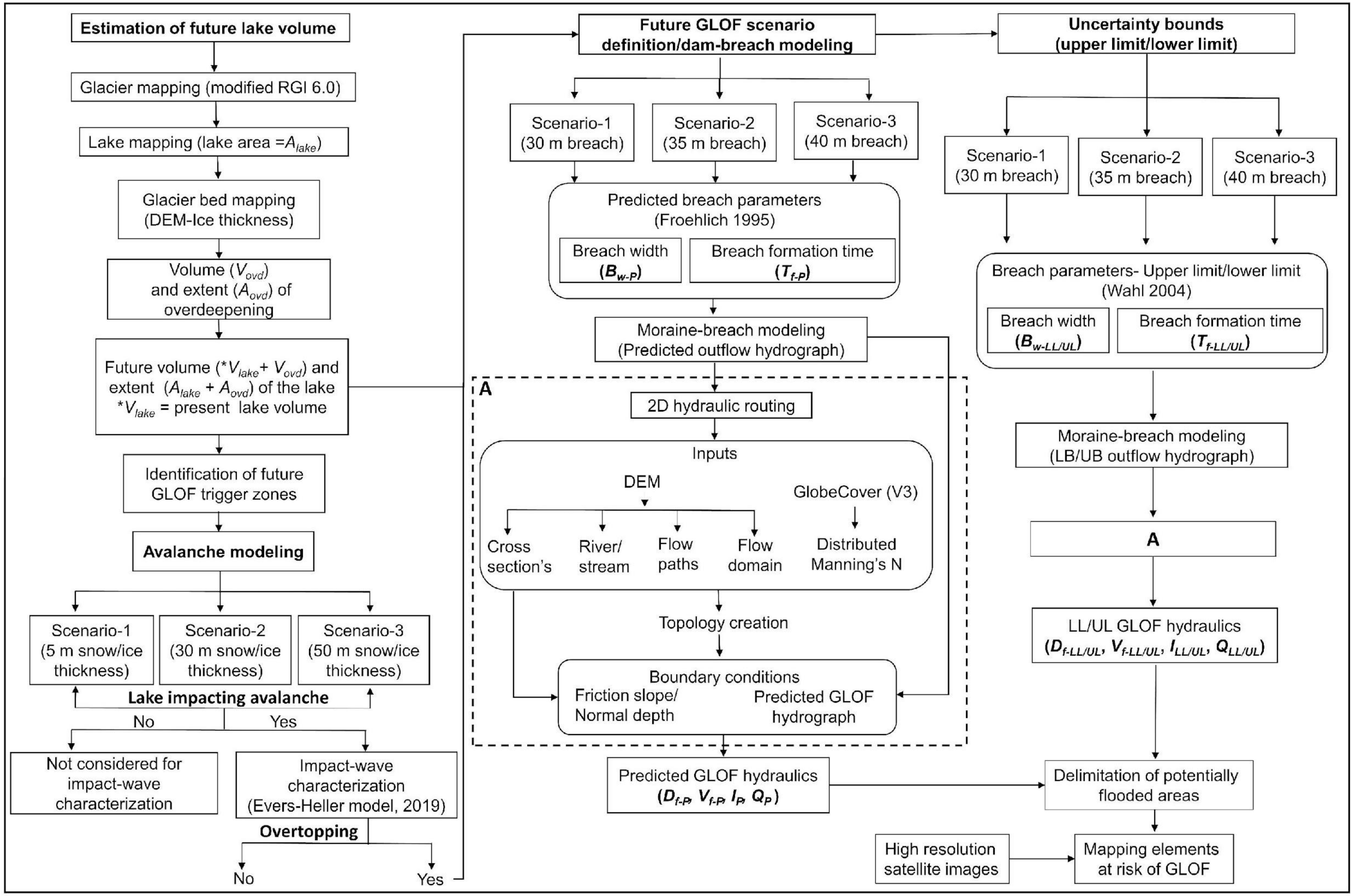
Glacial Lake Outburst Flood (GLOF) triggers and future hazard of the South Lhonak Lake, Sikkim

Sattar et al., 2020 Geomorphology

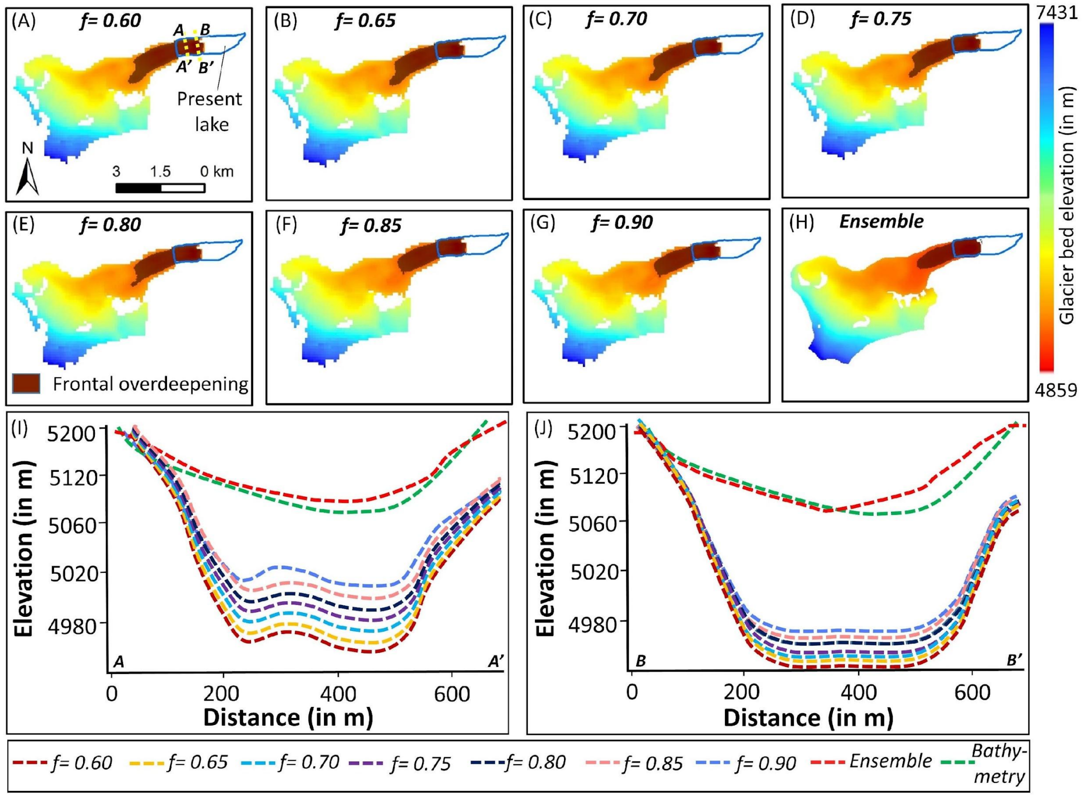


Schematic diagram showing (A) a proglacial lake system at present; (B) lake grows as the glacier bed is exposed in the future.





CALCULATING FUTURE LAKE VOLUME

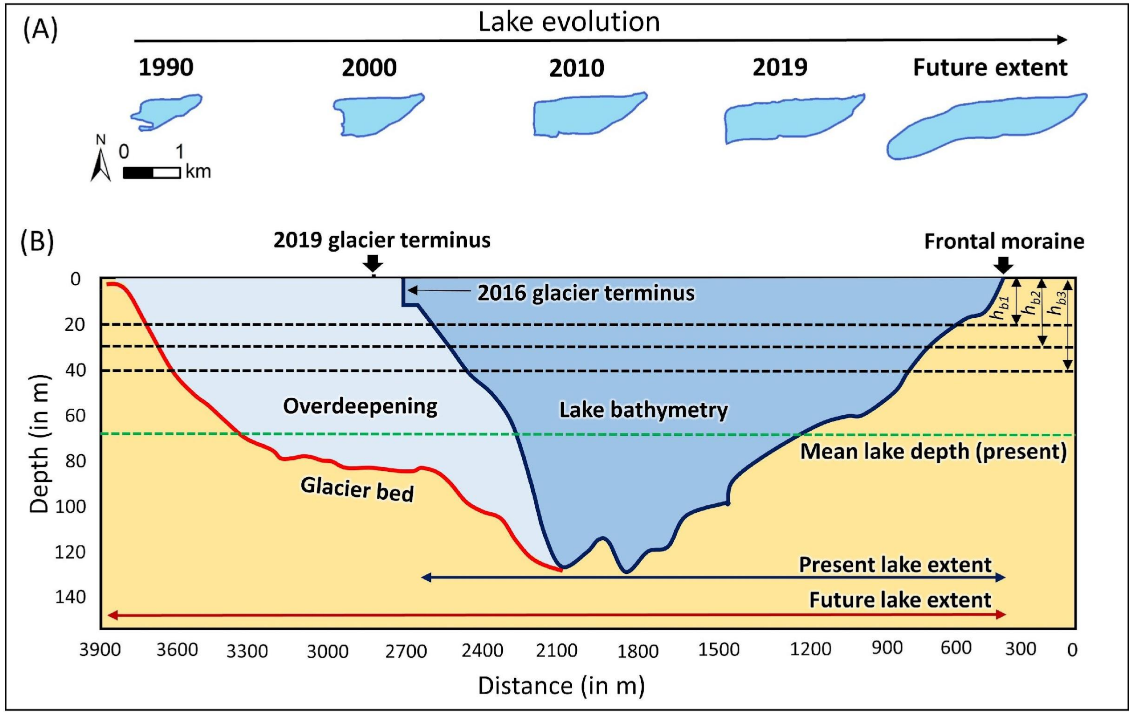


Spatially distributed modeled glacier bed for different values of 'f' using GlabTop (A-G);Ensemble (H) (Farinotti et al., 2019); (I-J) cross-sectional profiles of glacier beds along AA' and BB'.

$$\tau b = f \rho g H \sin \alpha.$$

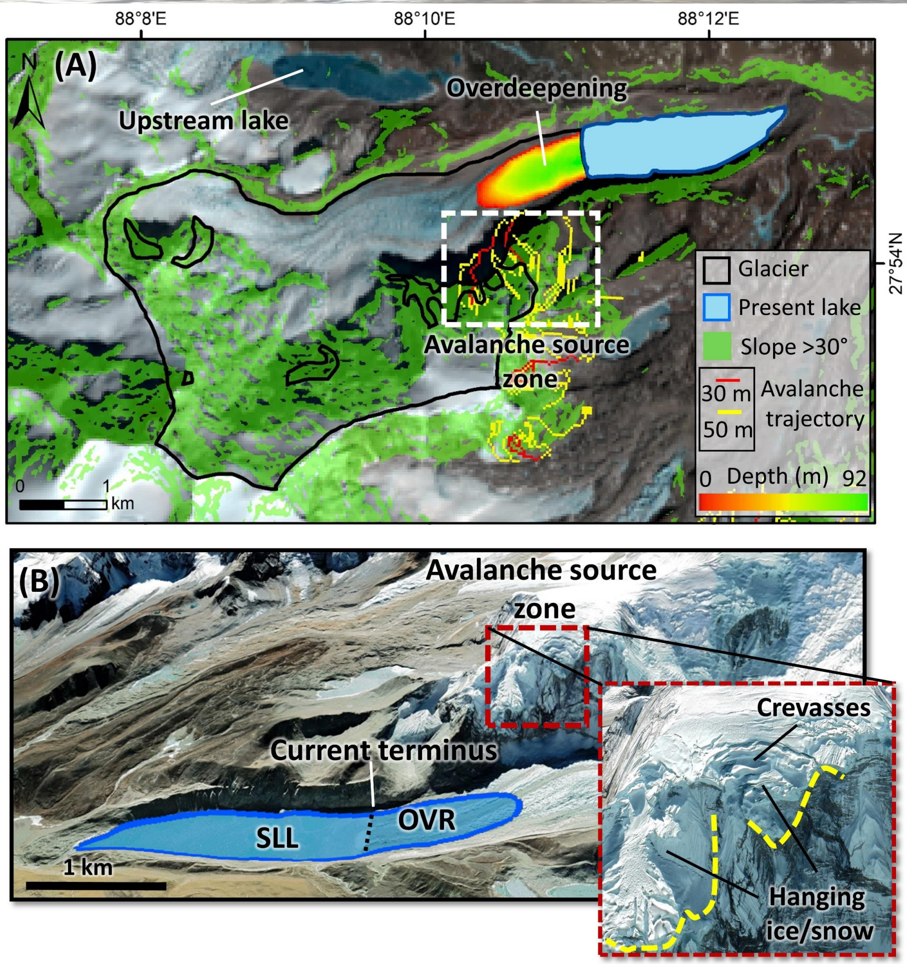
Here, τb is the basal stress, H is the ice- thickness, sin (α) is the slope, ρ is the ice density, g is the acceleration due to gravity (9.8 m s -1), f is the shape factor, and has a range of 0.6 to 1.0.

FUTURE LAKE BATHYMETRY AND FUTURE LAKE BREACH

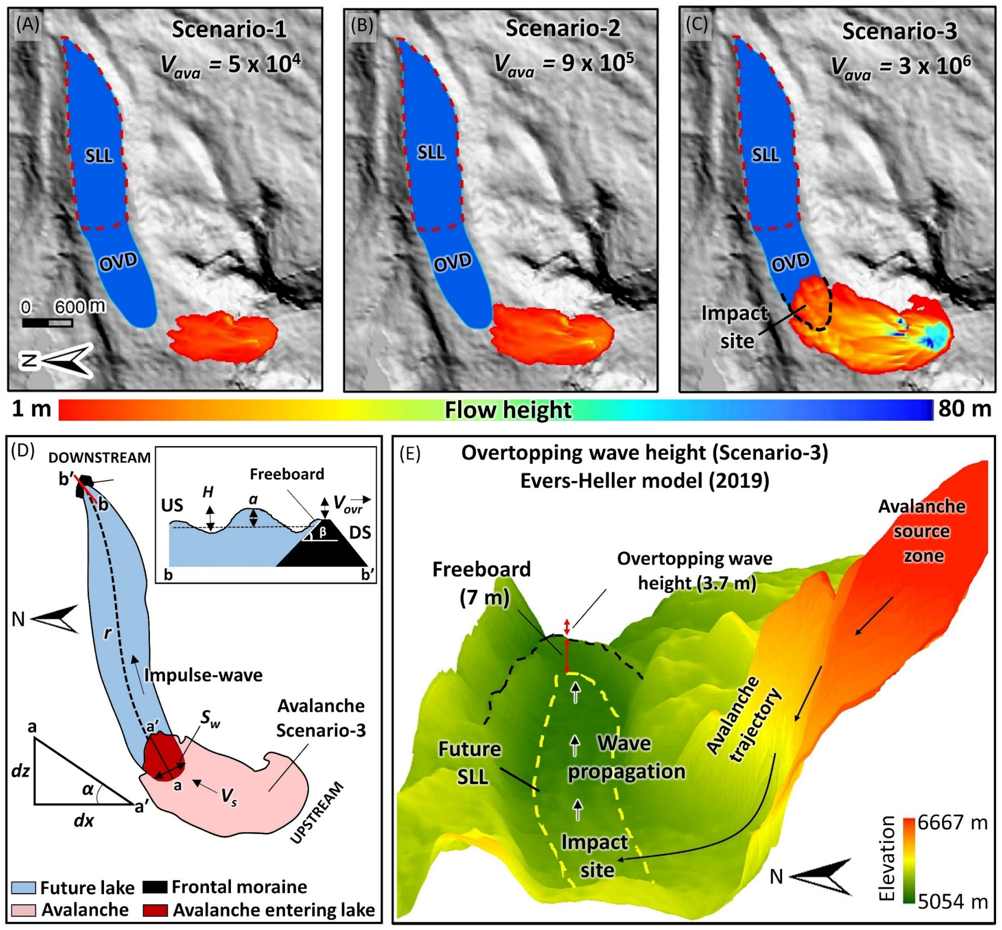


(A) Evolution of the South Lhonak Lake from 1990 to 2019 and the modeled future (maximum) extent of the lake; (B) Cross-sectional view of the lake showing the current lake bathymetry (Sharma et al., 2018) and the overdeepened site; marked are the breach depths of the three potential GLOF events (hb1, hb2, and hb3).

IDENTIFICATION OF AVALANCHE SOURCE ZONES AND FLOW MODELING



(A) South Lhonak glacier-lake system showing the extent of the overdeepening with a maximum depth of 92 m; the avalanche source zones (source slope>30°; trajectory slope>25°); avalanche flow trajectories for 30 m (red) and 50 m (yellow) ice/snow thickness **(Dubey et al. 2020)**, (B) Future lake extent- current extent South Lhonak Lake (SLL) and overdeepening extent (OVD); avalanche source zone showing highly crevassed and hanging ice/snow (located ~930 m upstream of the current terminus).



(A-C) Modeled avalanche scenarios for different released volumes; (D) Avalanche parameters for impact-wave modeling (Evers-Heller model; Evers et al., 2019); (E) 3D view showing the avalanche source zone, trajectory, and overtopping wave height of the impulse-wave; The present extent of the South Lhonak Lake is shown as SLL and the overdeepening as OVD

GLOF Hydraulics and Uncertainty

Predicted dam breach (Froehlich 1995)

$$B_{w\text{-}P} = 0.1803 K_o\,(V_w)^{0.32}\,(h_b)^{0.19} \quad (1)$$

$$T_{f\text{-}P} = 0.00254\,(V_w)^{0.53}\,(h_b)^{-0.9} \quad (2)$$

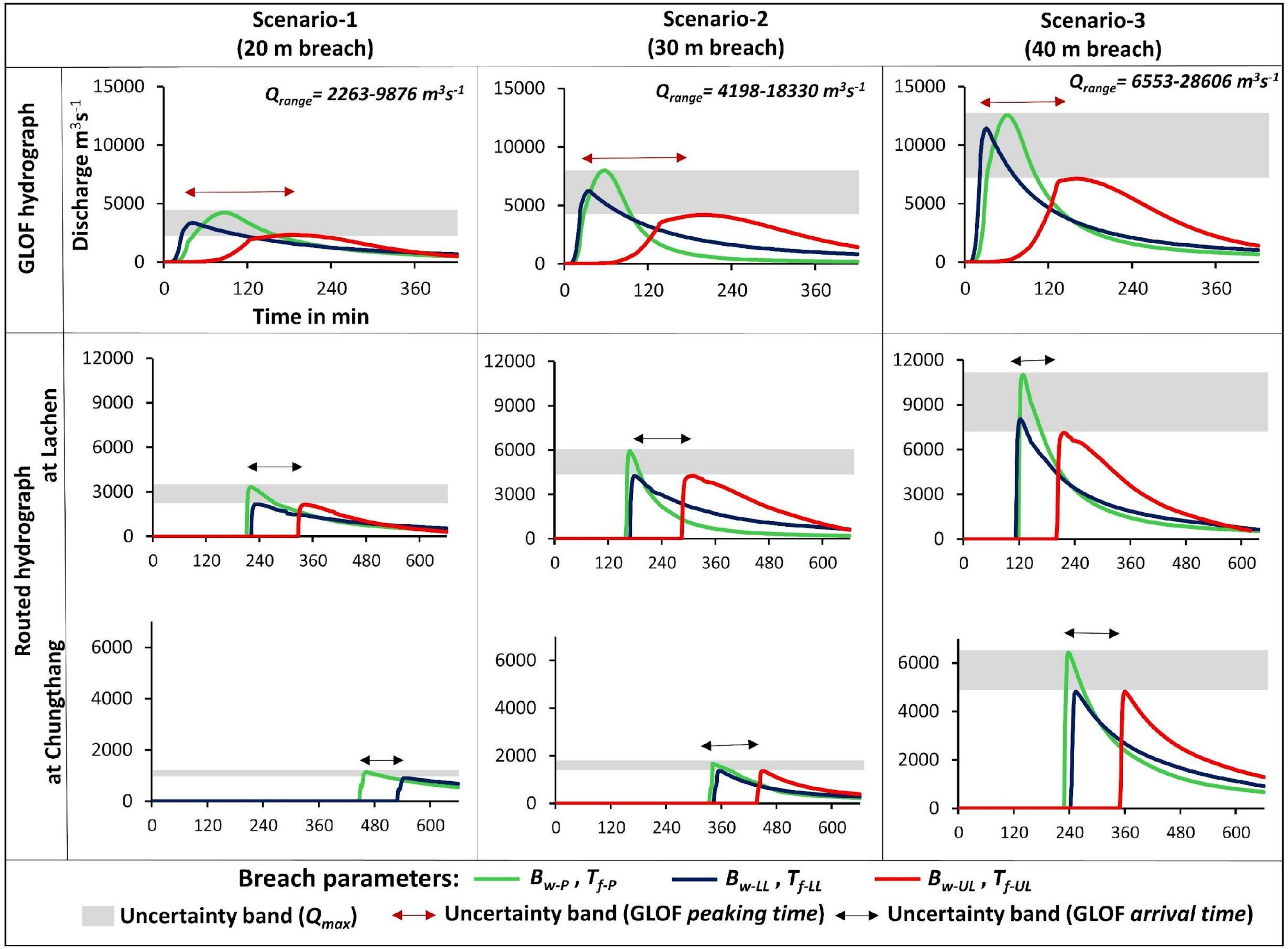
$$Q_{P} = 0.607 V_w^{\,0.295}\,h_w^{\,1.24} \quad (3)$$

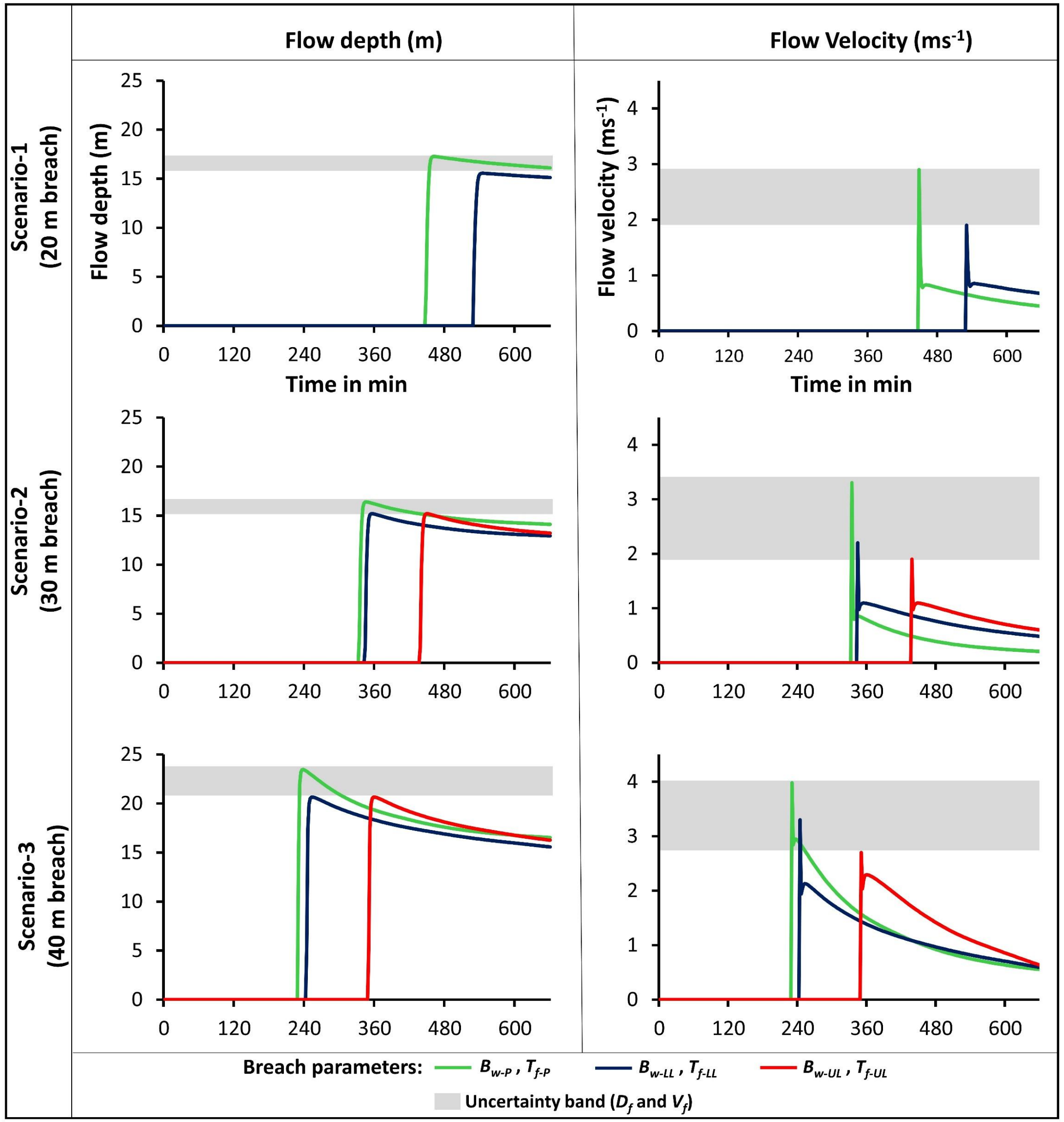
Lower and Upper breach limits (Wahl, 2004)

$$LL = P\,(10^{-e-2S_e}) \quad (4)$$

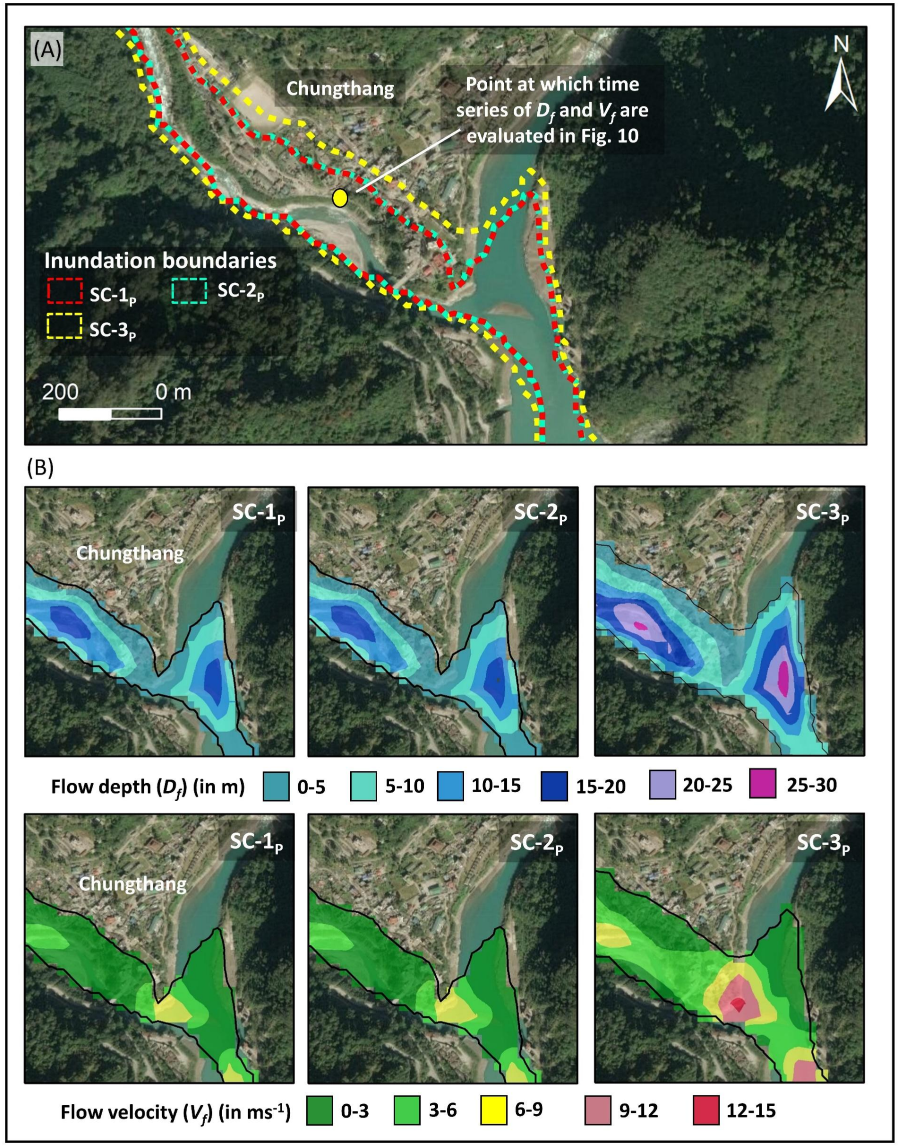
$$UL = P\,(10^{-e+2S_e}) \quad (5)$$

Breach Scenarios		Breach width (B_w) (in m)			Breach formation time (T_f) (in h)			Peak discharge (Q) (in m³s⁻¹)			Peak discharge range (Q_{range})
		P	LL	UL	P	LL	UL	P	LL	UL	
SC-1	20 m	119.43	47.5	286.4	1.79	0.68	12.90	4311	3367	2321	2263-9876
SC-2	30 m	146.8	58.4	352.1	1.54	0.58	11.15	8000	6230	4202	4198-18,330
SC-3	40 m	169.5	67.6	407.5	1.39	0.52	10.06	12,487	11437	7140	6553-28,606





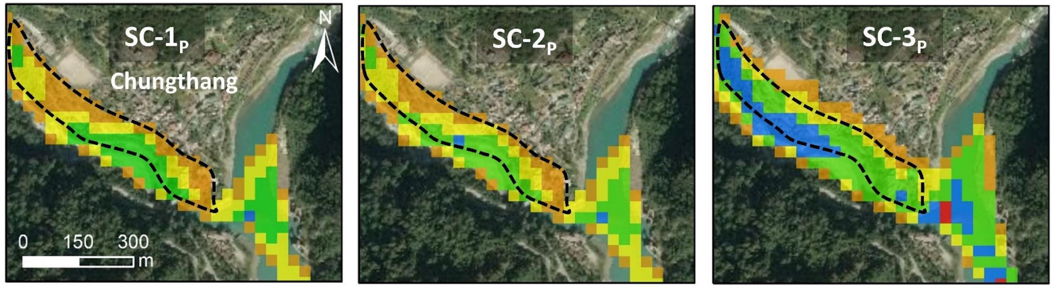
Time series of flow depth and flow velocity at Chungthang for each predicted GLOF scenario; the time series is evaluated at a single point at Chungthang, the location of which is marked in Fig. A (adjacent).



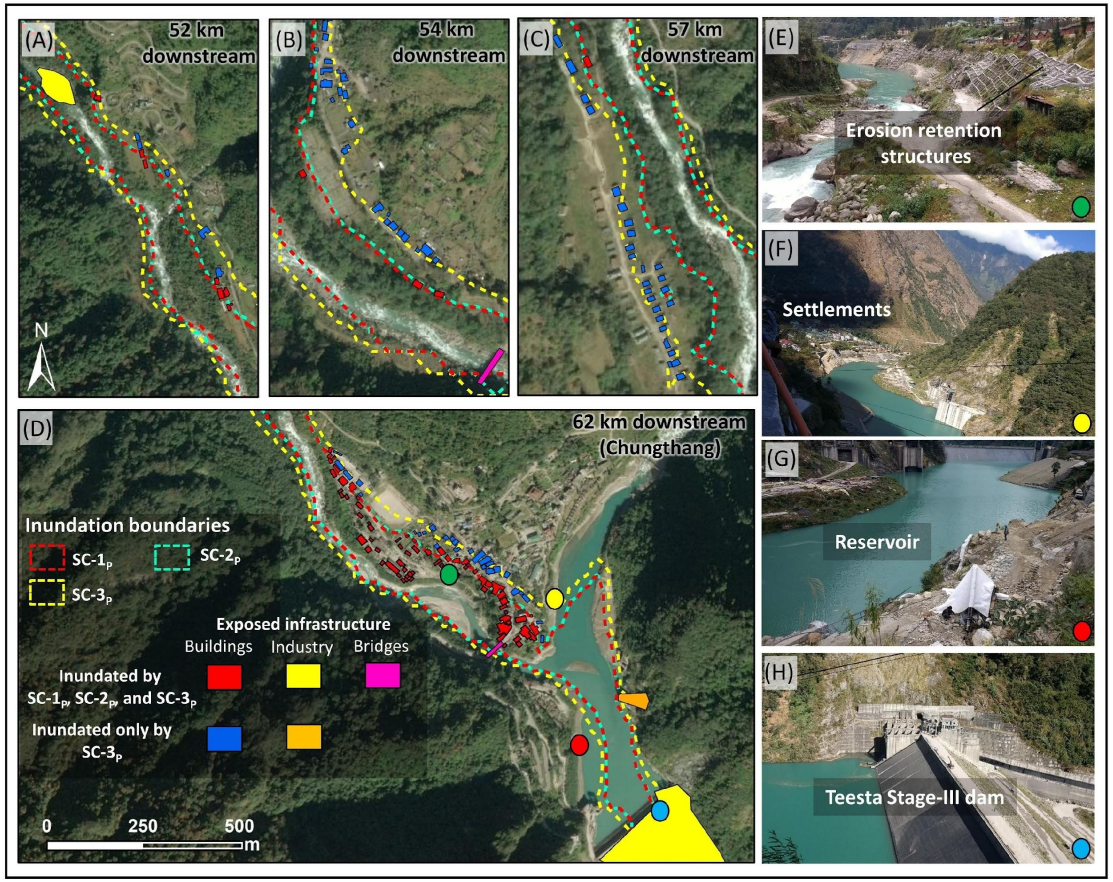
(A-D) Mapped "at-risk" infrastructure along the flow channel; (E-H) Field photographs at different locations (the colored dots represent the respective locations marked in Fig. D).

GLOF intensity mapping

Flow depth (m) \ Flow velocity (ms^{-1})	0-5	5-10	>10
0-5	low	moderate	moderate
5-10	moderate	high	very high
>10	high	very high	extreme



Hazard map of Chungthang based on flow heights (m) and velocity (m s^{-1}) of each predicted GLOF scenario; black dotted outline shows the area of inundated settlements.



(A-D) Mapped “at-risk” infrastructure along the flow channel; (E-H) Field photographs at different locations (the colored dots represent the respective locations marked in Fig. D).

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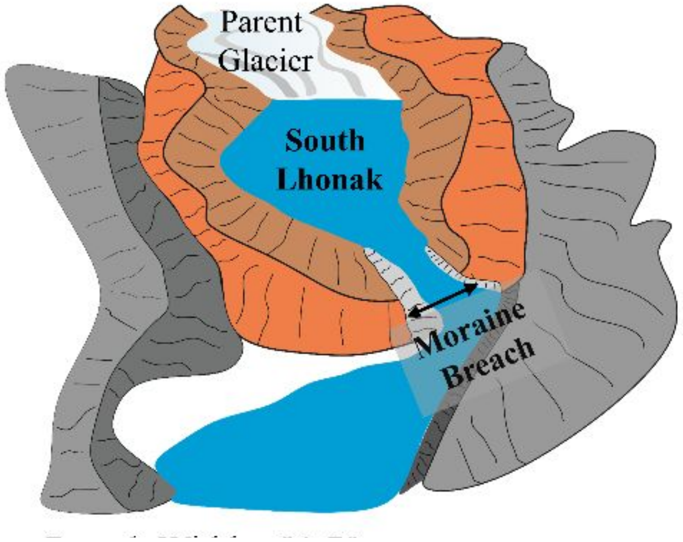
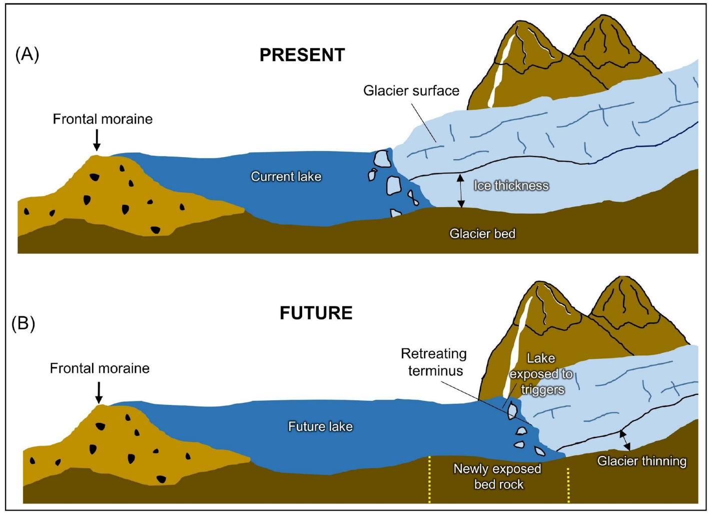
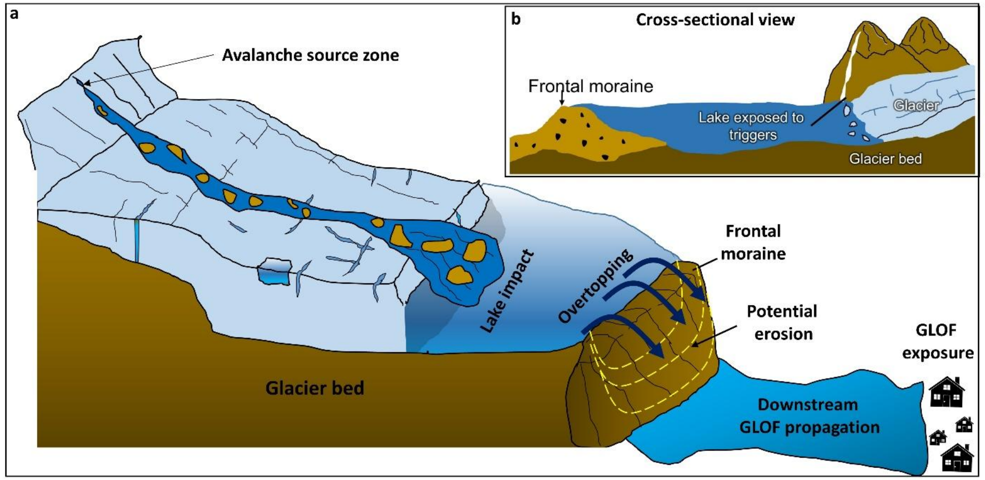
1. Overtopping and piping failure of the frontal moraine-Present GLOF hazard-GLOF exposure



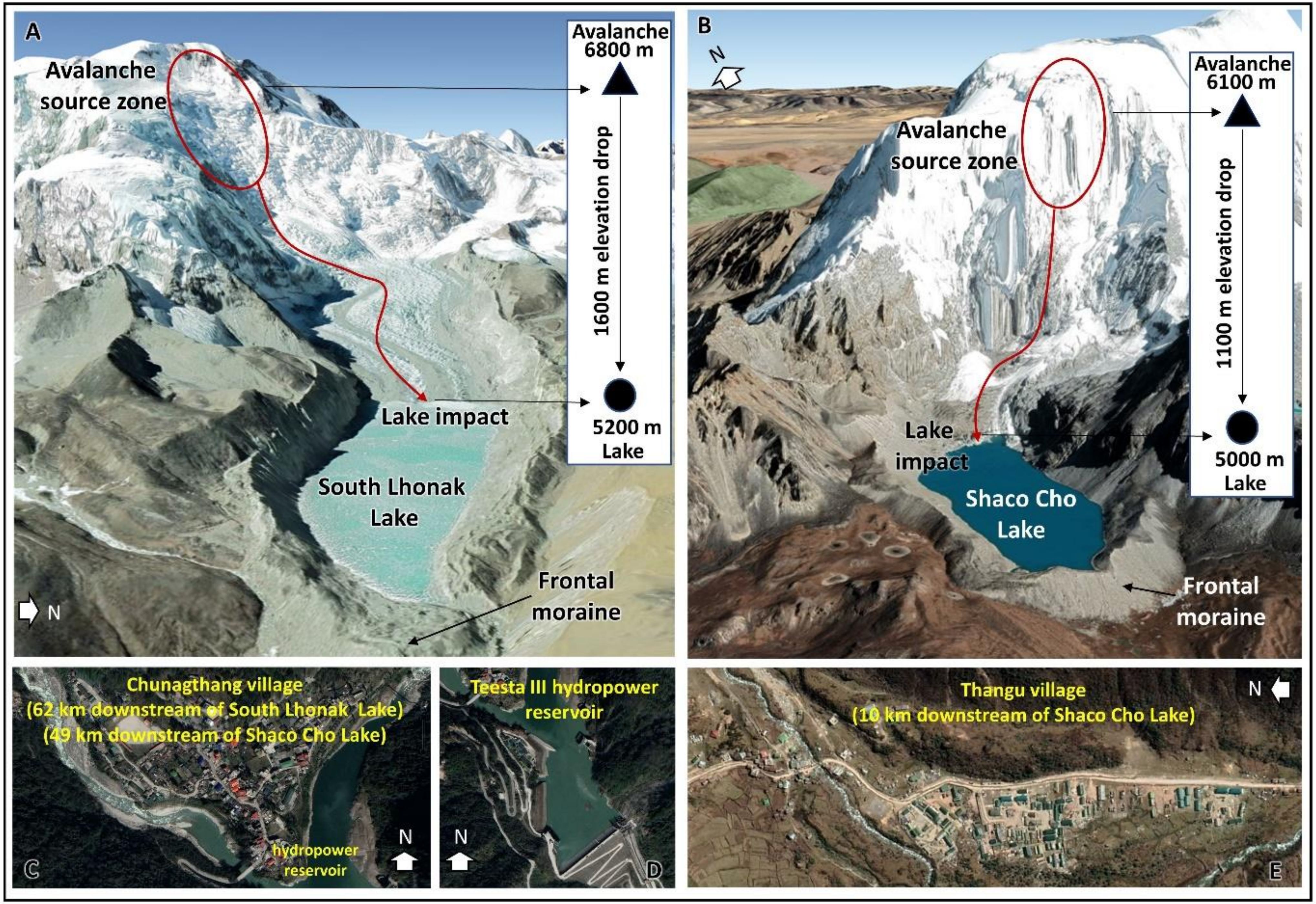
2. Overtopping failure of the frontal moraine identification of the potential GLOF triggers-Future GLOF hazard-GLOF intensity GLOF exposure



3. GLOF process chain-GLOF triggers-GLOF exposure



GLOF process chains:
Potential GLOF triggers, hazard and exposure



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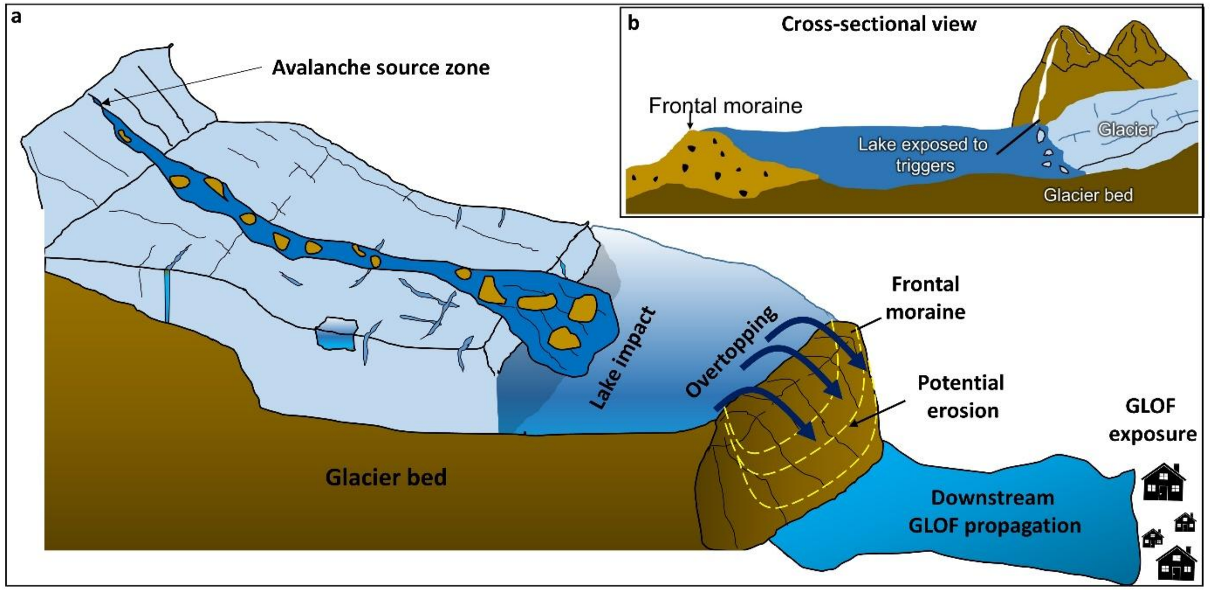
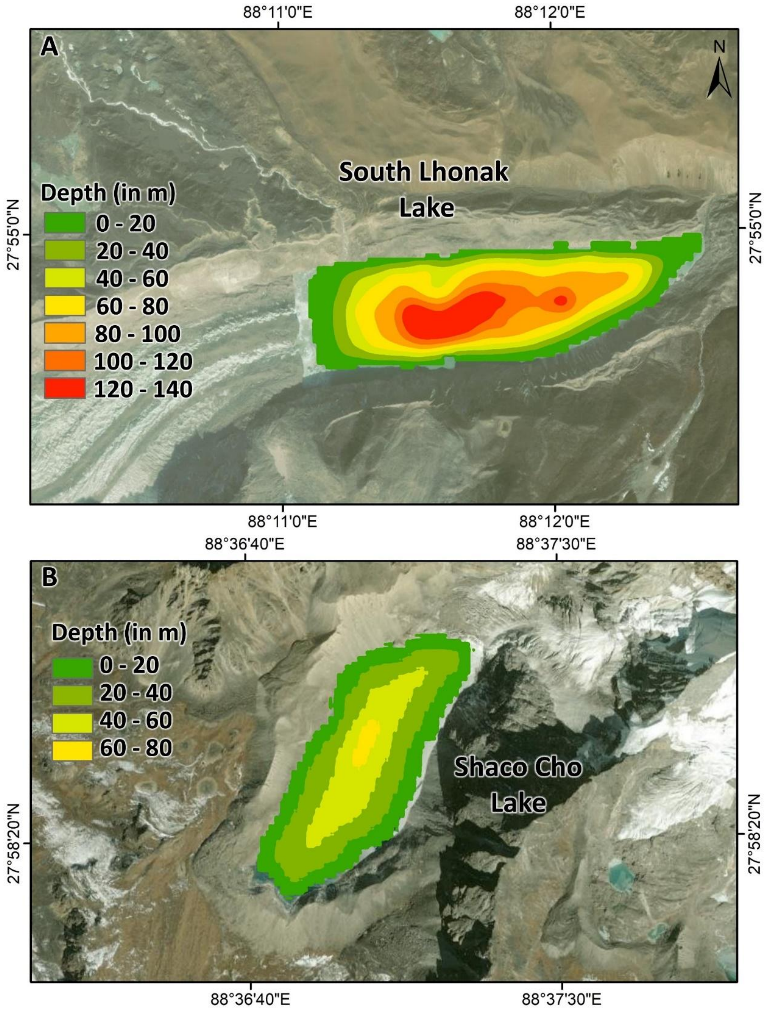
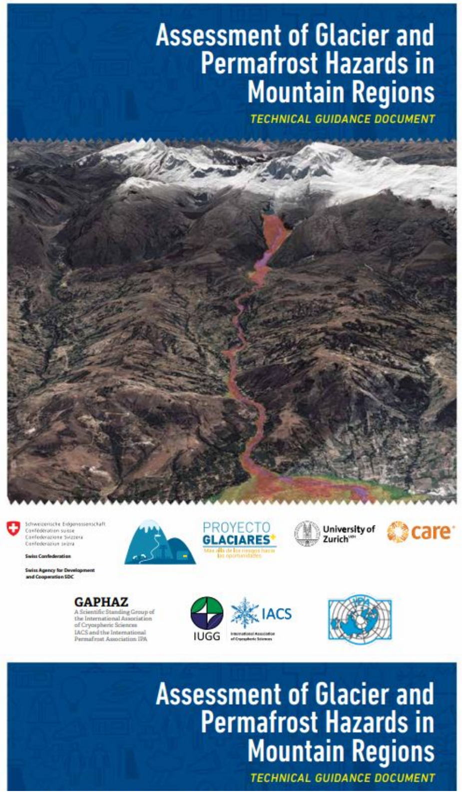




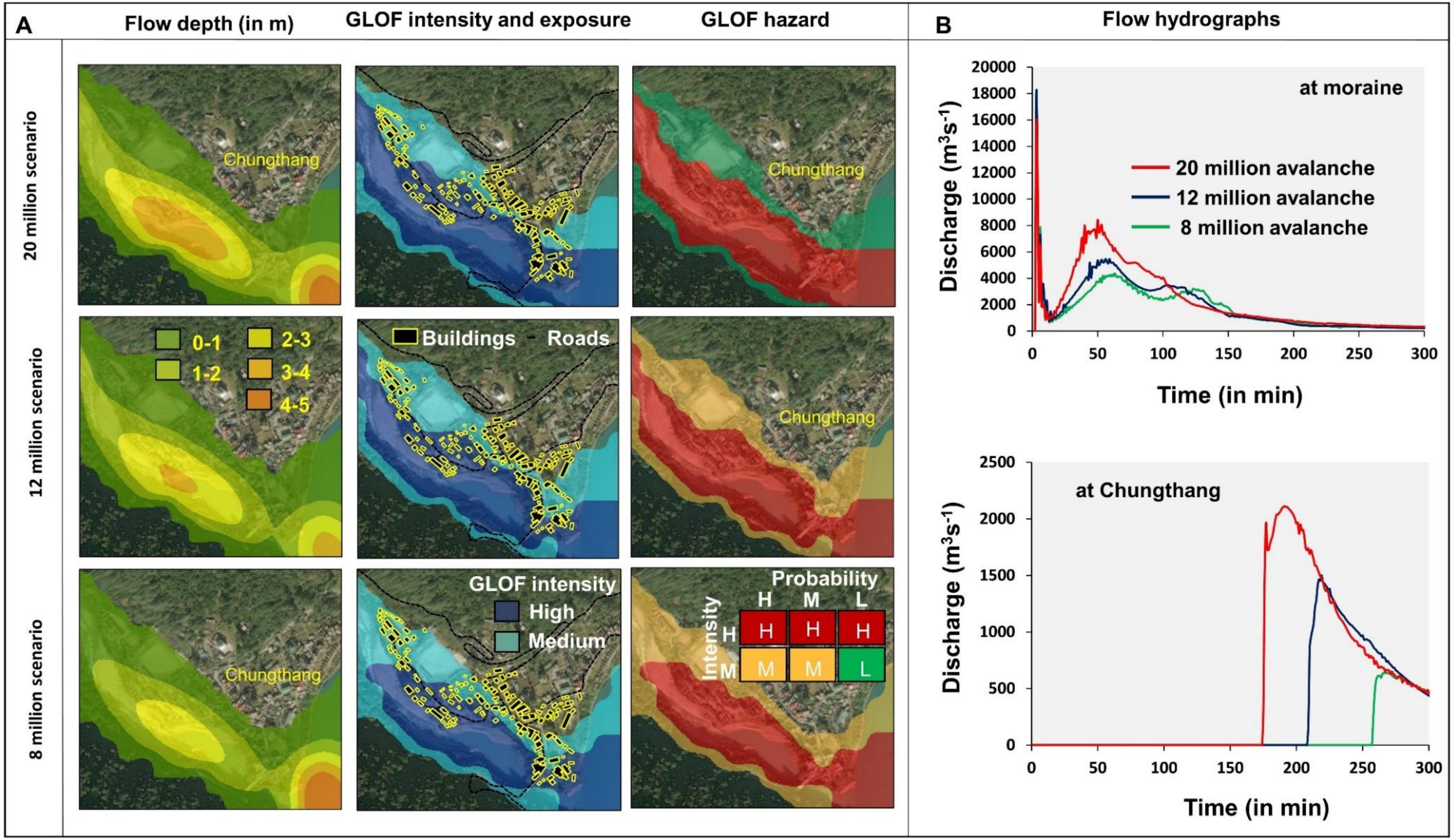
Scenarios	Avalanche Volume (m^3)	Ice volume (%)	Rock volume (%)	Density of the avalanche (kg/m^3)	Remarks
South Lhonak Lake					
SL-1	20 x 10^6	20%	80%	2300	Large magnitude rock-ice avalanche
SL-2	12 x 10^6	20%	80%	2300	Moderate magnitude rock-ice avalanche
SL-3	8 x 10^6	20%	80%	2300	Small magnitude rock-ice avalanche
Shako Cho Lake					
SC-1	20 x 10^6	20%	80%	2300	Large magnitude rock-ice avalanche
SC-2	12 x 10^6	20%	80%	2300	Moderate magnitude rock-ice avalanche
SC-3	8 x 10^6	20%	80%	2300	Small magnitude rock-ice avalanche

Hazard assessment

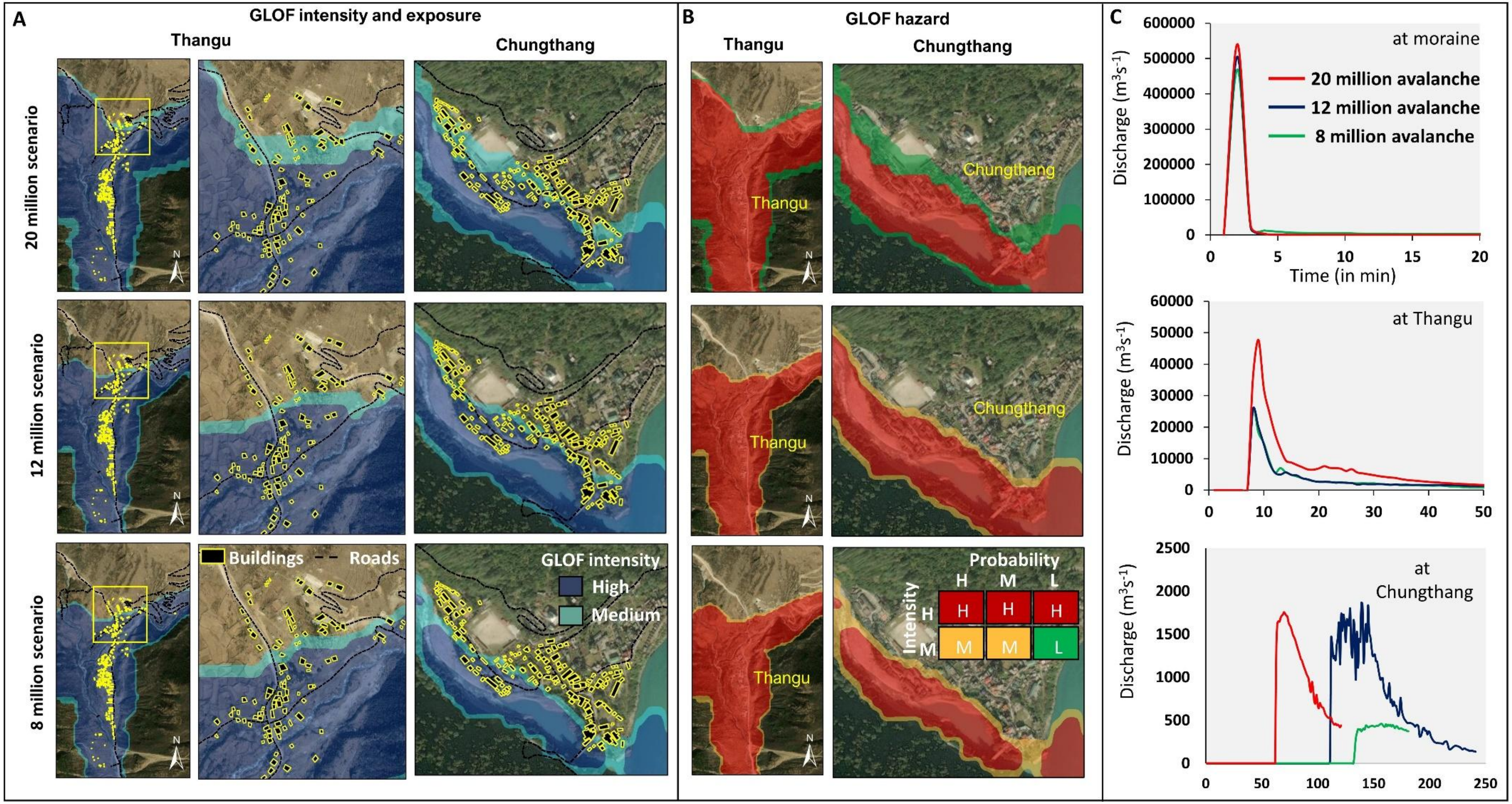
Intensity \ Probability	H	M	L
H	H	H	H
M	M	M	L



GLOF process chains: Potential hazard and exposure



(A) **South Lhonak GLOF** flow depths (in m), intensity, exposure, and hazard (individual scenarios; see next slide for combined hazard) at Chungthang for different magnitude GLOF process chains; (B) discharge (m^3s^{-1}) vs. time (in min) plots at the damming moraine and Chungthang for different magnitude GLOF process chains.



(A) **Shako Cho GLOF** intensity, exposure; and (B) hazard (individual scenarios; see below for combined hazard) at Thangu and Chungthang for different magnitude GLOF process chains; (C) discharge (m^3s^{-1}) vs. time (in min) plots at the damming moraine, Thangu and Chungthang for different magnitude GLOF process chains.

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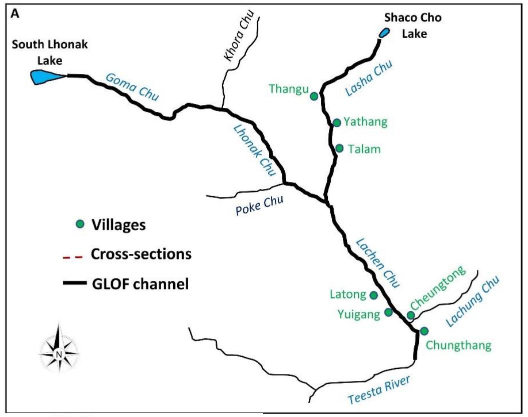
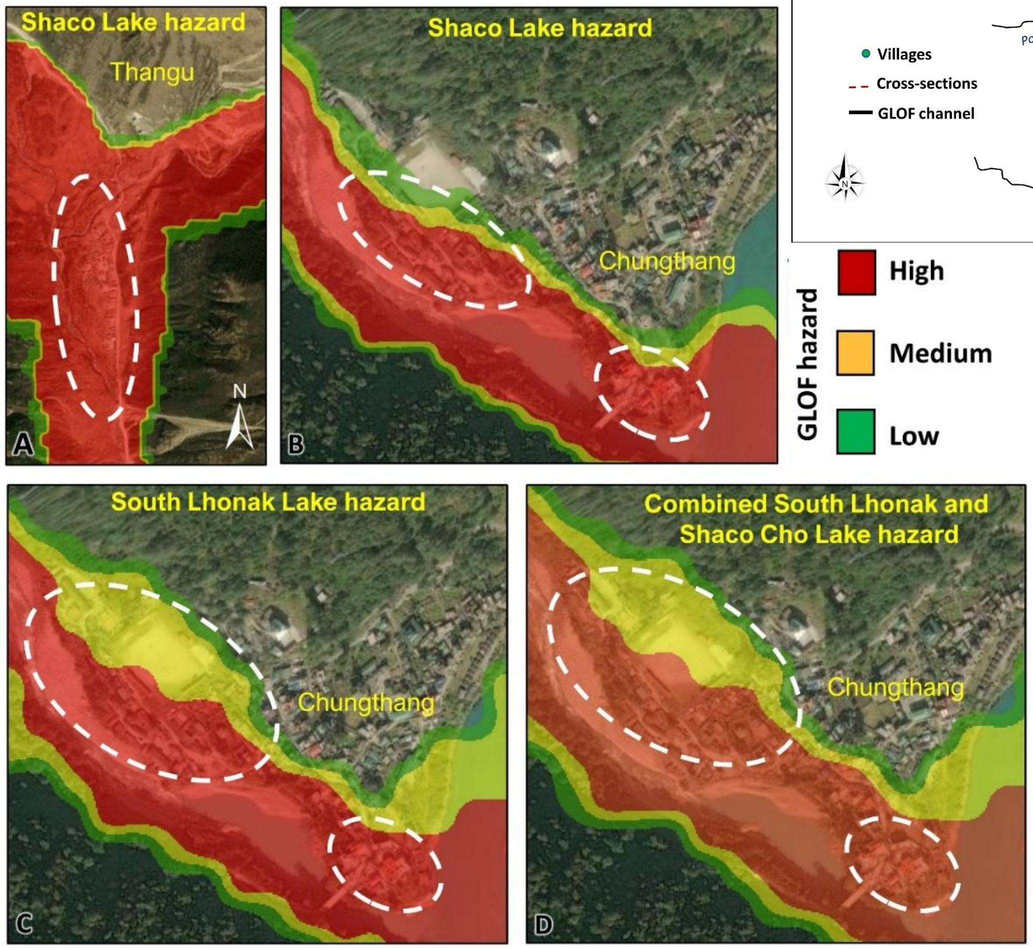
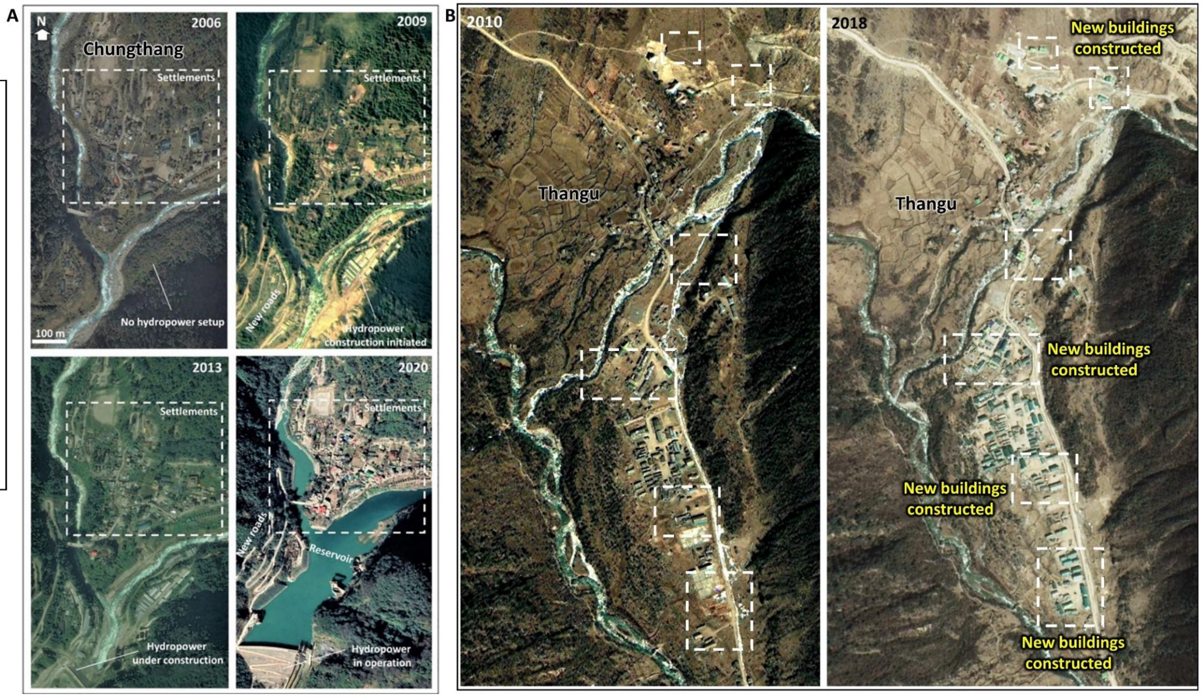




GLOF hazard of Shako Cho Lake (A) at Thangu ; (B) at Chungthang; GLOF hazard at Chungthang for (C) South Lhonak Lake ; (D) combined South Lhonak and Shako Cho lakes; dotted circles show the impacted build-up area.



(A) Changes in the infrastructure in different years (2006, 2009, 2013, and 2020) at the Chungthang village; (B) Changes in the infrastructure in different years (2010 and 2018) at Thangu village; dotted squares show the locations with new constructions.

	Estimated arrival time (in min after process chain initiation by an avalanche)					
	South Lhonak Lake			Shako Cho Lake		
	large	moderate	small	large	moderate	small
at moraine	2	2	2	1	1	1
at Thangu		(not affected)		8	8	8
at Chungthang	175	200	250	60	110	130

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Conclusions and recommendations

- For South Lhonak Lake and Shako Cho Lake, both considered as critical glacier lakes
- The village of Thangu is a critical high-risk situation. Almost the entire village is situated in the high-hazard zone combined with flood arrival times **of only 7 to 8 minutes, even for moderate and small magnitude events**. This leaves little to no response options, due to extremely short arrival times on the one hand, and the lack of evacuation routes and safe zones on the other. An EWS might only have little to no effect on the level of disaster risk in this particular village. Alternative risk mitigation measures need to be considered to reduce the risk level significantly.
- Next to Thangu, also Chungthang and several settlements upstream have buildings and infrastructure exposed to potential GLOF impacts. **GLOF exposure increased over the past 10 to 15 years**, due to the construction of new infrastructure in areas potentially affected by GLOFs. Here, however, estimated flood arrival times indicate that an efficient EWS could help to timely warn the population and therefore lower the risk from GLOFs.
- For Chungthang, flood arrival times vary between **1 hr (large magnitude scenario from Shako Cho) to 4 hrs 10 min (small magnitude scenario from South Lhonak Lake).** This is short, in particular for the large magnitude scenario from Shako Cho, but still, allow for a timely warning of the potentially affected population by a well-designed and maintained EWS.

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Ashim Sattar [a,e,*], Ajanta Goswami [b], Anil.V. Kulkarni [c], Adam Emmer [d], Umesh K. Haritashya [a], Simon Allen [e,f], Holger Frey [e], Christian Huggel [e]

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[d] Cascade – Mountain Processes and Mountain Hazards Group, Institute of Geography and Regional Science, University of Graz, Austria
[e] Environment and Climate: Impacts, Risks and Adaptation (EClim), Department of Geography, University of Zurich, Switzerland
[f] Climatic Change Impacts and Risks in the Anthropocene (C-CIA), Institute for Environmental Sciences, University of Geneva, Geneva, Switzerland

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Ashim Sattar [a,*], Ajanta Goswami [a], Anil V. Kulkarni [b]

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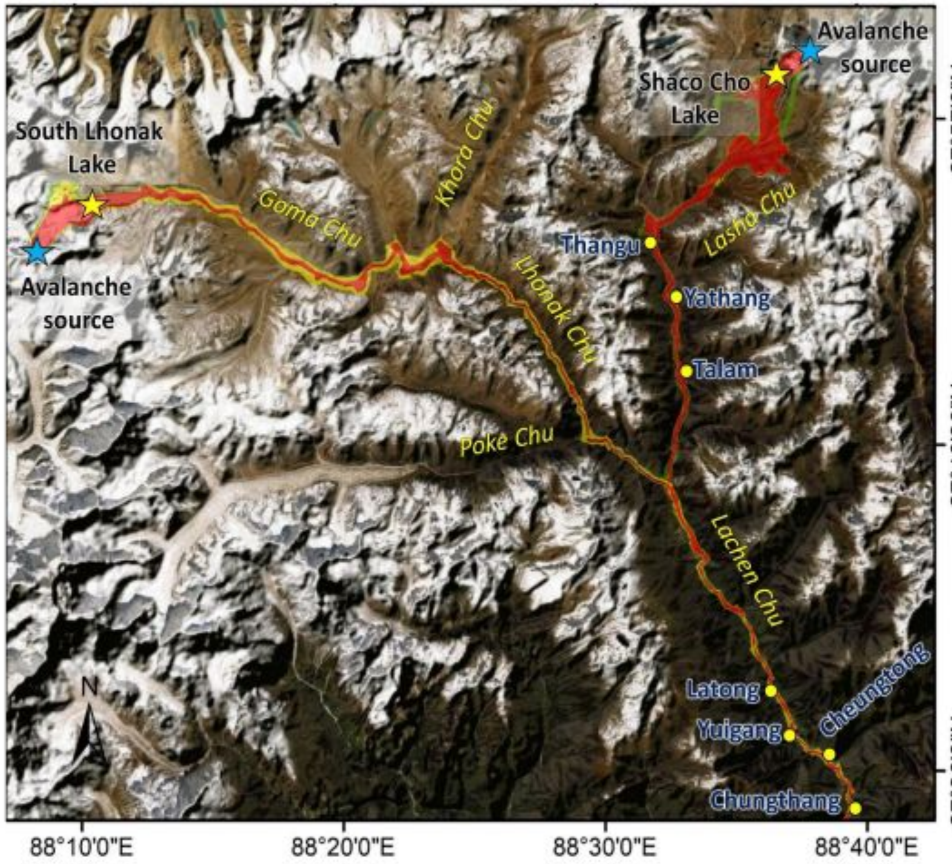
[b] Indian Institute of Science Bangalore, 560012 Bangalore, Karnataka, India

Hazard and exposure mapping for outburst floods from Shako Cho and South Lhonak glacial lakes in Sikkim, India



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4. STUDY OF LANDSLIDE-GLACIOLOGY-HYDROLOGY BASED GEOHAZARDS IN HIGH MOUNTAIN ASIA (HMA)- NASA

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Simon Allen; Holger Frey; Christian Huggel; Anil V. Kulkarni; Ajanta Goswami; Umesh Haritashya; Adam Emmer

Special thanks to the collaborators and funding bodies :

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