Importance of Glacial Lake Outburst Flood (GLOF) Study specially in changing climate condition: A Case Study in Chenab Basin

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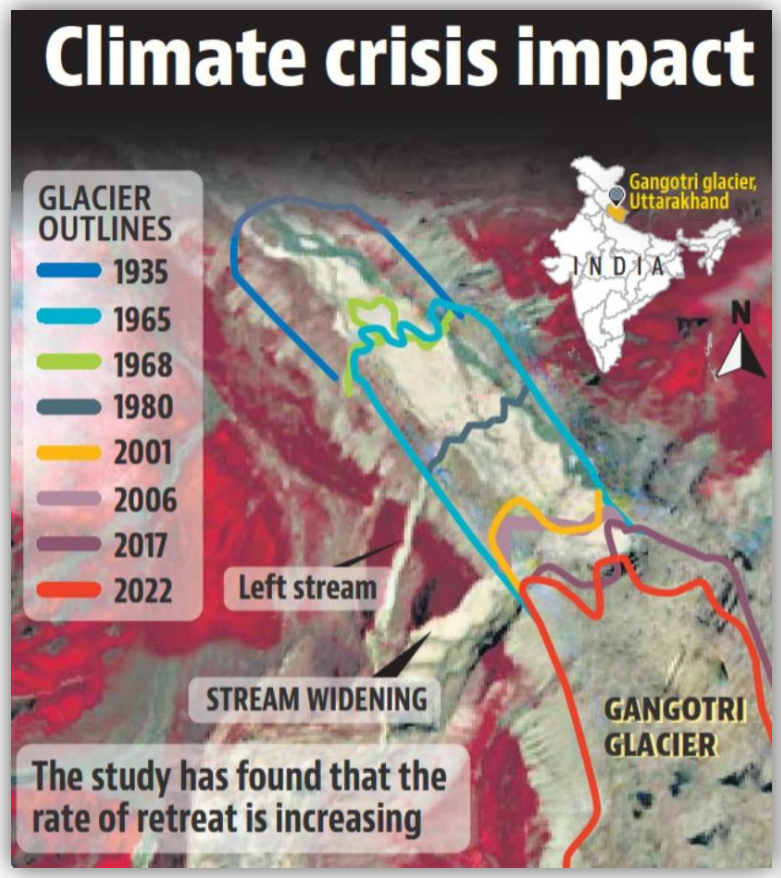
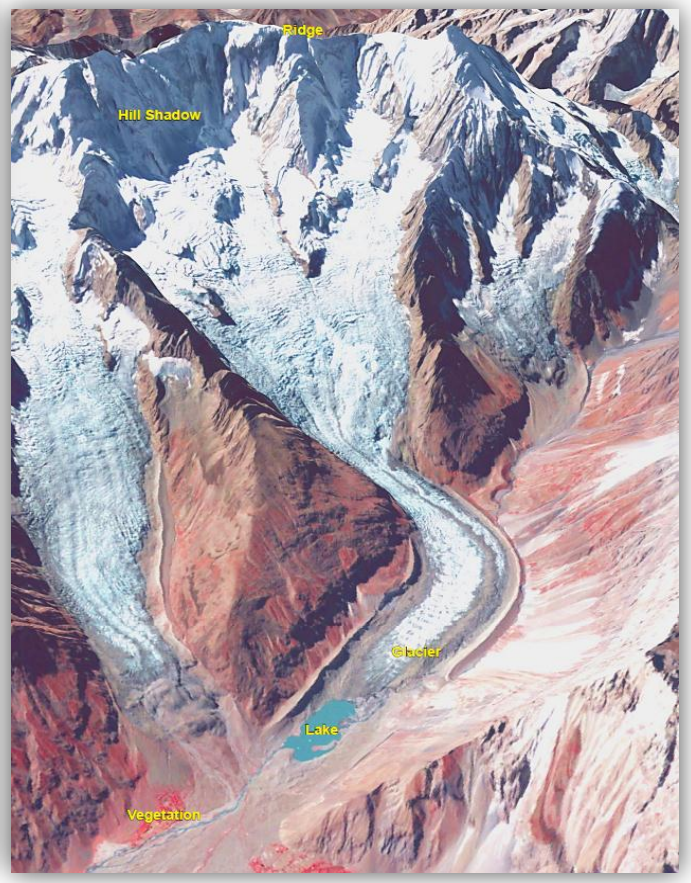
Glacial Lakes and climate change in Himalayan Region

- ✓ GL are natural part of landscape, their rapid expansion and increased instability can lead to GLOF.
- ✓ abundant region with glaciers and snow outside the polar region, is facing the heat of climate change.
- ✓ global warming, new glacial lakes and also resulting in expansion of existing glacial lakes
- ✓ GLOFs occur when the natural dams holding back the water in these lakes fail, often due to pressure exerted by increasing volume of water.
- ✓ Gangotri is the largest glacier in Uttarakhand Himalayas, 1700m , 1935-1922, 20 metres per year which has increased to up to 38 metres per year
- ✓ Indus, Ganga, Brahmputra
- ✓ 477, 50 ha since 2011 and 385, 10 ha since 2022



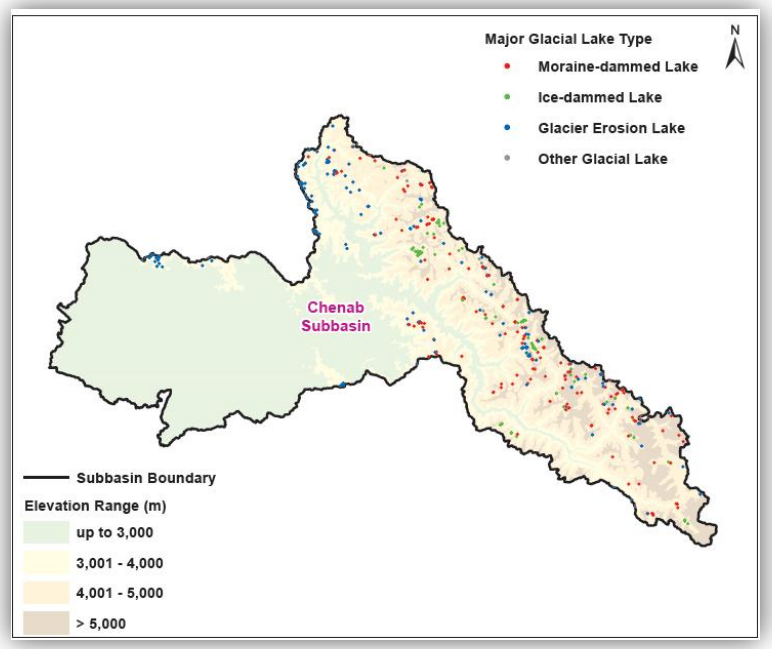


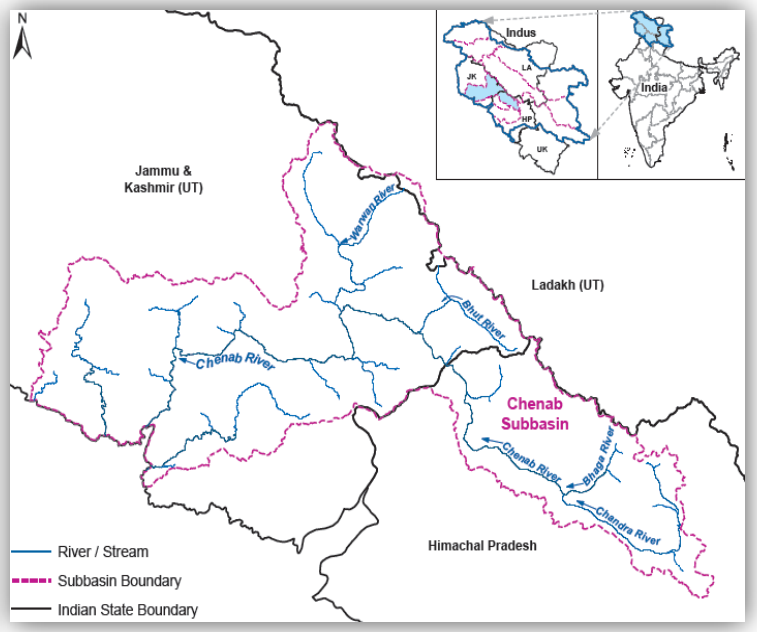
Glacial Lakes in Chenab basin

SI No.	Type of Glacial Lake	Remark
1	Moraine dammed Lake	These lakes are fed by glacial and dammed by moraine
2	Ice-dammed Lake	Pond or lake on the surface of a glacier and Lake dammed by glacier ice with no lateral moraines
3	Glacier Erosion Lake	Lakes formed in the glacier trough as a result of the glacier erosion process
4	Other Glacial Lake	Lakes formed in a glaciated valley, and fed by glacial melt, but damming material not directly part of the glacial process

✓The Chenab subbasin is the fifth largest subbasin of the Indus basin covering a total area of 29,257 Km2 i.e. 8.53% of the total basin area.

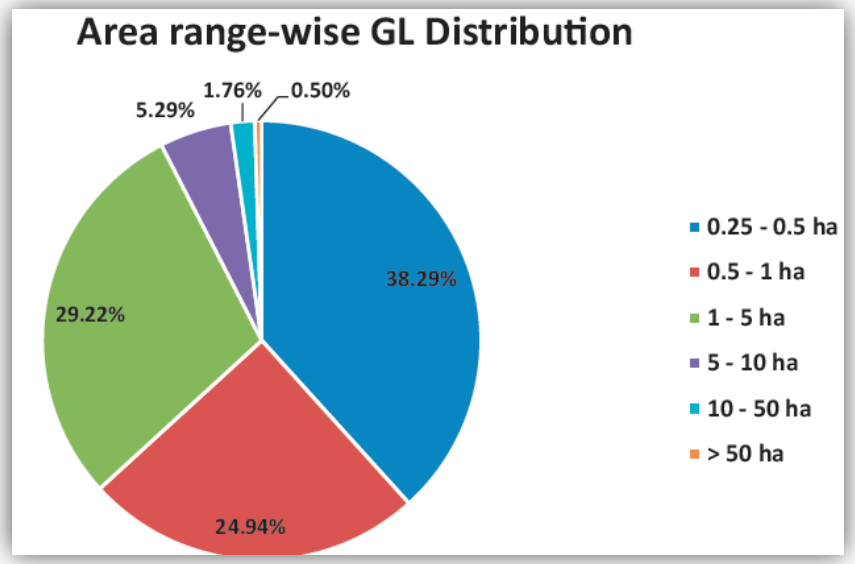
✓Chandra and Bhaga Rivers are the two main tributaries of Chenab subbasin, and with the confluence of both rivers at Tandi in Lahul & Spiti District of Himachal Pradesh from where the Chenab River starts.

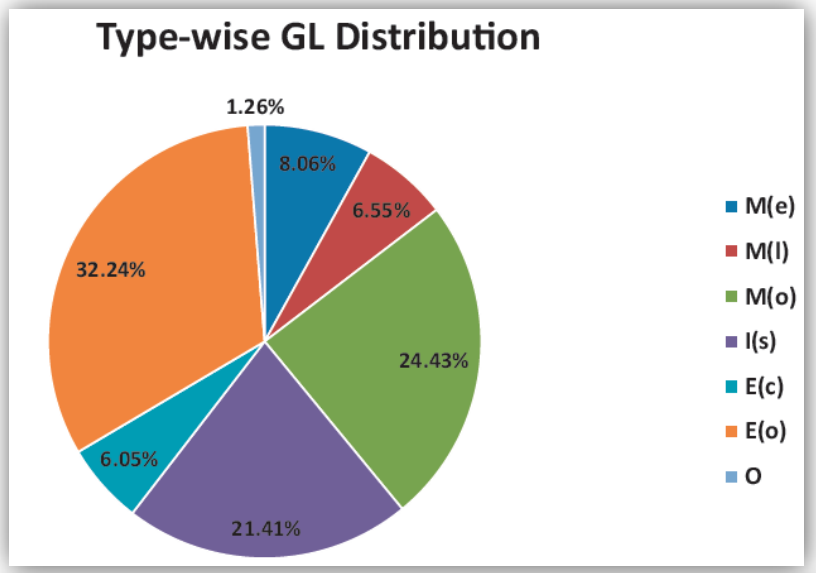


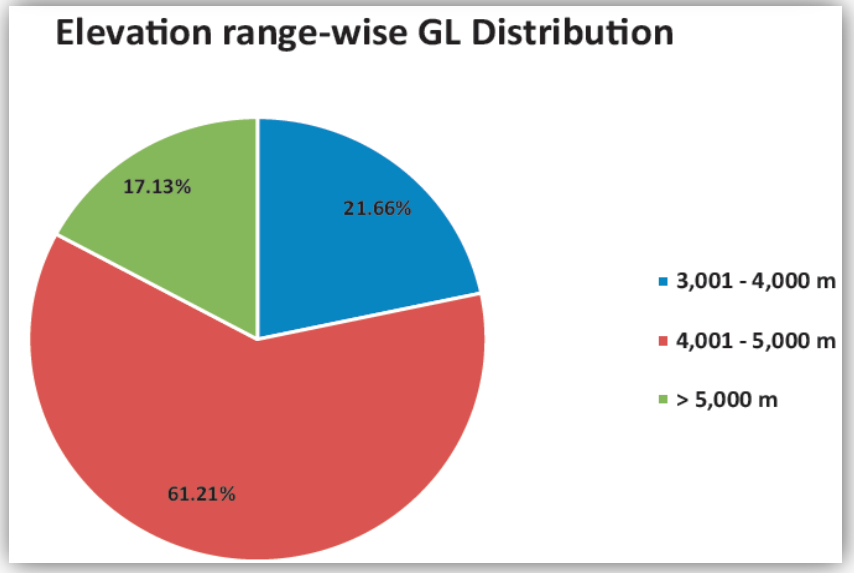


Glacial Lakes in Chenab basin

Total of 397 glacial lakes has been mapped, covering a total area of 896.11 ha i.e. 0.03% of the total area of the subbasin. About 367 (92.44%) lakes are with < 5 ha lake area contributing to 40.48% of total lake area. The remaining lakes with > 5 ha in size are only 30 (7.56%) contributing to 59.52% of total lake area in the subbasin.







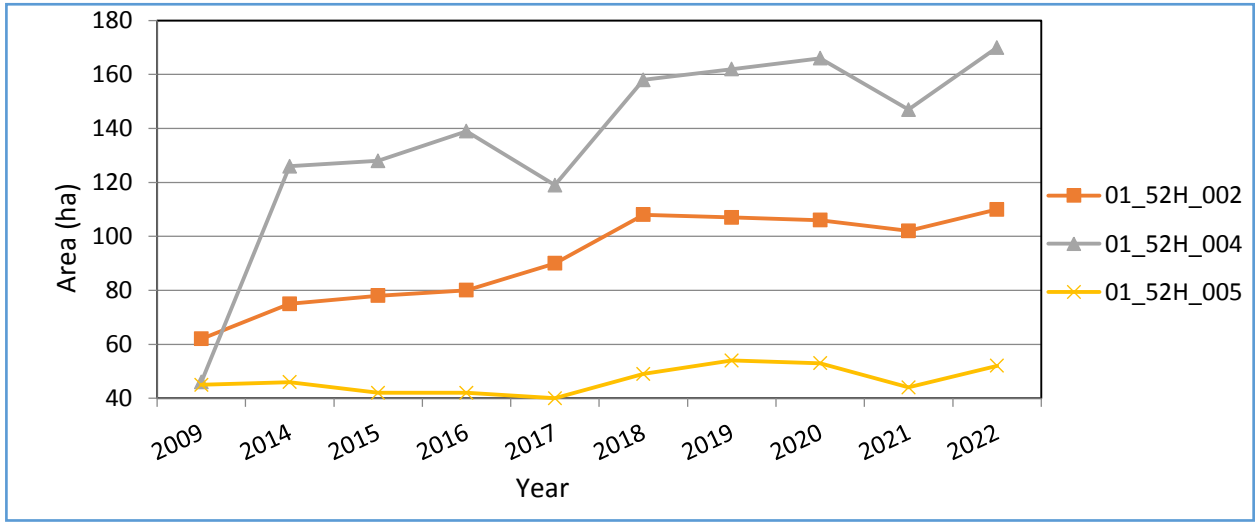
Potentially dangerous glacial lakes identified in Chenab basin

	Lake ID as per CWC Inventory		
	01_52H_002 (GL1)	01_52H_004 (GL2)	01_52H_005 (GL3)
Longitude	77°13'06"	77°32'58"	77°36'58"
Latitude	33°31'29"	32°29'55"	32°28'56"
Elevation (m)	4069	4150	4275
Area in ha (2009)(Maximum)	62	46	45
Area in ha (2014)(Maximum)	75	126	46
Area in ha (2015)(Maximum)	78	128	42
Area in ha (2016)(Maximum)	80	139	42
Area in ha (2017)(Maximum)	90	119	40
Area in ha (2018)(Maximum)	108	158	49
Area in ha (2019)(Maximum)	107	162	54
Area in ha (2020)(Maximum)	106	166	53
Area in ha (2021)(Maximum)	102	147	44
Area in ha (2022)(Maximum)	110	170	52
Type	Moraine	Moraine	Cirque

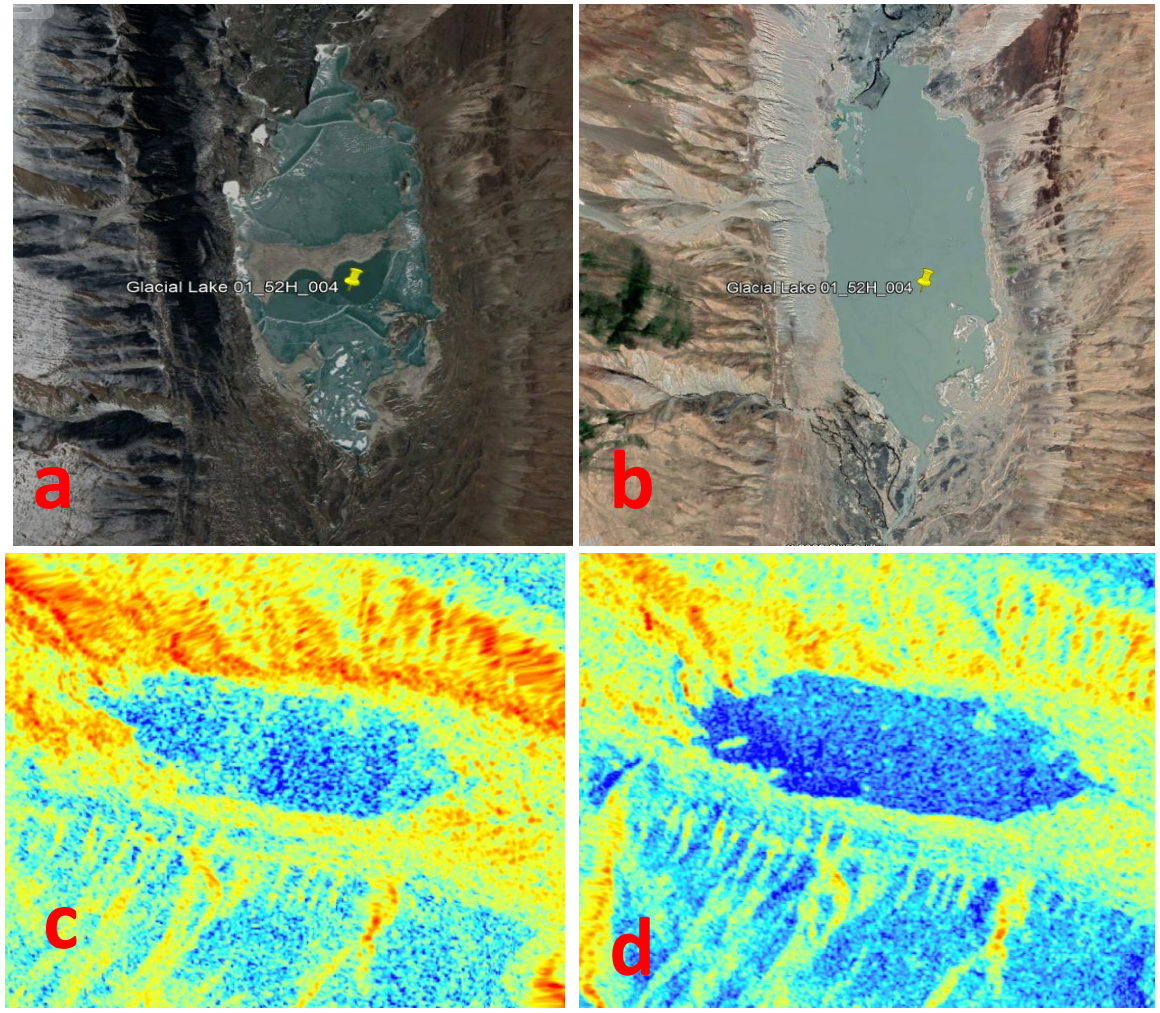
✓Three glacial lakes upstream of having size more than 50 ha were identified based on vulnerability analysis.

✓After criticality analysis, the moraine dammed glacial lake 01_52H_004 (GL2)

✓Estimated volume of 11.43 MCM and 73.15 MCM as per the surface area of 2009 and 2022.



Monitoring of Glacial Lake 01_52H_004 (GL2)

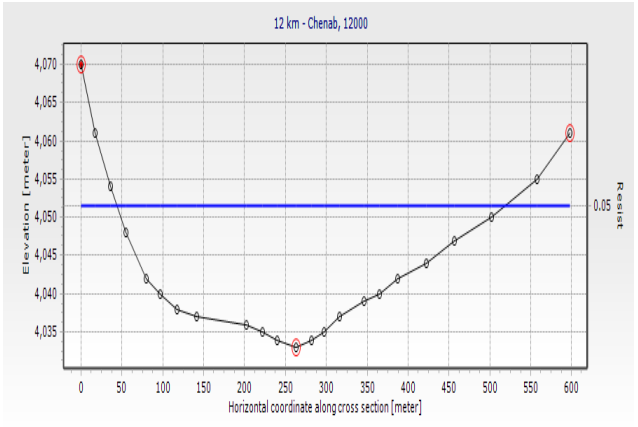


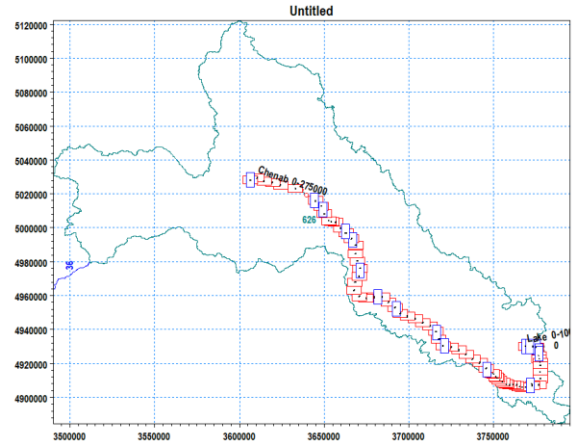
01_52H_004 in different satellite images taken between 2014 and 2000.

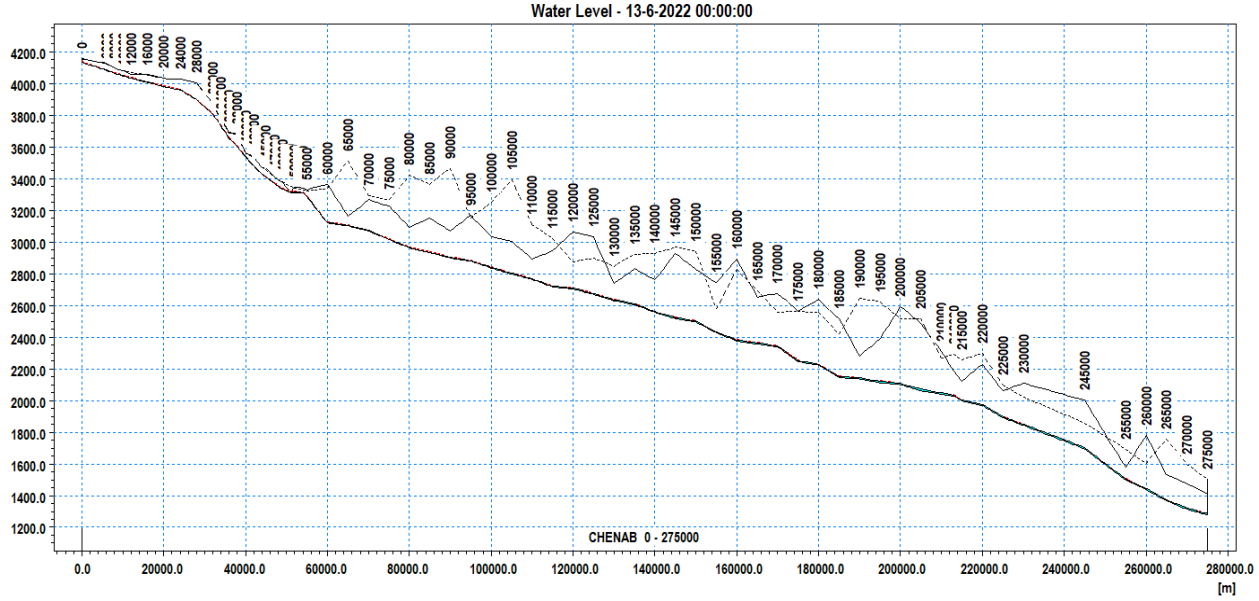
a) Google Earth Image of Glacial Lake (2014),
b) Google Earth Image of Glacial Lake (2020),
c) Sentinel 1A 2015,
d) Sentinel 1A 2020

GLOF – A Dam Break Modelling

- ✓ GLOF is a sudden and often catastrophic event that occurs when water stored in a glacial lake is released rapidly.
- ✓ GLOF is a type of dam break unsteady flow modelling.
- ✓ The possible failure mechanism associated with moraine dammed lakes are almost the same as of an earthen dam with difference being only in the time of full breach development.
- ✓ Further there are two basic parts of a GLOF modelling:
  - i. Estimation of outburst flood hydrograph just downstream of glacial lake
  - ii. Hydrodynamic channel routing of outburst flood to get the GLOF output at a project site through proper attenuation and translation mechanism.







Input Data and Breach Parameters of Glacial Lake

- ✓ International Centre for Integrated Mountain Development (ICIMOD) guidelines and Christian Huggel's equations are widely used.
- ✓ Cirque Lake- 10 m, Lateral Moraine Lake- 20 m, Moraine Lake- 30 m, Blocking Lake and Glacial Erosion Lake- 40 m.
- ✓ The Christian Huggel's equations are developed for moraine glacial lakes in Swiss Alps region, but are being used satisfactorily for glacial lakes of Himalayan regions as well.

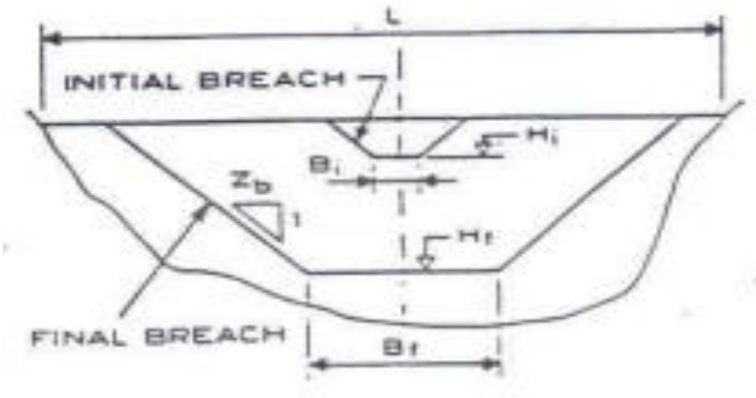
$$\text{Depth (D)} = 0.140A^{0.42}$$

$$\text{Volume (V)} = 0.140A^{1.42}$$

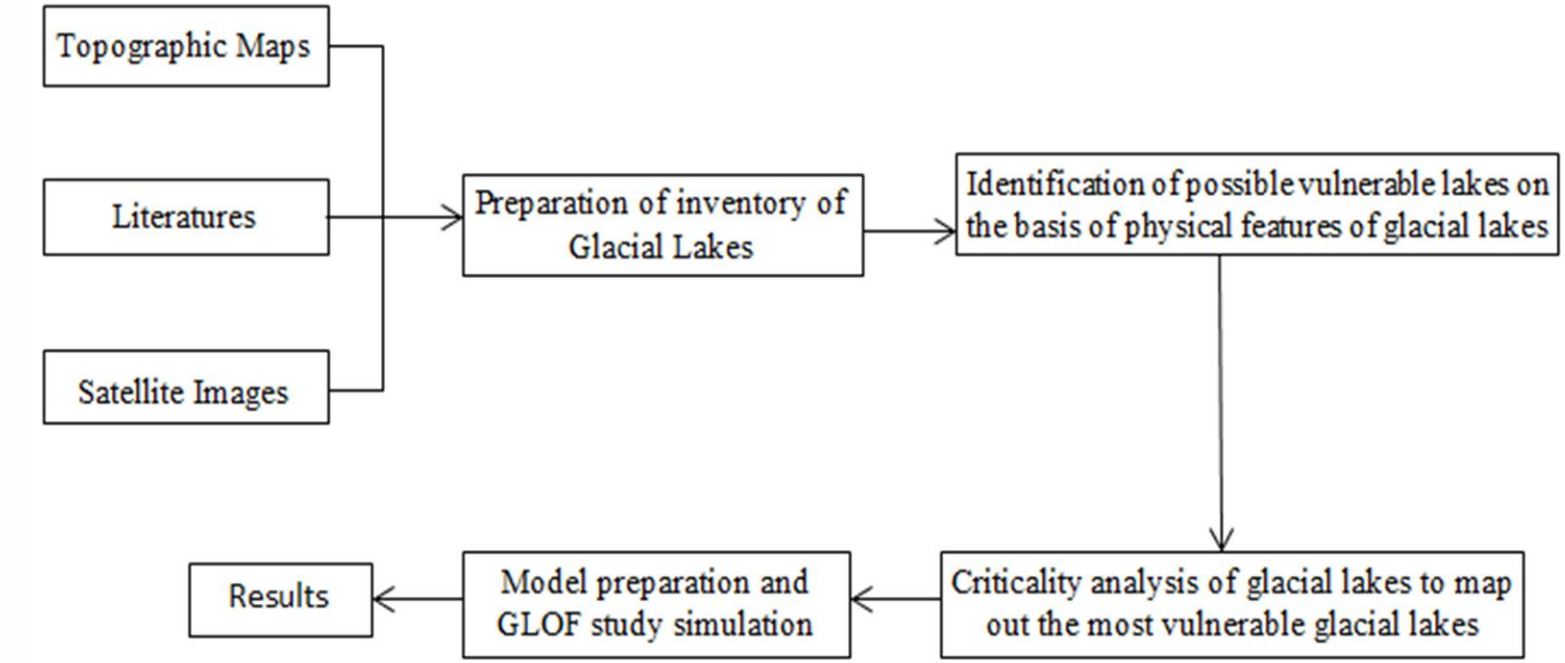
Froelich's formula (1995 B)

Von-thun and Gillette's formula (1990)

Federal Energy Regulatory Commission's formula (FERC 1987)



Flow Diagram for GLOF Study



✓The stream cross sections at an interval of 2 to 5 km, extracted from SRTM DEM, have been utilised to carry out the channel routing in MIKE-11.

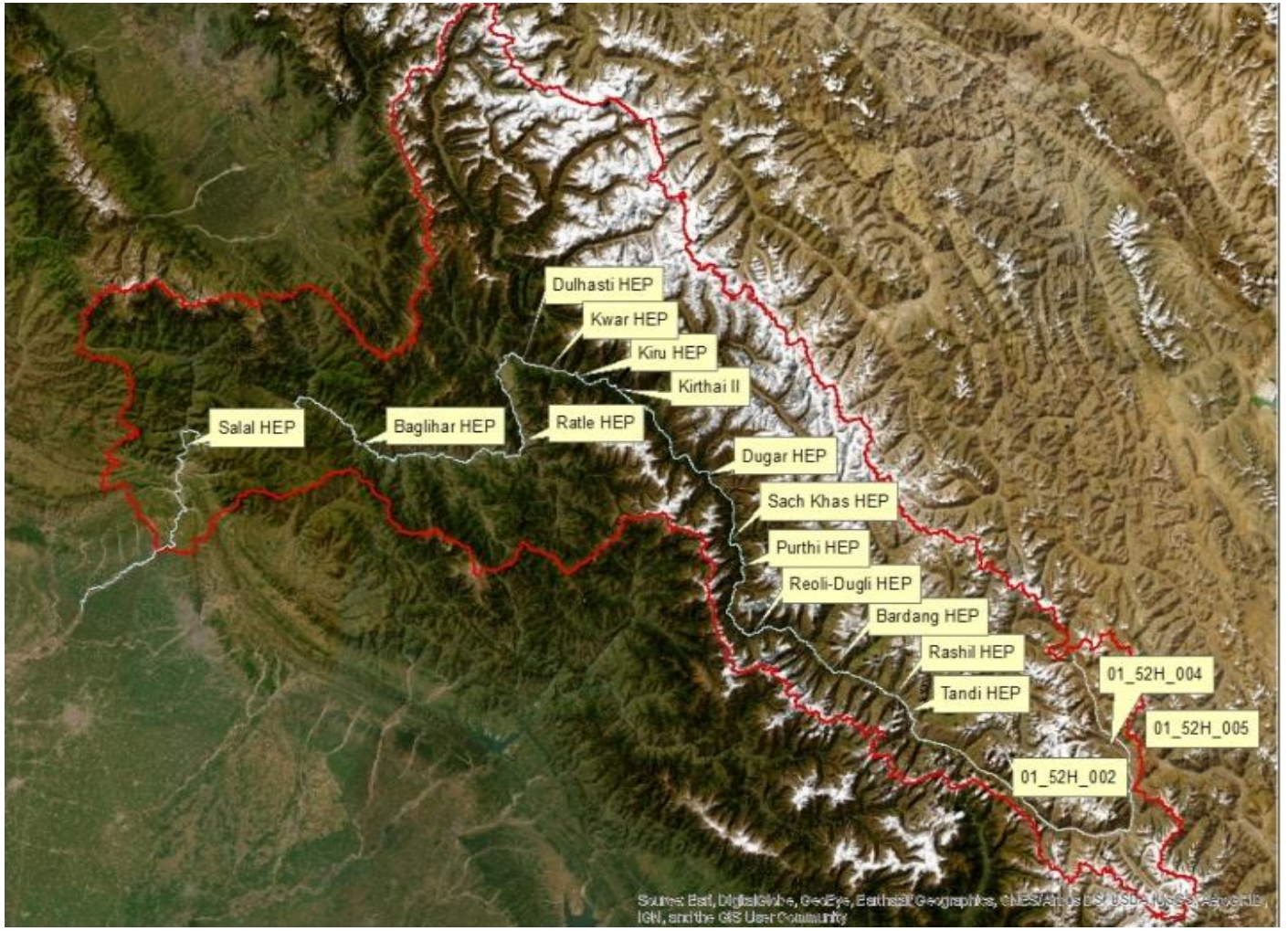
Case Study of GLOF in Chenab Basin (year 2009 and 2022)

✓**Why the Chenab Basin Matters??**

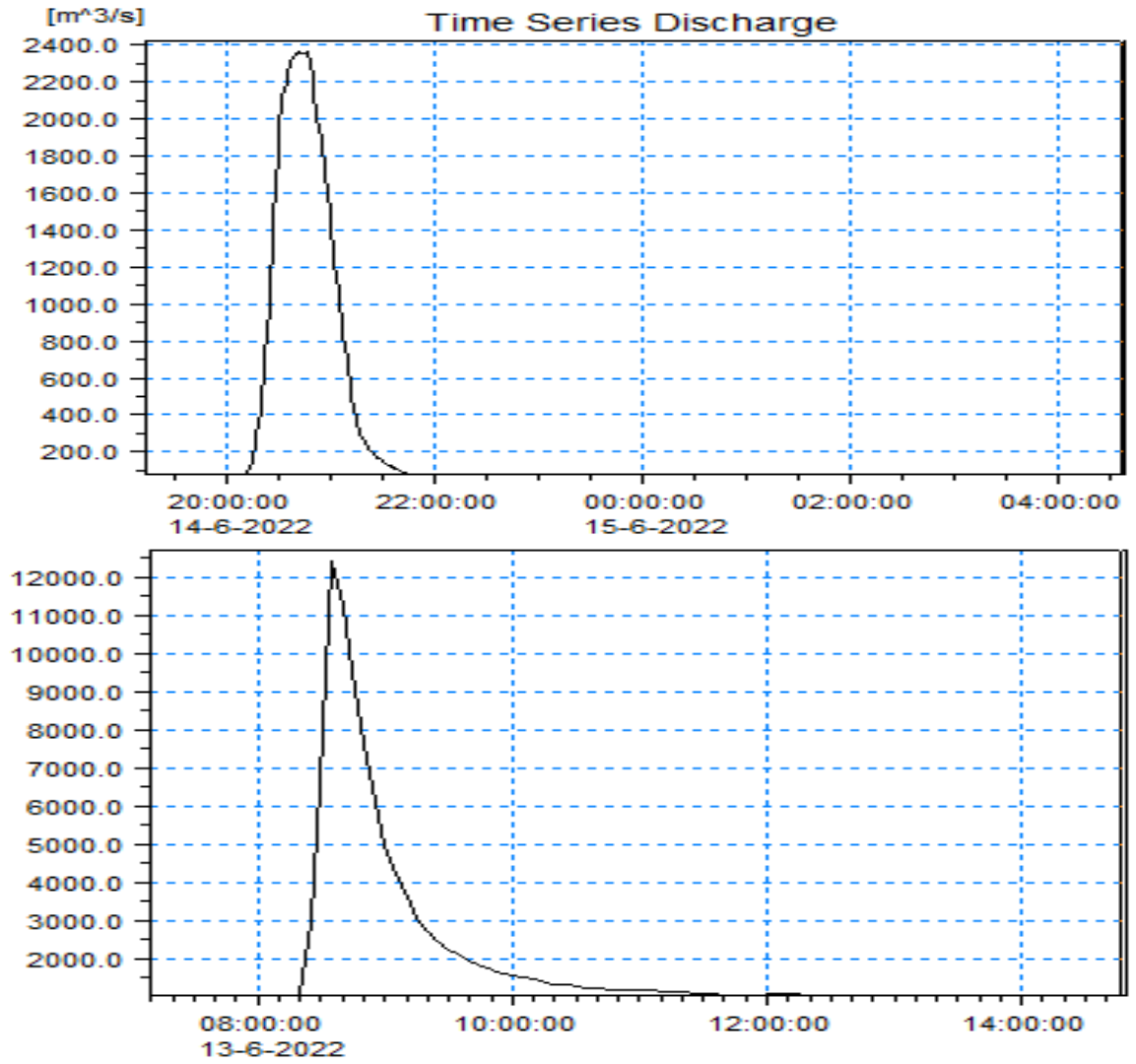
✓The present study is GLOF study in the Chenab Basin that covers the major project such as Tandi HEP, Rashil HEP, Badrang HEP, Reoli Dugli HEP, Purthi HEP, Sach Khas HEP, Dugar HEP, Kirthai II etc.

✓GLOF study in Chenab basin considering the satellite images of 2009 and 2022. The model is developed in MIKE 11 in order to simulate the GLOF hydrograph downstream.

✓DEM, C/S, Lake, Manning n



Results and Discussion



	2009	2022
Breach Width (Top)	55	110
Breach Width (Bottom)	38	72
Average Depth (m)	18	32
Breach Formation Time (Minutes)	30	30
Side Slope	0.75	0.75
Peak Discharge (cumec)	3254	12197
At 275 km d/s (cumec)	916	3075
Flood Arrival time (at 275 km d/s)	9 hr	7hr 35 min

Results and Discussion

Sl No.	Projects Downstream	Distance from Lake (km)	Based on 2009 Lake area				Based on 2022 Lake area				
			Discharge (m3/s)	Increase in Water Depth (m)	Velocity (m/s)	Flood Arrival Time (hh:mm)	Discharge (m3/s)	Increase in Water Depth (m)	Velocity (m/s)	Flood Arrival Time (hh:mm)	Increase in GLOF Peak
1	Tandi HEP	98	1251	1.57	4.02	04:05	4459	4.91	5.44	03:05	3208
2	Rashil HEP	105	1227	1.89	5.02	04:20	4321	5.29	6.87	03:20	3094
3	Bardang HEP	123	1150	1.84	5.68	05:00	3973	5.08	7.08	03:50	2823
4	Reoli-Dugli HEP	149	1096	1.29	3.99	05:45	3765	3.57	4.97	04:30	2669
5	Purthi HEP	172	1068	1.16	8.01	06:15	3637	3.54	9.78	05:00	2569
6	Sach Khas HEP	180	1061	1.11	7.13	06:25	3605	3.15	8.72	05:09	2544
7	Dugar HEP	205	977	1.45	6.69	07:10	3318	3.78	7.51	05:50	2341
8	Kirthai II HEP	238	941	0.74	7.52	08:05	3180	2.34	8.43	06:45	2239
9	Kiru HEP	250	933	0.61	9.19	08:25	3156	1.92	10.21	07:00	2223
10	Kwar HEP	257	929	0.72	7.74	08:35	3137	2.1	8.47	07:09	2208
11	Dulhasti HEP	264	925	0.68	8.24	08:45	3121	1.87	8.99	07:15	2196

Conclusion

I. The very first step in minimizing the threat can be to start the monitoring of vulnerable lakes more actively and regularly. The next step would be to carry out detailed studies and model simulation of potentially vulnerable lakes and to share the outcome with the concerned stakeholders.

II. It is also important to closely assess the bathymetric changes of identified lakes, instead relying only on satellite and remote sensing data.

III. Various methods and techniques may be used to mitigate potential GLOF hazards in Chenab basin. If the environment permits, lowering the level of the lake water is usually considered the most effective mitigation measure. When the lake water level is reduced, the hydrostatic pressure exerted by the water on the moraine wall is correspondingly reduced, ultimately diminishing the risk of outburst from the lake.

Conclusion

IV. An additional flood cushion may be provided during construction stage of projects to accommodate the increased discharge due to increase in size of glacial lakes.

V. Early Warning System (EWS), The transmitter station at glacial lakes sites that receives signals from sensors and transmits to other remote warning stations.

VI. Climate change is significantly impacting the Himalayan region, leading to the formation and changes in glacial lakes. Their rapid expansion and potential for GLOFs pose significant challenges to project downstream.

Thank You