ICIMOD

Glaciers and Glacial Lake hazard assessment in the transboundary Kailash Sacred Landscape

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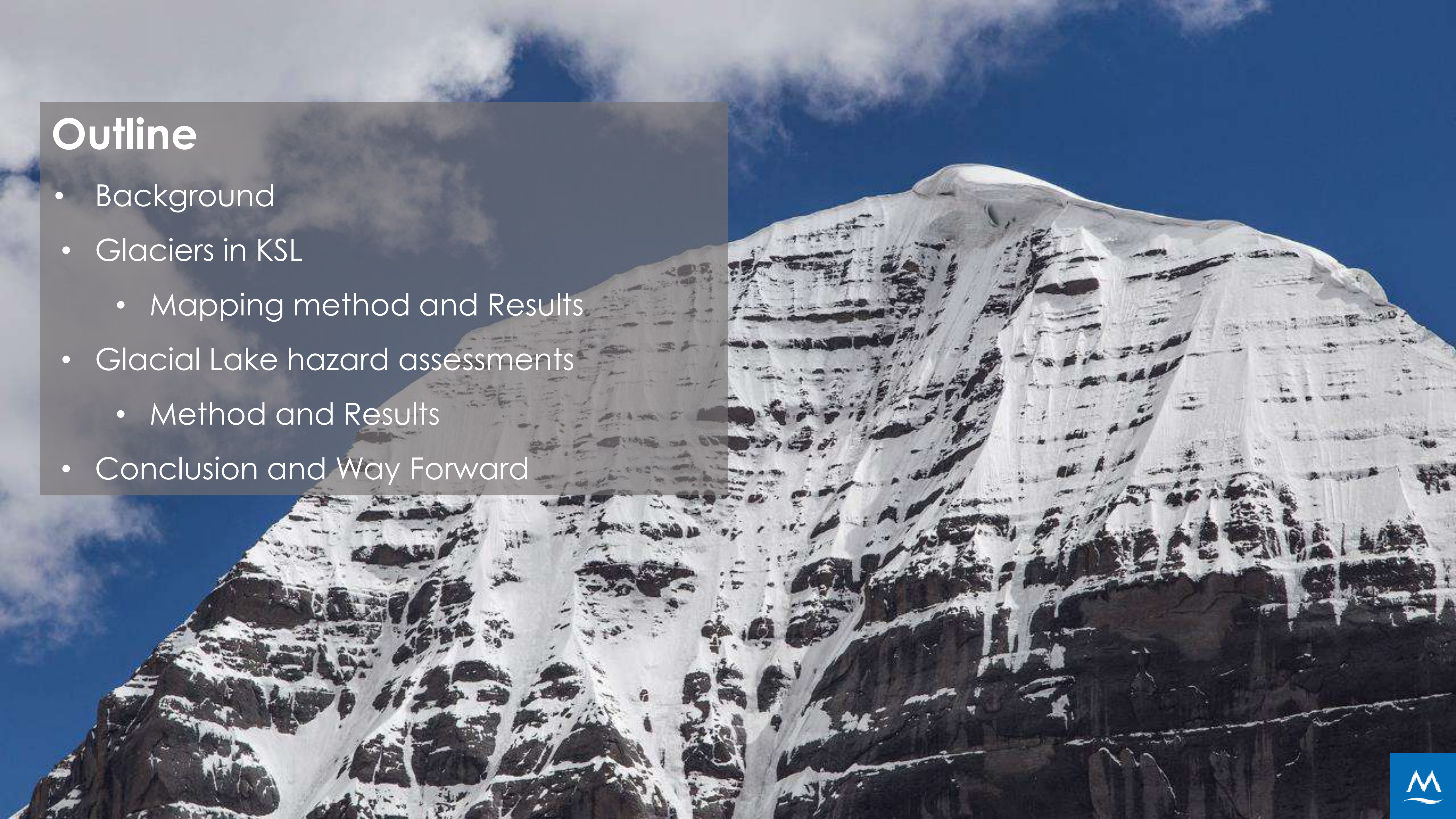
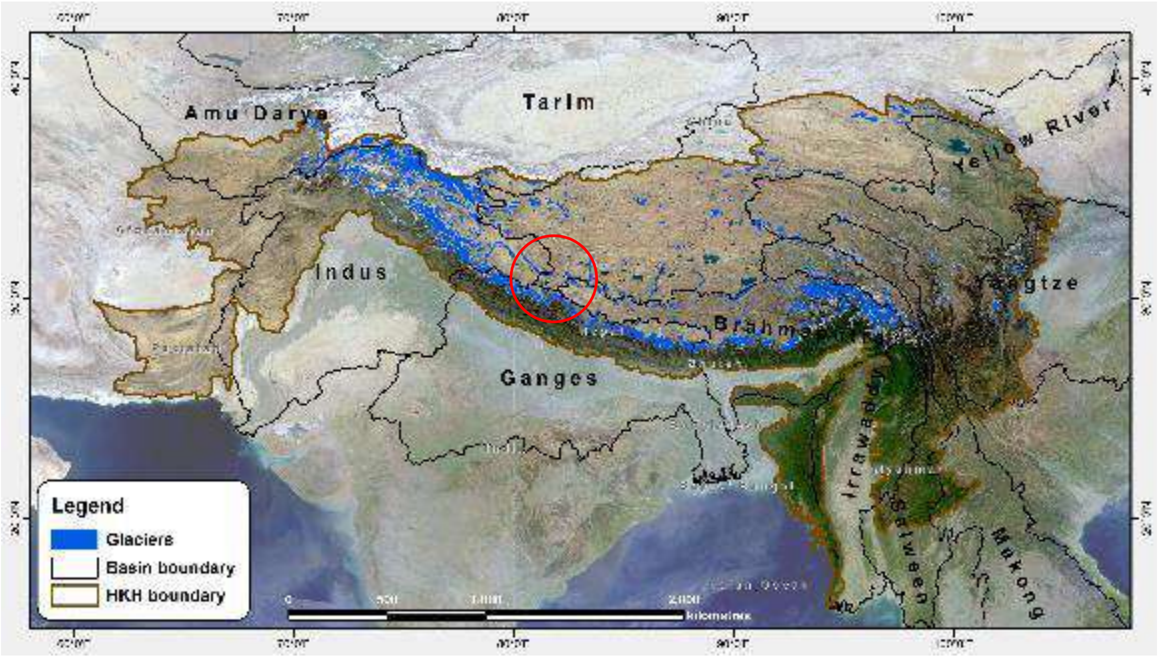
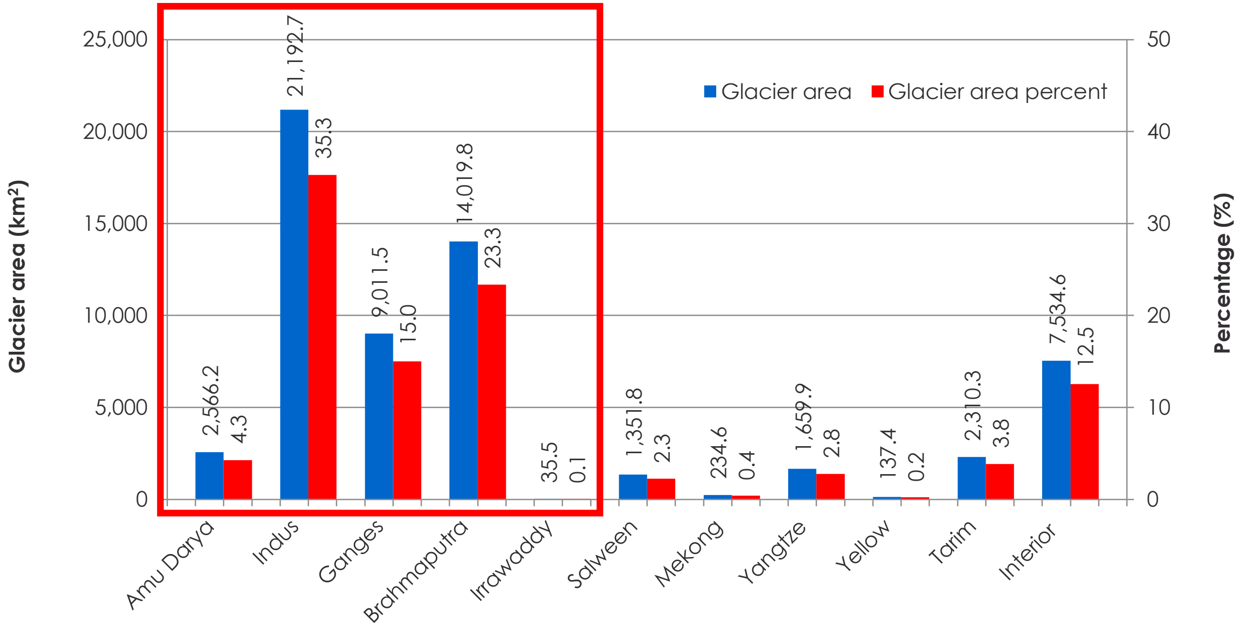


Outline

- Background
- Glaciers in KSL
  - Mapping method and Results
- Glacial Lake hazard assessments
  - Method and Results
- Conclusion and Way Forward

The Hindu Kush Himalaya Region



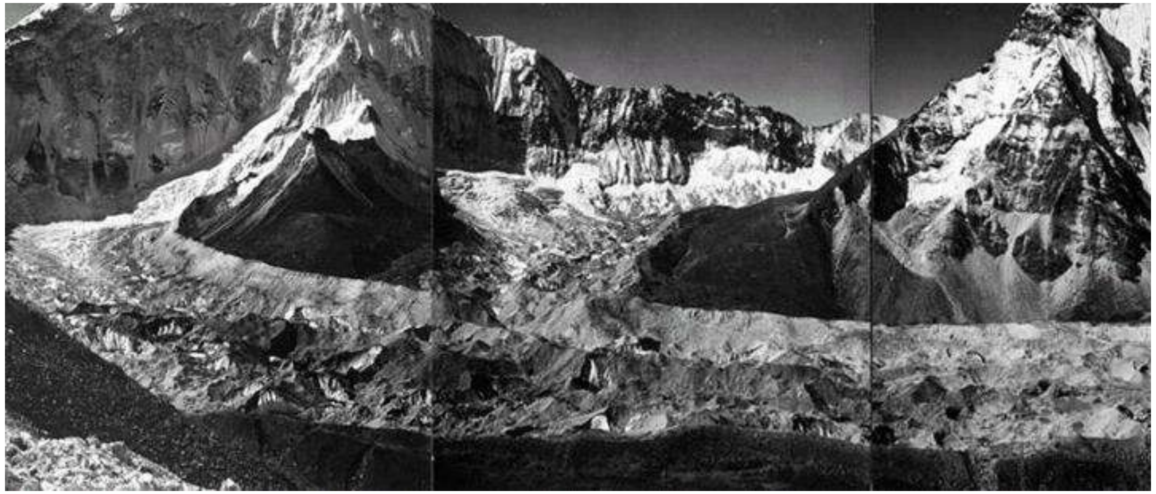


HKH area: 4.19 million km²

- **~9% of glaciers in globe**
- **240 million people** depend directly on HKH for their lives and livelihood
- **1.9 billion people depend** on the HKH for water, Food and Energy
- **>30% of world population** benefits indirectly from HKH resources and ecosystem

- It is the source of countless perennial rivers that originate from glaciers.
- It is also the source of various natural disasters such as snow avalanche, glacial lake outburst floods (GLOF).

Background



1956 photograph of Imja glacier
(Photo: Fritz Muller; courtesy of Jack Ives)

2006 photograph of Imja glacier
(Photo: Giovanni Kappenberger courtesy of Alton C Byers)

Safer limits of global warming to **1.5°C is even Too HOT for the HKH**

The HKH is warming more compared to global mean

Elevation dependent warming

Increase glacier recession and **increase in number and area of glacial lakes**; **increase of Glacial Lake Outburst Floods (GLOFs) risk**

In a 1.5˚C world, glaciers in the HKH will **lose 1/3 of their volume by 2100** and **2/3 of their volume** under current emission trends

Snow covered areas and snow volumes will decrease and snowline elevations will rise;

Snow melt induced run-off peak will be stronger and occur earlier in the year

Kailash Sacred Landscape

The landscape covers 31,000 km^2 area and **located in the central and western Himalayas spanning parts of China, India, and Nepal**

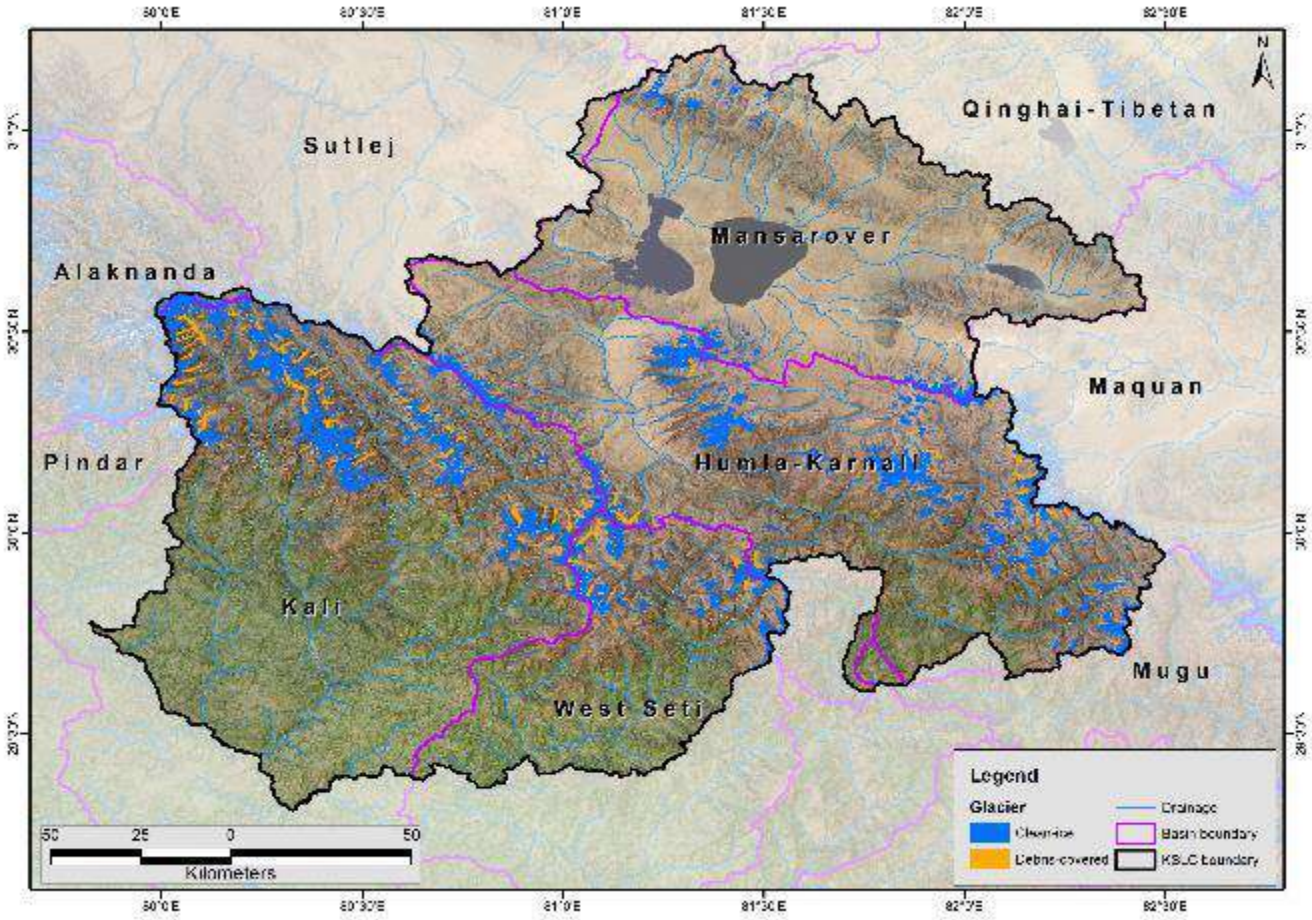
Renowned for the sacred Mount Kailash (6638 masl)

Religious and Spritual Values – Mount Kailash and Mansarover lake – Buddhism, Hinduism, Bon-Po, Jainism

Three major gigantic river basin of HKH starts from four sides of the Kailash region

Glacier and Glacial lakes are essential element of the multi-cultural and fragile cultural landscape.

Altitudinal variation ranges from 400 – 7700 masl.



Glaciers in KSL

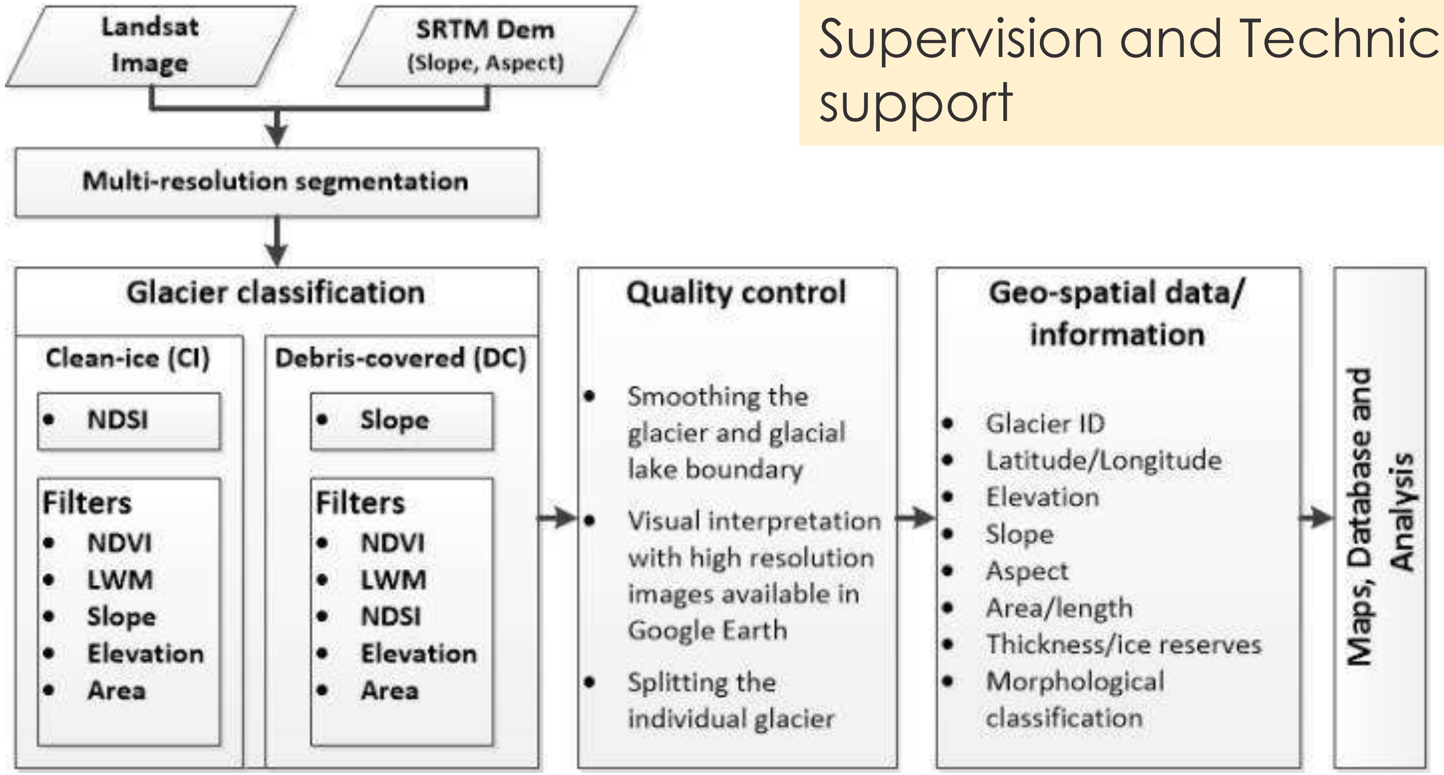
Large perennial ice mass originates on land by recrystallization of snow and other forms of solid precipitation that is moving slowly.

Area larger than or equal to 0.02 km^2. Scale 1: 50,000

Consistent and homogenous remote sensing data source and methods

Mapping guidelines based on World glacier inventory, Global Land Ice Measurement from Space (GLIMS) and GlobGlacier consortium

Methodology



Training

On–the–Job Training

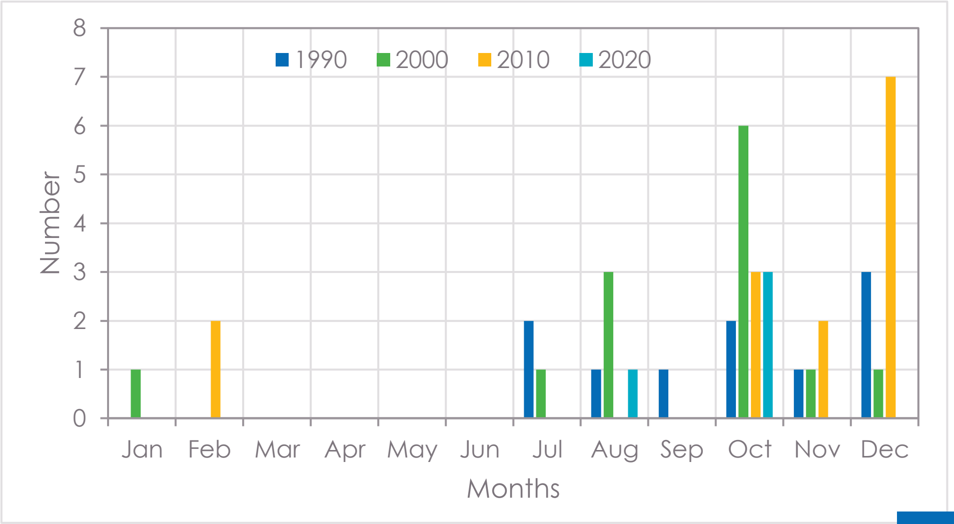
Supervision and Technical support

Consistent data source

Spatial resolution

Temporal resolution

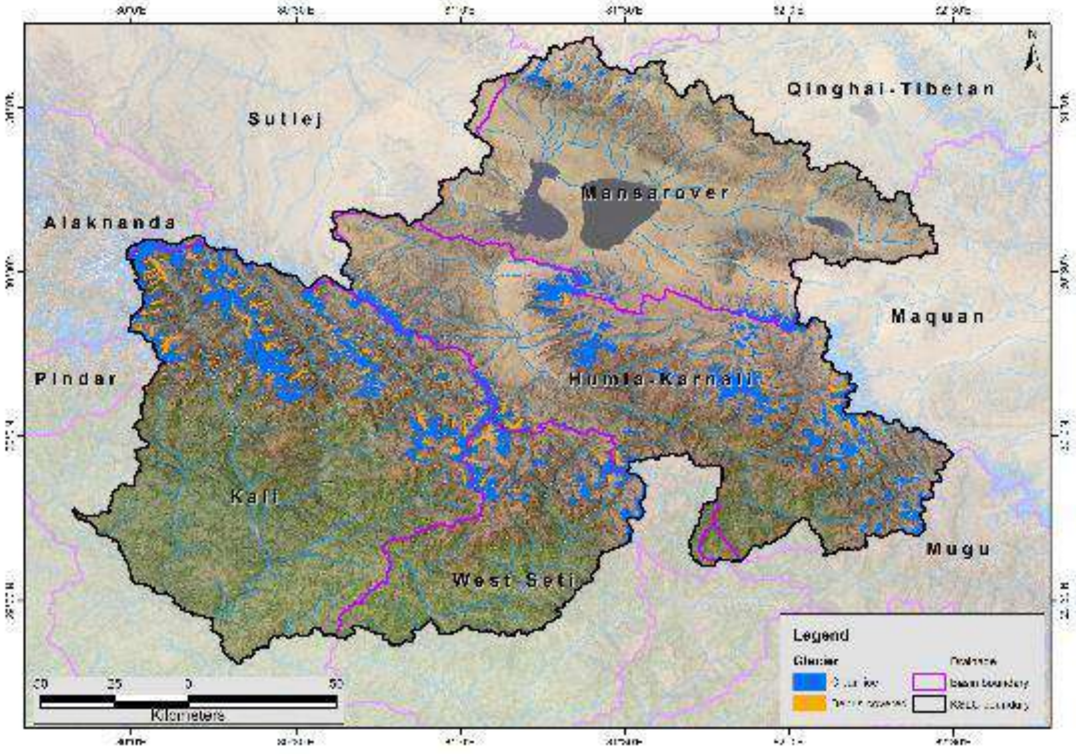
Accuracy and Quality



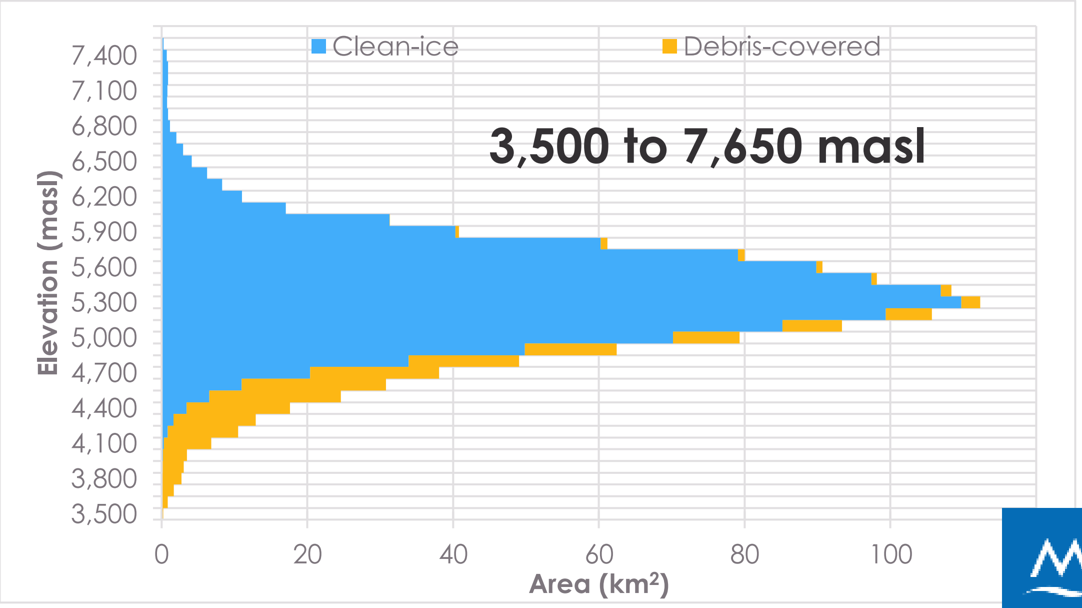
Images used – 40 Landsat Tiles

Glacier Status in KSL (2020)

- Glacier area covered **3.8% of the total landscape area**.
- Almost **13.3% of glaciers** are **debris covered**.
- **Milam glacier** lies in Kali River is the **largest glacier**, which covers an area of **49.5 km^2**.
- Majority (77%) of glaciers are of size less than 0.5 km^2 which covers only 18.5% of total glacier area.
- One third of total glacier area is covered by glacier size of 1 to 5km^2.



Basin	Sub-Basin	Glacier Number			Area (km^2)			
		CI	DC	Total	CI	DC	Total	Largest
Ghaghara	Kali	751	57	751	429.9 ± 10.9	93.44 ± 0.9	523.4 ± 12.8	49.46
	Humla-Karnali	739	42	739	406.4 ± 8.7	43.81 ± 0.5	450.2 ± 9.5	12.53
	West Seti	282	13	282	105.8 ± 2.2	17.78 ± 0.1	123.6 ± 2.5	12.33
	Total	1772	**112**	**1772**	**942.1 ± 21.8**	**155.03 ± 1.5**	**1097.2 ± 24.7**	**49.46**
Manasarover		169	**0**	**169**	**71.9 ± 2.5**	**0 ± 0**	**71.9 ± 2.5**	**7.13**
Total		1941	**112**	**1941**	**1014.01 ± 24.6**	**155.03 ± 1.5**	**1169.04 ± 27.7**	**49.46**



Decadal change (1990 -2020)

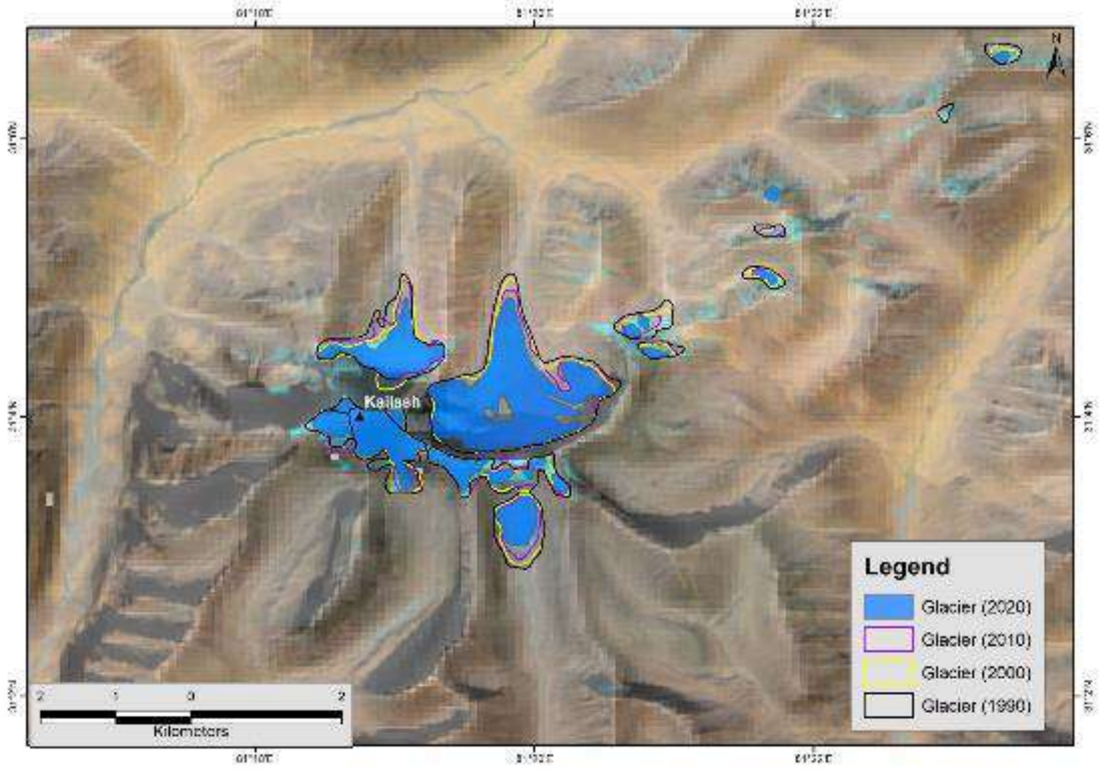
Glacier number has increased by 7.8% (fragmentation)

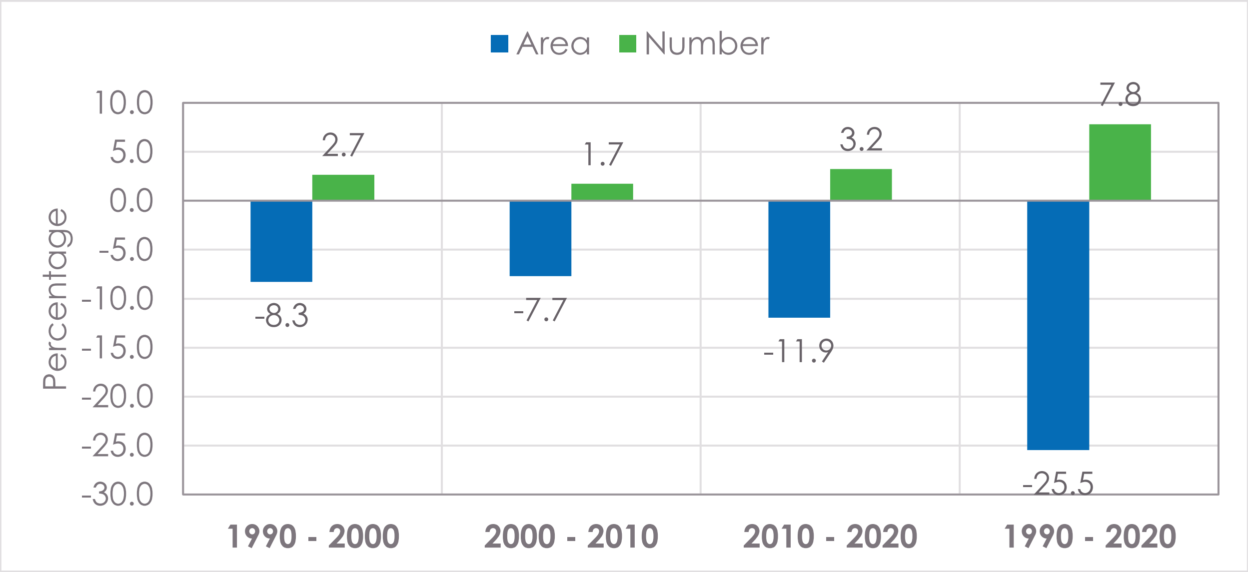
Glacier area has decreased by 25.5%

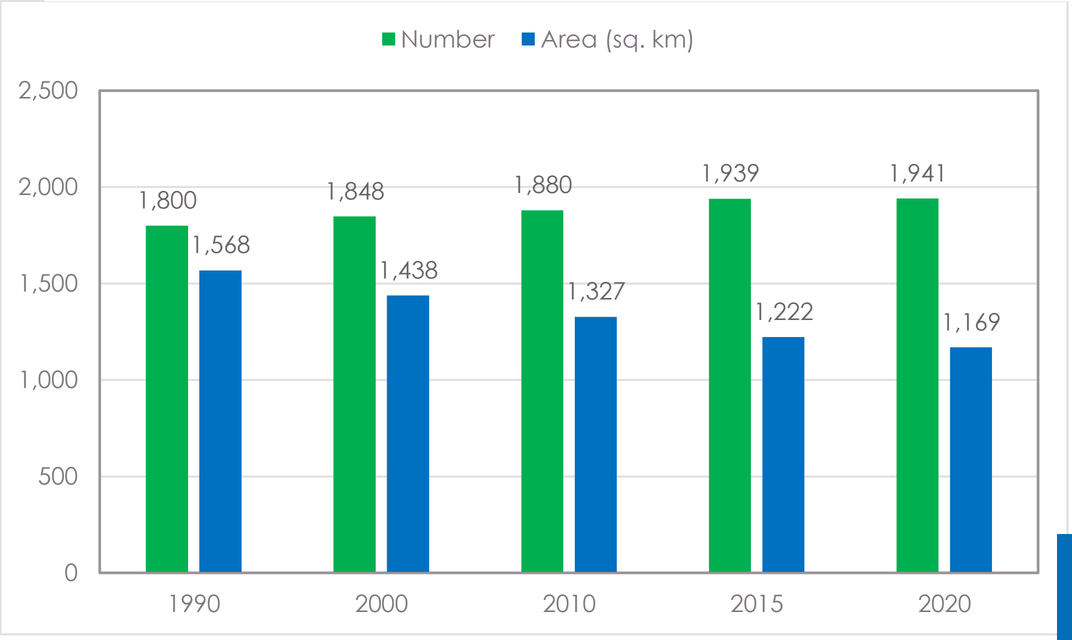
Drastic decrease in recent decades, i.e. 2010-2020 (11.9%)

Area percentage of debris-covered (DC) glaciers has increased from 8.7% to 13.3%,

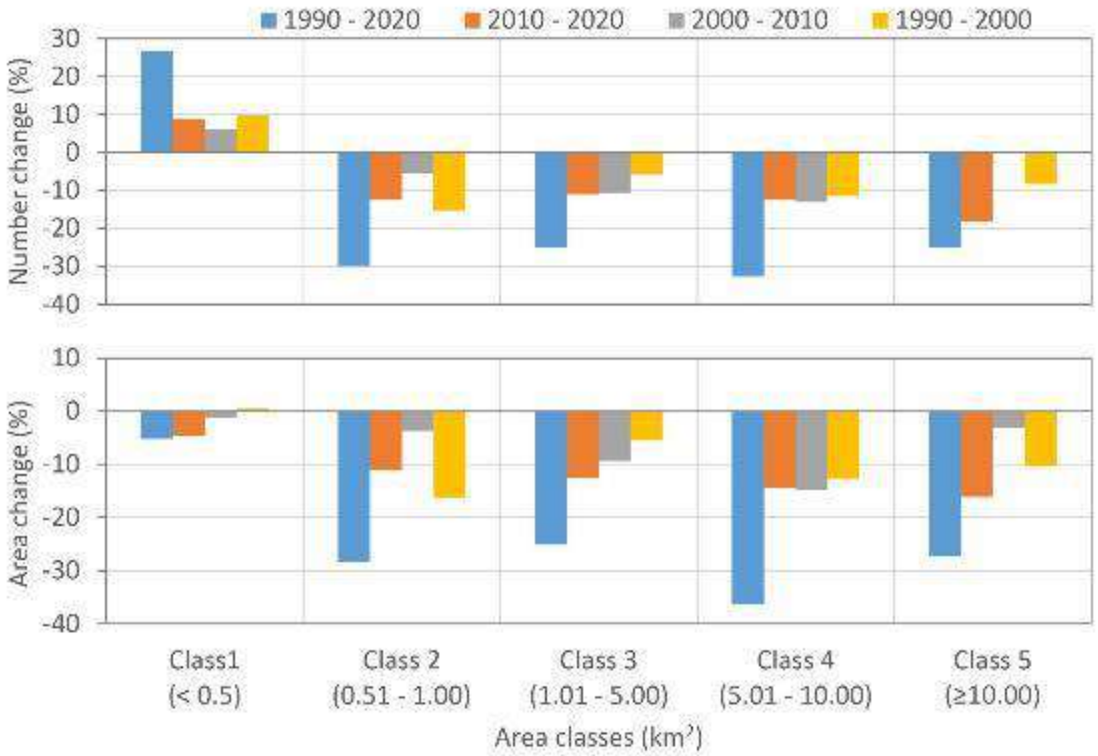
Clean-Ice (CI) glaciers decreased from 91% to 87% from 1990 to 2020

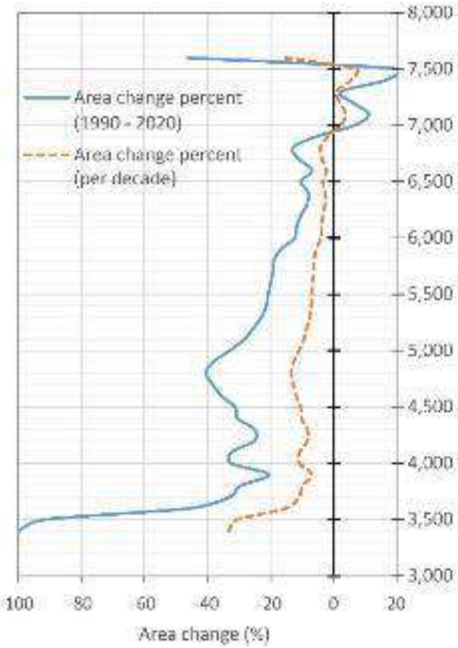


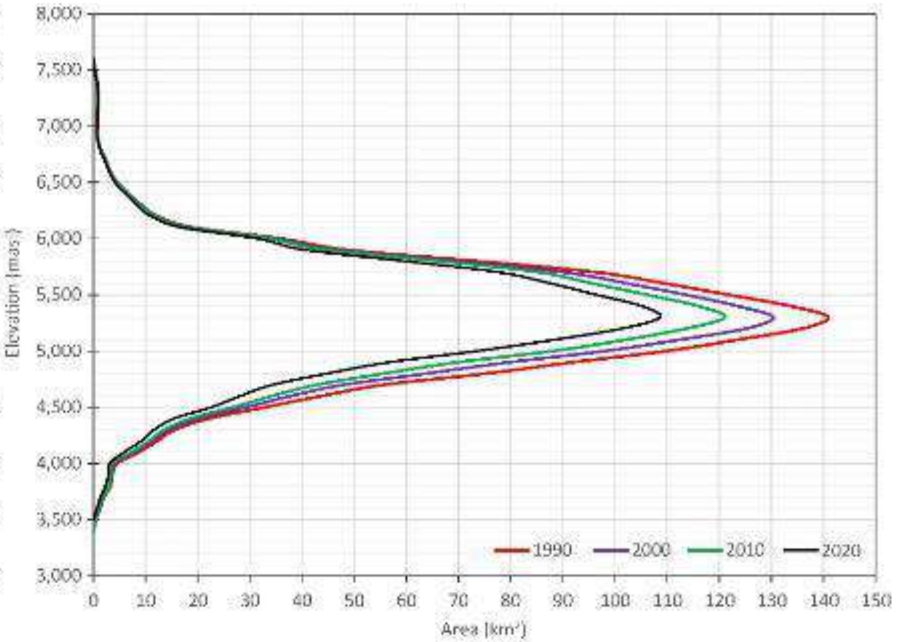




Decadal change (1990 -2020)







- Shrinkage of larger glaciers led to fragmentation into smaller glaciers.
- Area of all glacier size decreased in each decade with **higher area decreased in larger sized glaciers**.
- **Maximum glacier area loss (33%) was in class 4** and glaciers larger than 10 km^2 (class 5) showed 25% loss in 30 years.
- The **largest glacier** also **decreased** by **more than 9%** (54.5 km^2 in 1990 to 49.5 km^2 in 2020).

- **Maximum glacier area loss** is at an elevation range from **5,000 to 5,500 masl** – ranges 20 -40% in each 100m elevation band.
- **Less than 20% area loss** in 100 elevation band between **5,500 to7,000 masl.**
- **Decreased area below 4,000 masl** indicated the **retreat of the glacier terminus and upward shifting** of glacier elevation
- The **lowest elevation glacier** is highly sensitive to temperature, thereby **influencing higher rates of ablations**

Glacial Lake and hazard assessment

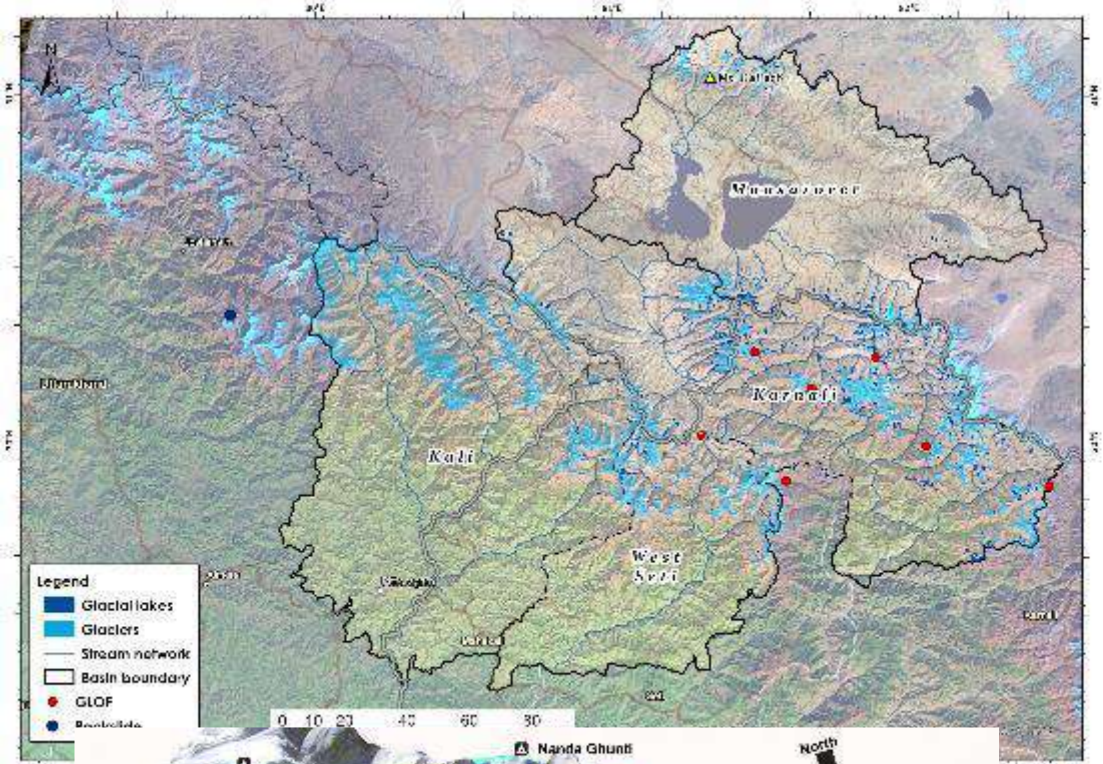
- Glacial melt water dammed by – Ice, moraine(debris), bedrock, landslide or alluvial fan
- Area ≥0.003 km^2 (at least 3-4 pixels in 30m resolution satellite image)
- **737 glacial lakes** covering **31.2km^2**. (Largest Glacial lake 1.9km^2)
- **65%** of glacial lakes are in **Humla-Karnali** (498) followed by Mansarover (125), Kali (63) and West Seti (51).
- Elevation ranges **3400 - 6100 masl** (90% above 4500 masl)
- More than 45% of GL covering 51% of total lake area are in elevation ranges of 5000 to 5500 masl
- 65 % are moraine dammed – 13% end-moraine dam contribute higher area coverage than others.

GLOFs and other disaster around KSL

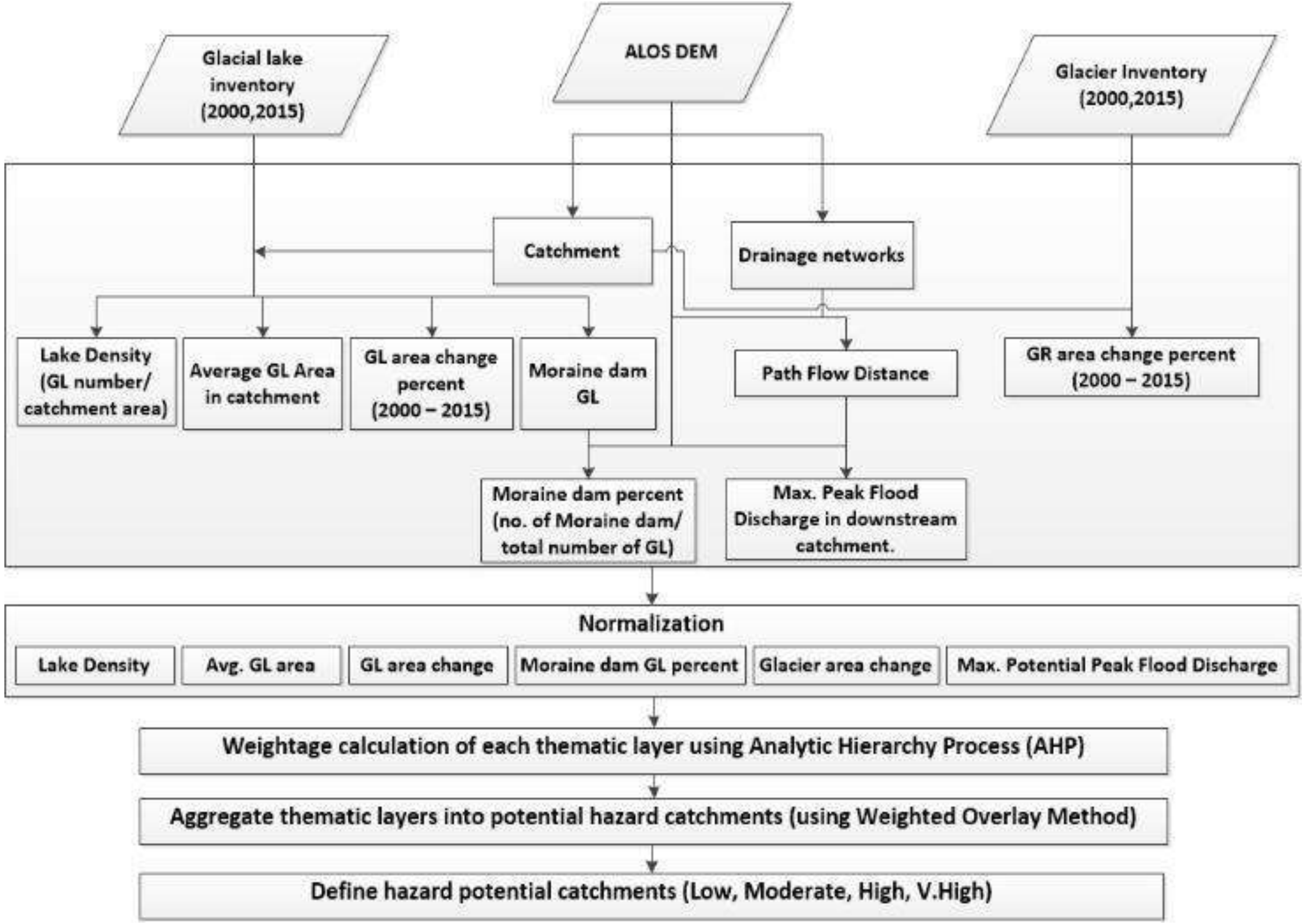
- 11 GLOFs have been recorded from 6 glacial lakes within KSL
- Six outburst event from supraglacial lake in Halji (2004 – 2011)

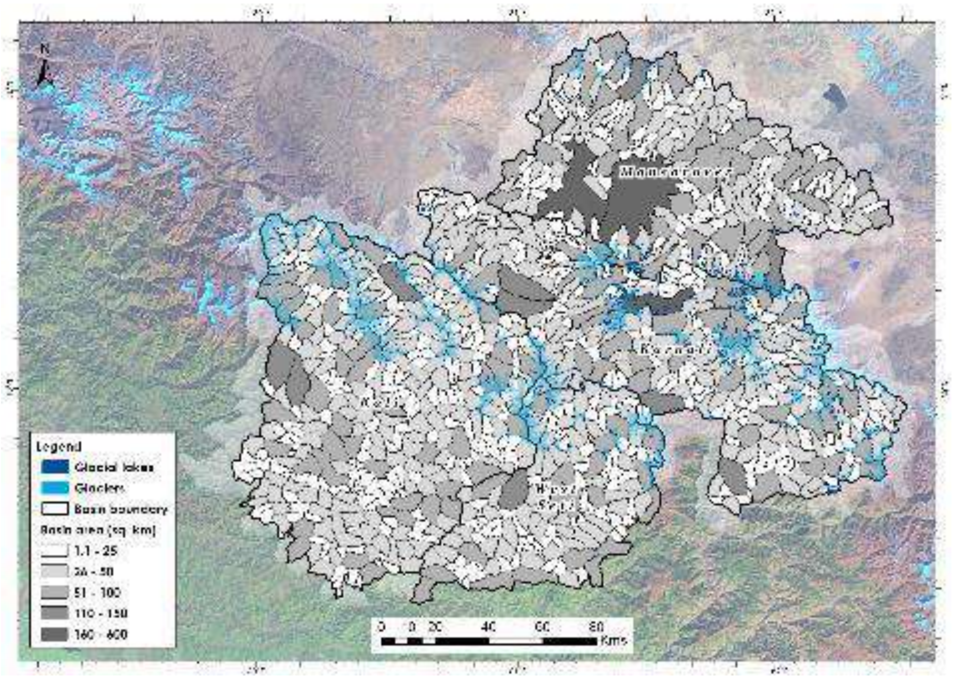
SN	Year	Location	Elevation	Lake type	River Basin
1	NA	GL081295E30029N	5136	Moraine dammed	West Seti
2	NA	GL082044E29994N	4716	Moraine dammed	Humla
3	NA	GL082451E29875N	5285	Moraine dammed	Humla
4	NA	GL081877E30251N	5377	Supraglacial	Humla
5	NA	GL081664E30164N	4907	Moraine dammed	Humla
6	2004	Halji	5347	Supraglacial	Humla
7	2006	Halji	5347	Supraglacial	Humla
8	2007	Halji	5347	Supraglacial	Humla
9	2008	Halji	5347	Supraglacial	Humla
10	2009	Halji	5347	Supraglacial	Humla
11	2011	Halji	5347	Supraglacial	Humla
12	NA	GL081578E29898N	3581	Moraine dammed	Humla

Sources: Zheng et al., 2021; Kropacek et al., 2015; ICIMOD, 2021

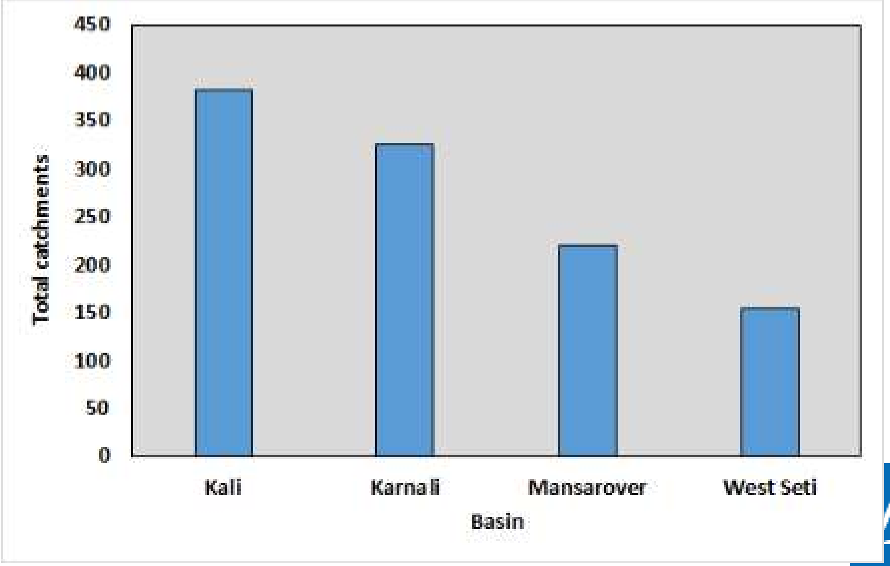


Methodology

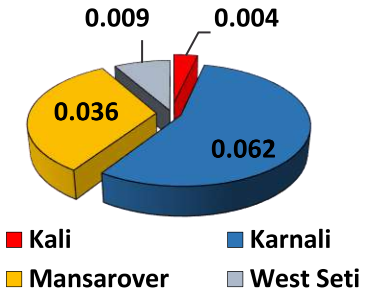


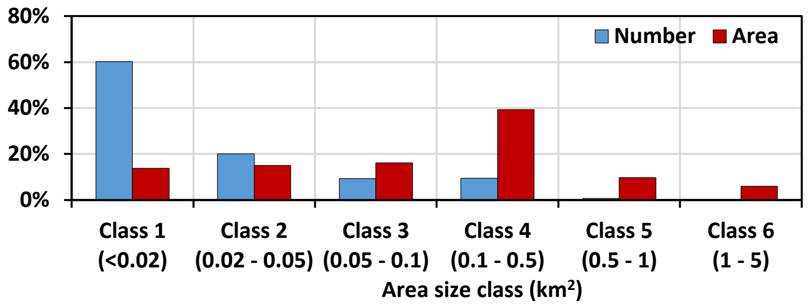


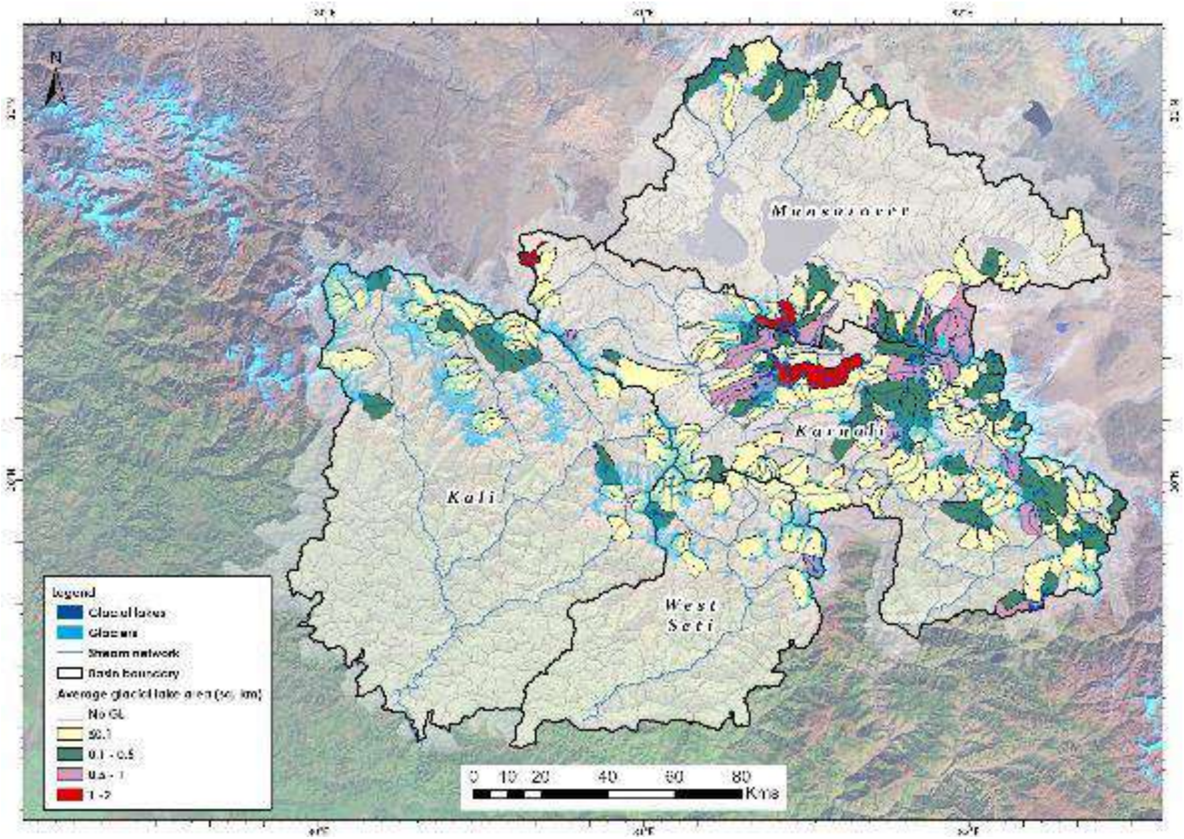
- Total number – 1080
- Size ranges – 1.1 to 155 km^2 except two catchments
- Average size – 28.6 km^2

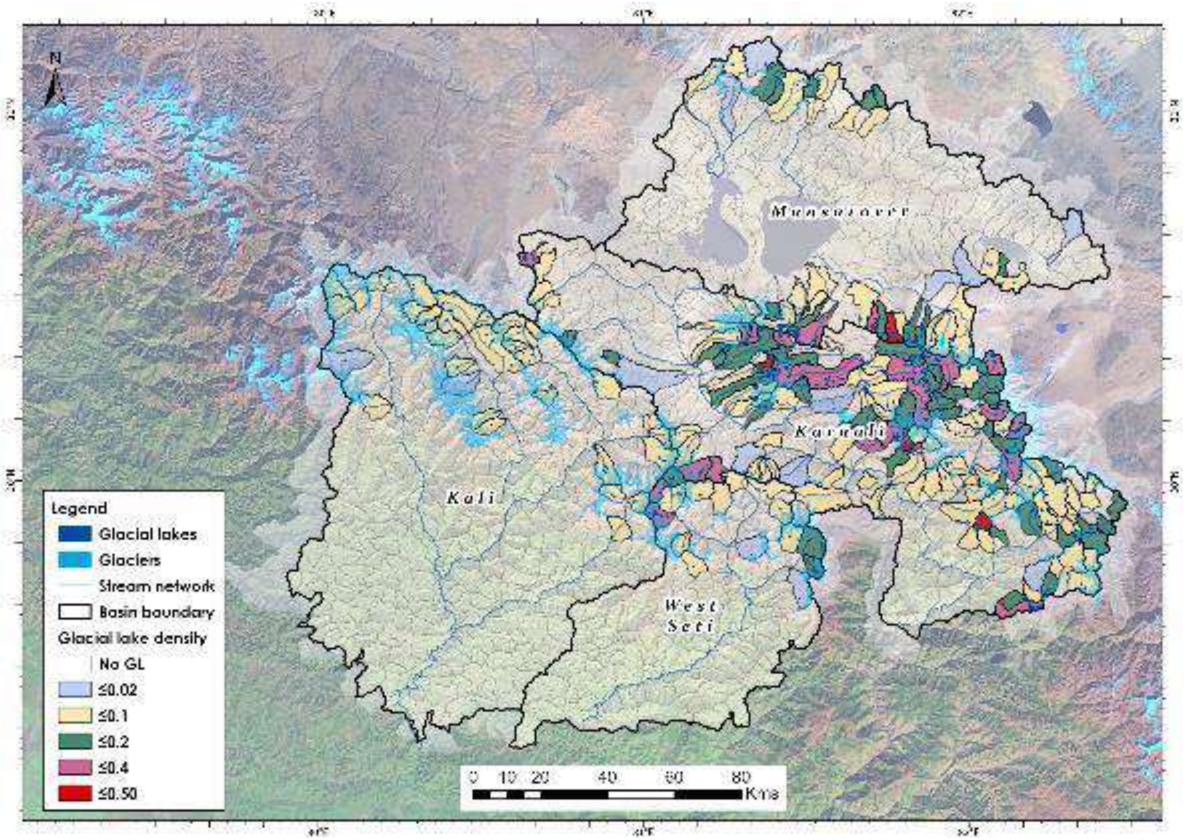


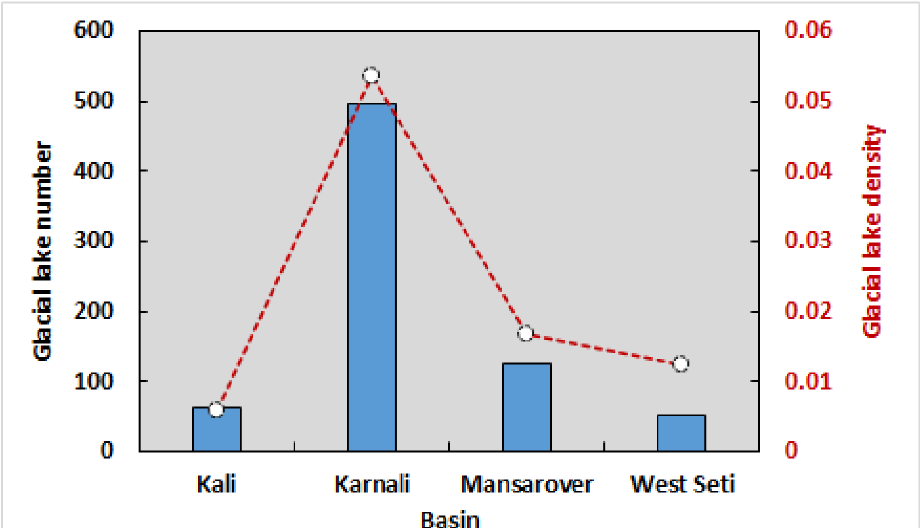
Glacial lake size and density





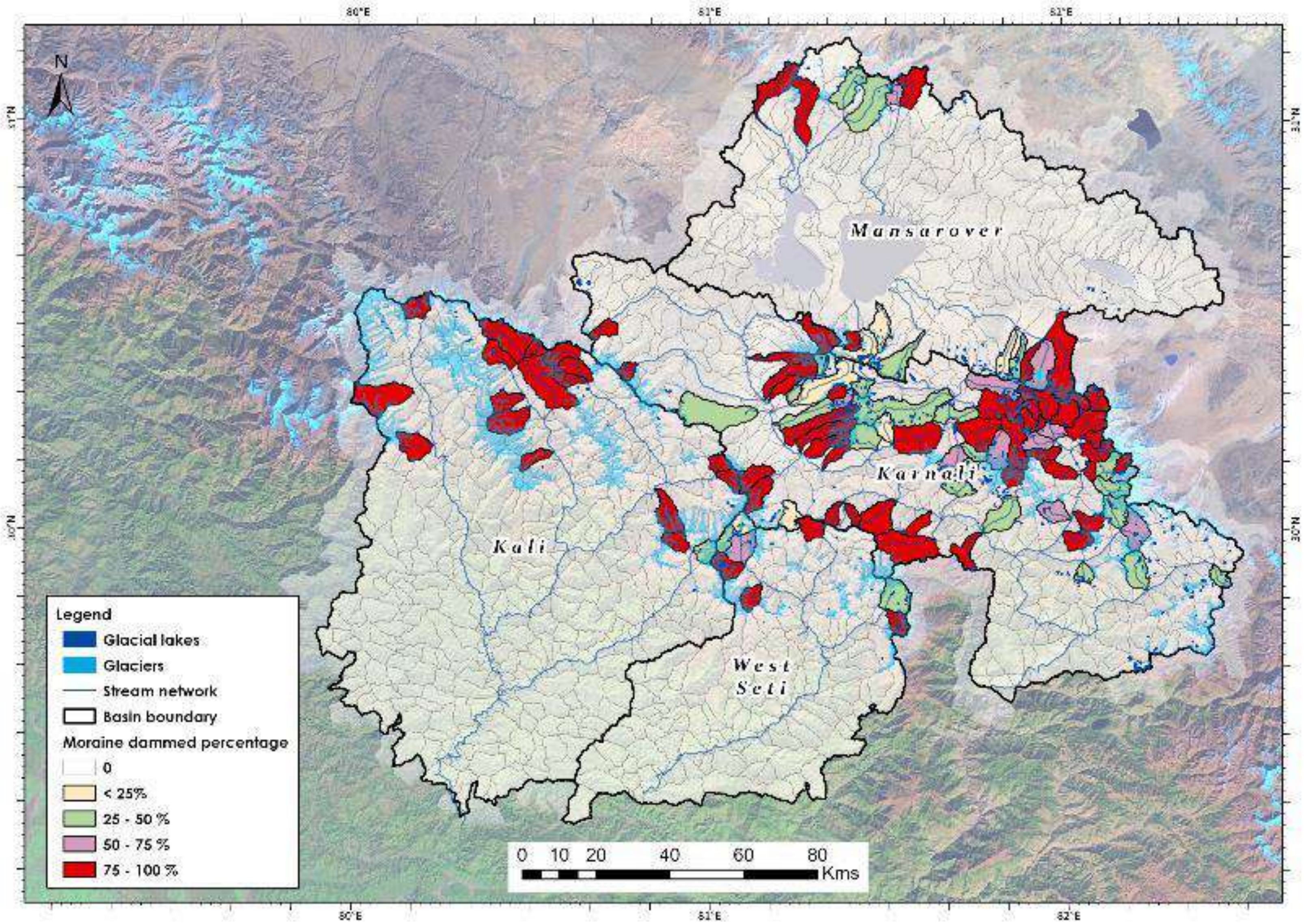


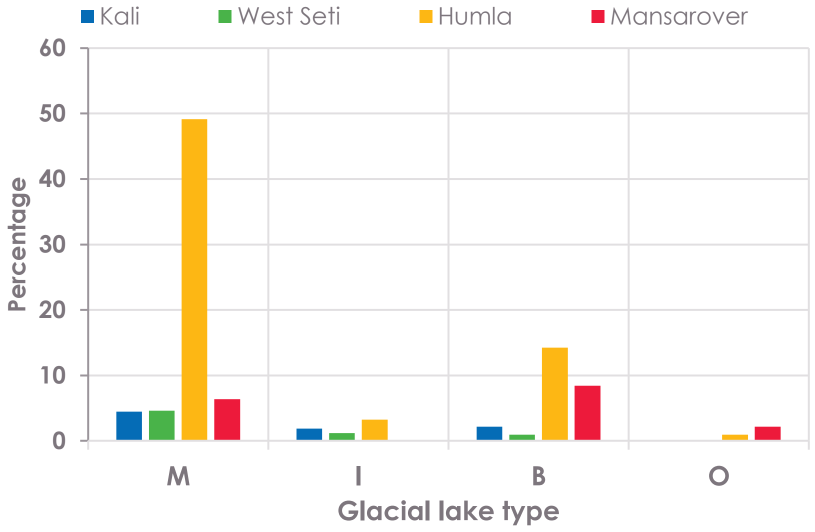


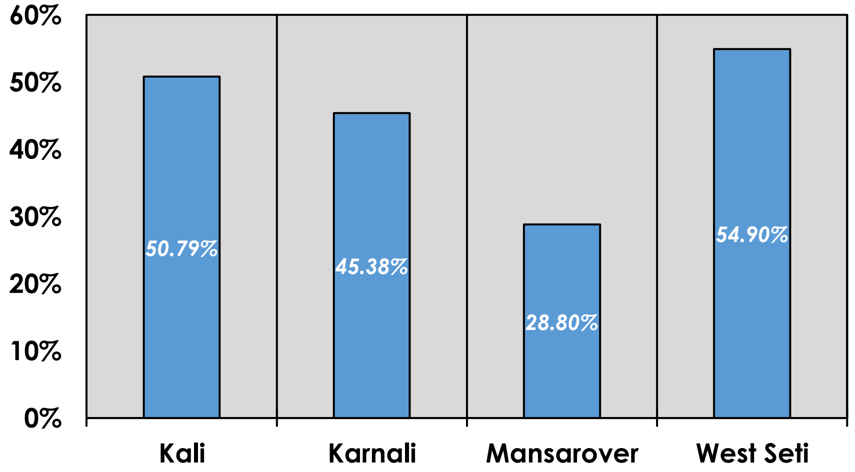


Moraine dammed lake percentage

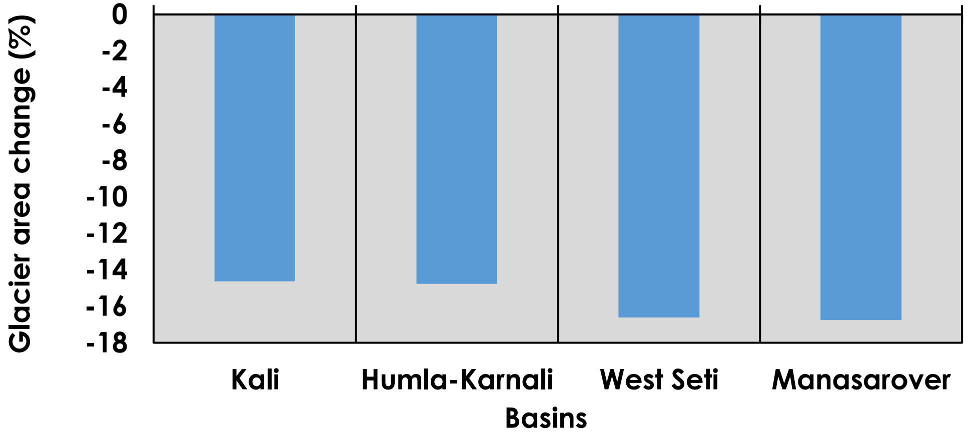
$$\frac{\text{Total Moraine dammed lake number}}{\text{Total glacial lake number}}$$

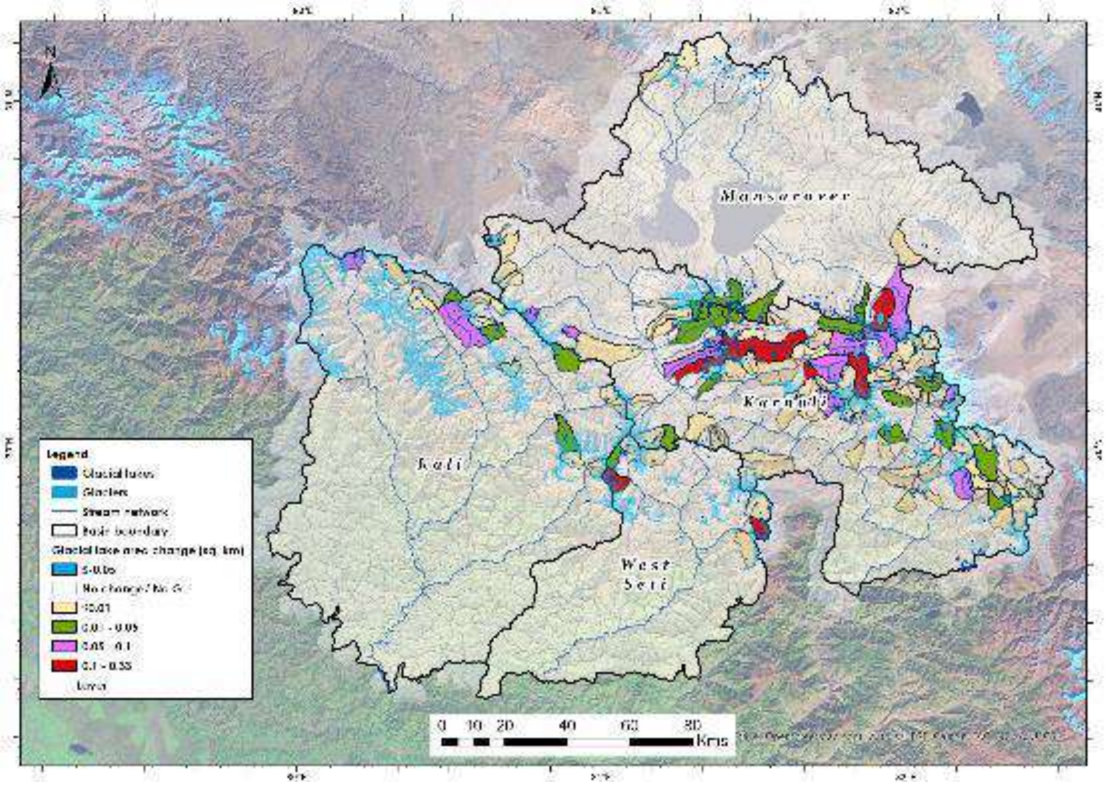


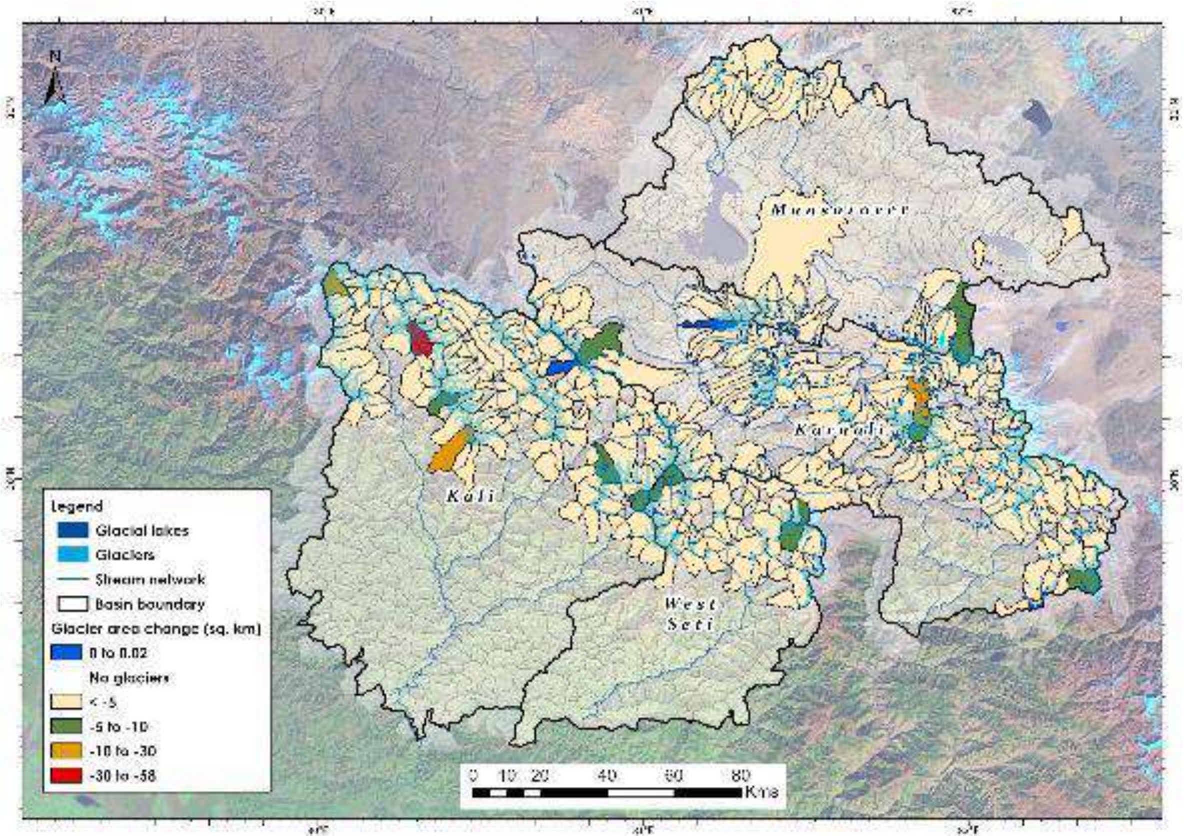


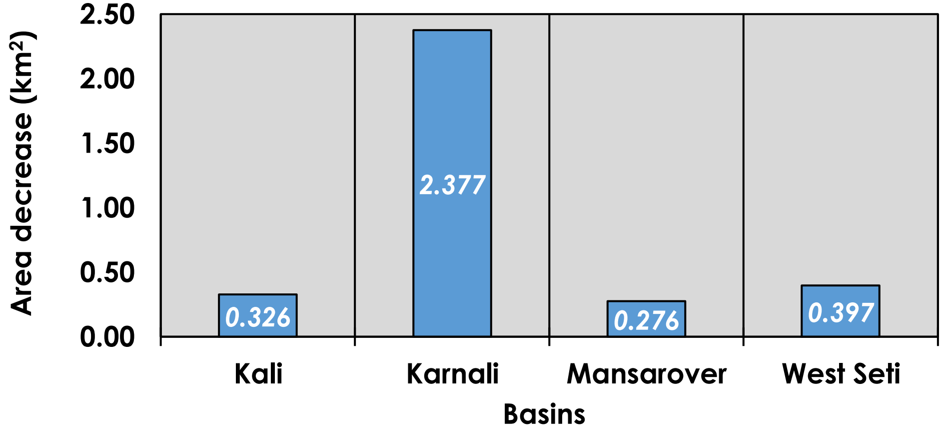


Glaciers and glacial lake area changes (2000 – 2015)

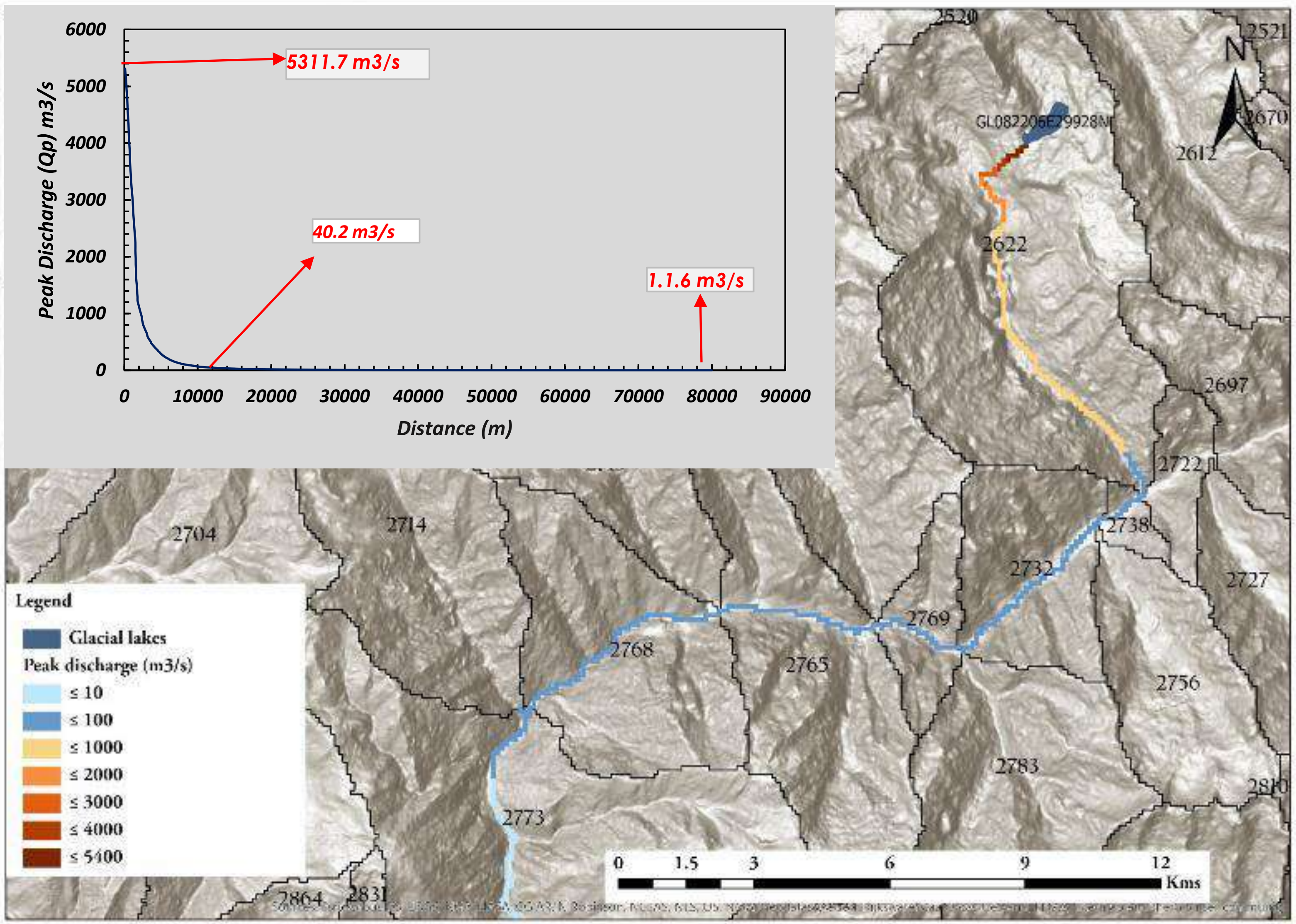








Peak flood discharge estimation



Peak flood discharge scenario at Lake GL082206E2992N

Maximum possible Discharge from glacial lake
(Huggel et.al 2002)

$$Q_{max} = 0.00077V^{1.017}$$
$$where, Qmax\ is\ dischage\ m^3\ per\ second$$

Peak flood discharge in downstream
(Chi et al 2012; Fan et. al. 2012)

$$Q_{pl} = \frac{V}{\frac{V}{Q_p} + \frac{L}{vk}}$$

Q_{pl} *: Flood peak discharge* m^3/s

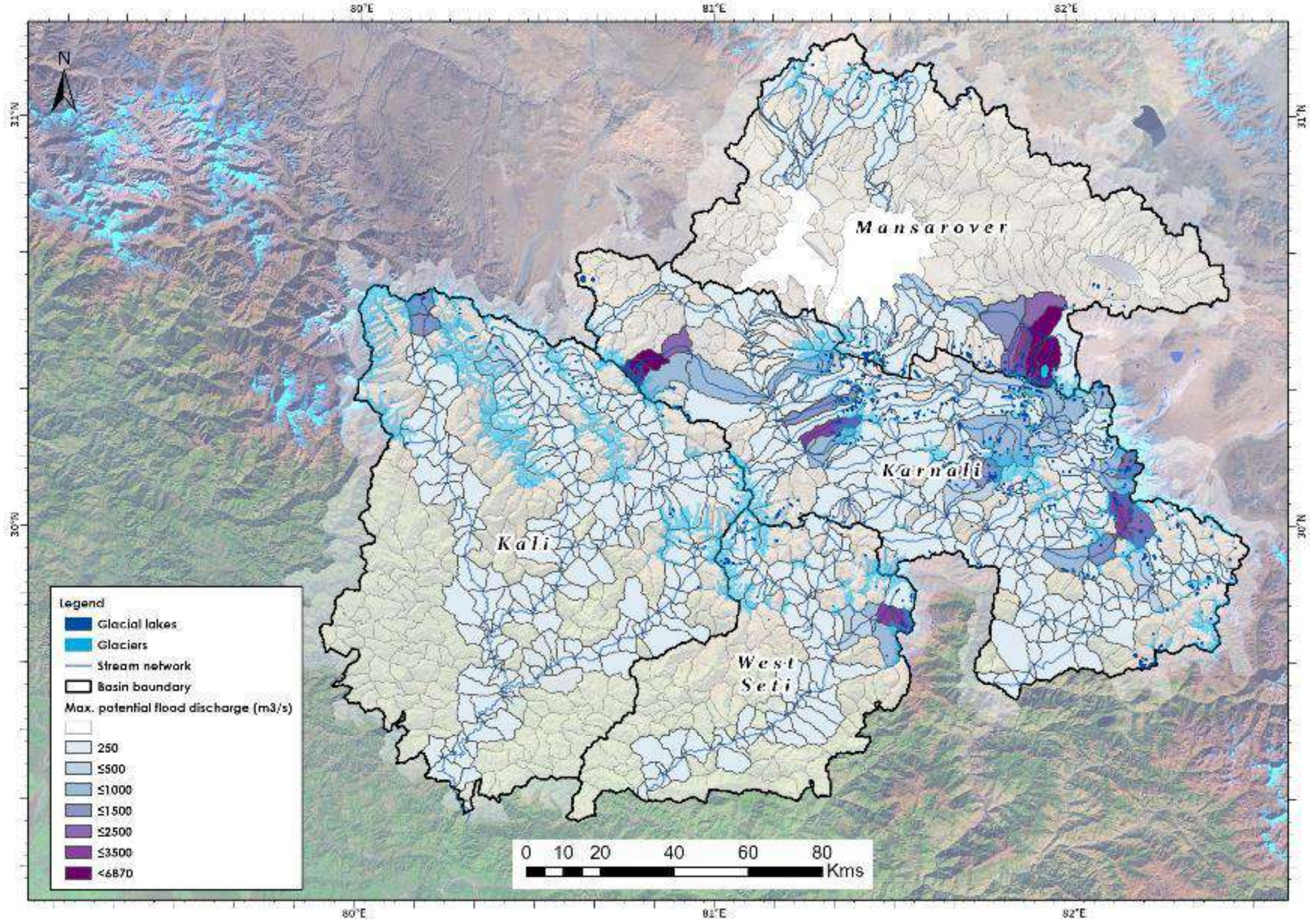
V *: Volume of the lake,* m^3

Q_p *: Peak discharge at the breach,* m^3/s

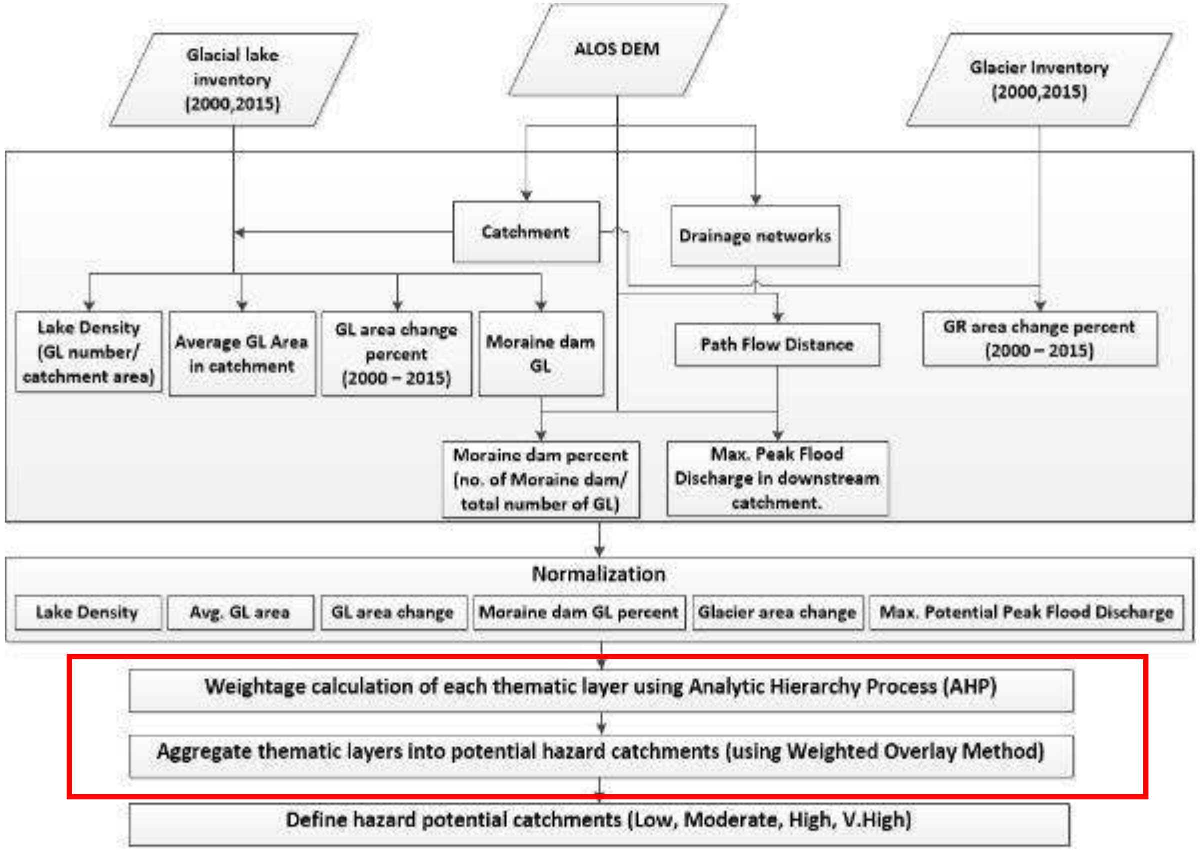
L *: Distance from the glacial lake dam, m;*

vk *is an empirical coefficient equal to 3.13 for rivers on plains, 7.15 for mountain rivers and 4.76 for rivers flowing through terrain with intermediate relief, which here we set the value as 7.15.*

Maximum potential flood discharge (m^3/s)

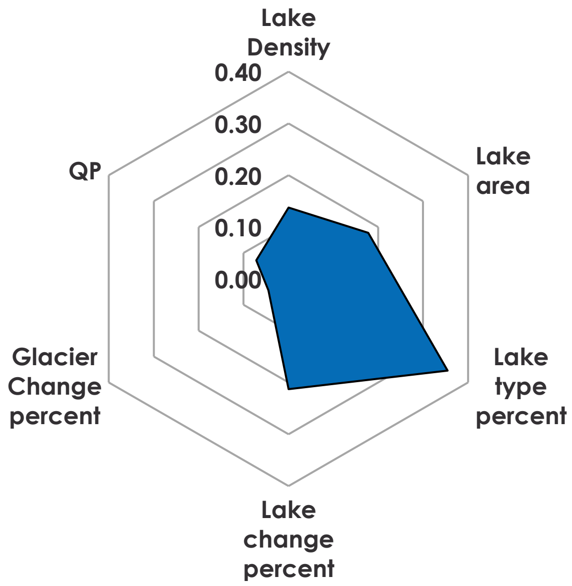


Weightage calculation

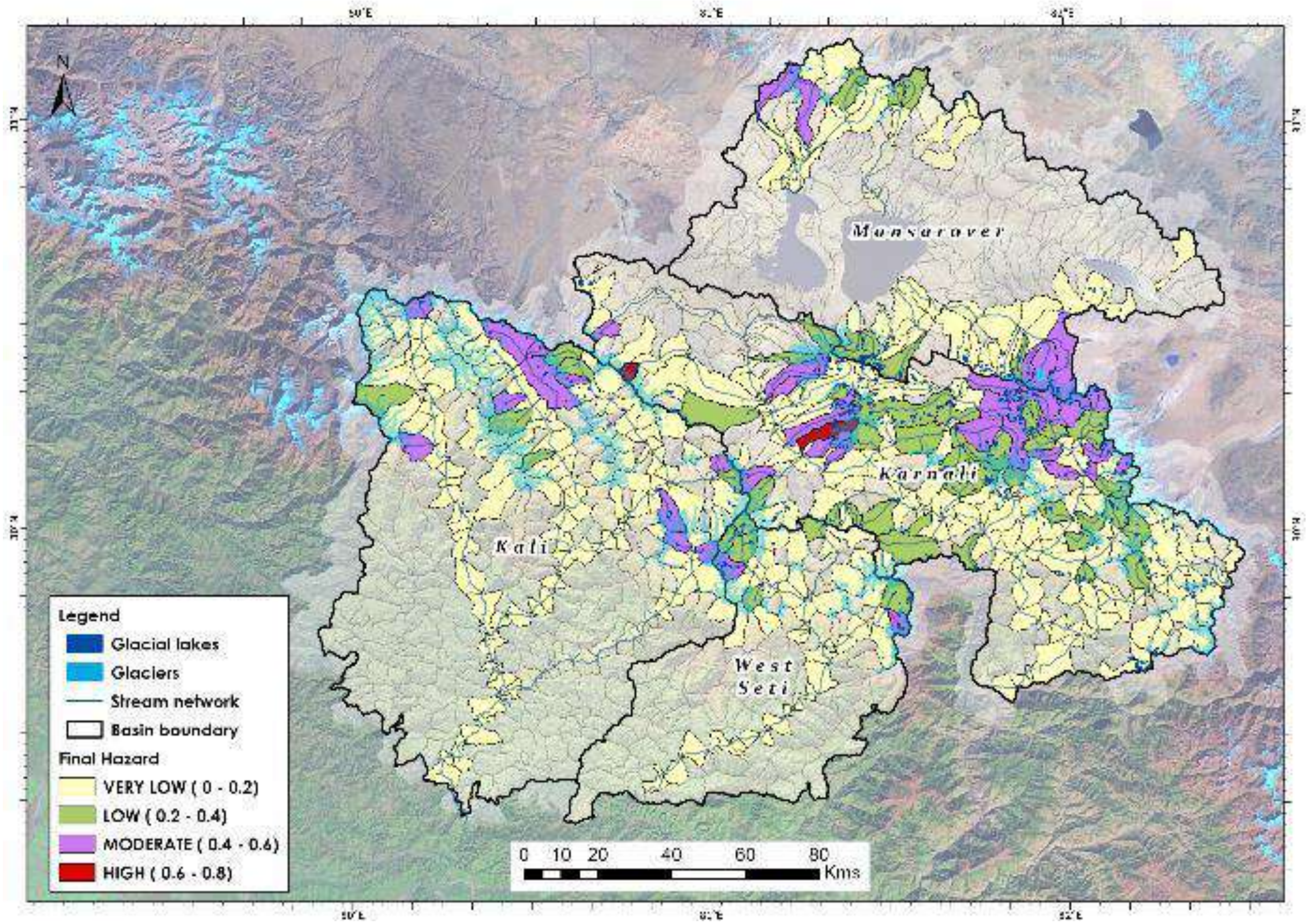


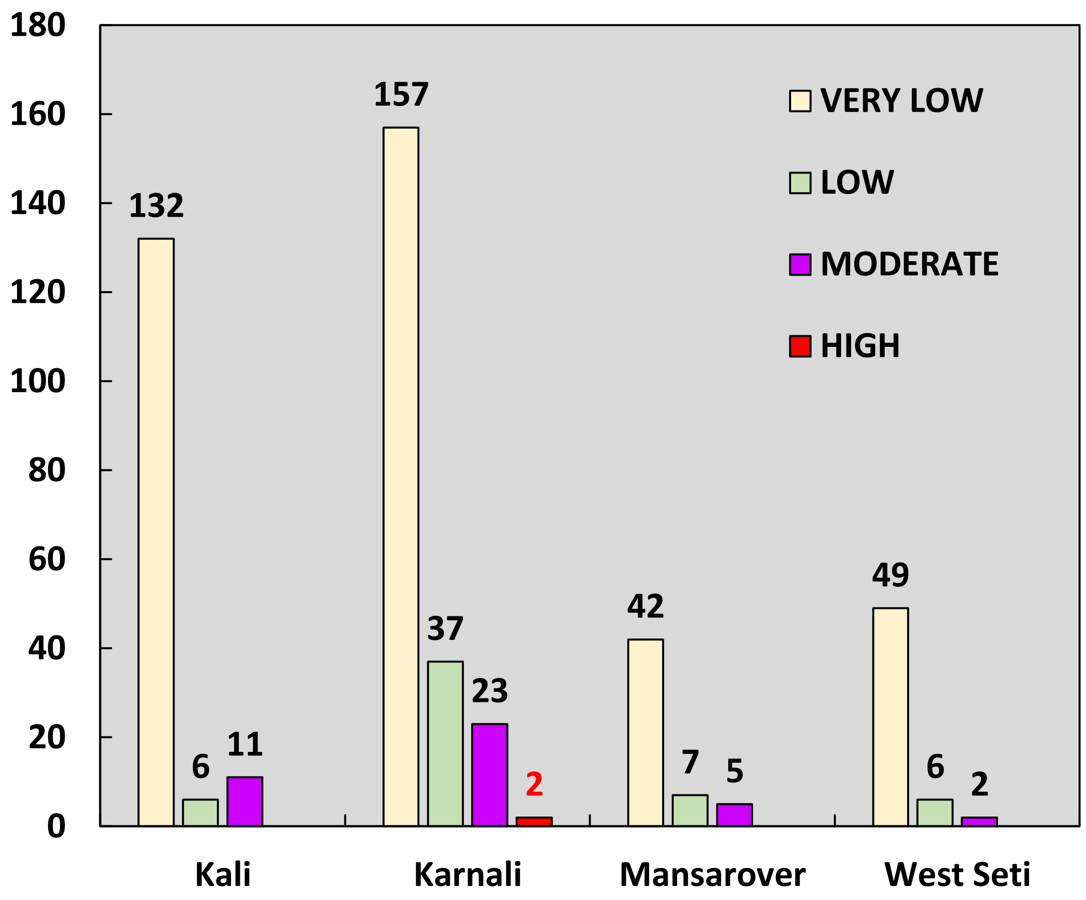
Pairwise comparison matrix and weightage value (AHP)

Parameters	GL Density	GL size	GL type percent	GLC Percent	GrC. percent	QP	Wt. value
GL Density	1.00	0.50	0.25	1.00	3.00	3.0	**0.14**
GL size	2.00	1.00	0.50	0.50	4.00	3.00	**0.18**
GL type percent	4.00	2.00	1.00	2.00	5.00	5.00	**0.35**
GLC Percent	1.00	2.00	0.50	1.00	4.00	4.00	**0.21**
GrC. percent	0.33	0.20	0.20	0.25	1.00	0.33	**0.04**
QP	0.33	0.33	0.20	0.25	3.00	1.00	**0.07**



Final Hazard





Conclusion and way forward

- Significant decreases in glacier area accompanied by an increase in number of glaciers is clear evidence of fragmentation because of uneven shrinkage of individual glaciers.
- Distribution of glacier area and its retreat amount was higher at elevation range from 5,000 – 5,500 masl.
- Moreover, glaciers in the steep slopes, facing the southern aspect and frontal parts of the glaciers associated with glacial lakes are retreating faster.
- The trend of retreat will continue with warming climate and increases the formation and expansion of glacial lake that will increase risk of GLOF
- Present trend in glacier melt enhance economic opportunities and productivity of the region by surplus supply of freshwater for livelihood, agriculture and hydropower generation.
- Necessary to understand the availability of these resources which will depleted with reduction of glaciers in long run.
- Need systematic ground-based monitoring to better understand
- Need to raise awareness and sharing information to local community
- **Transboundary collaboration is very much important** – single person/country can't solve the entire issue of the landscape


Thank you