Status and decadal change of glaciers in the Indus Basin (1990 – 2010)



Tenzing Chogyal Sherpa &
Sudan Bikash Maharjan

ICIMOD

8th Feb 2023, 10th EARSeL Workshop, Bern, Switzerland

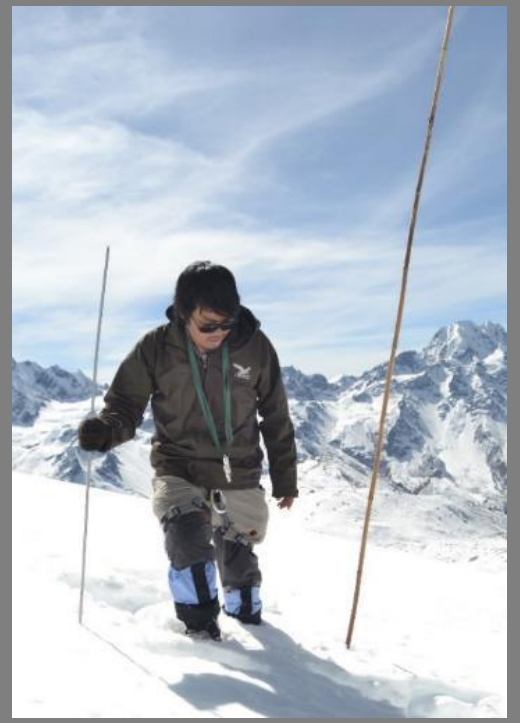
Background

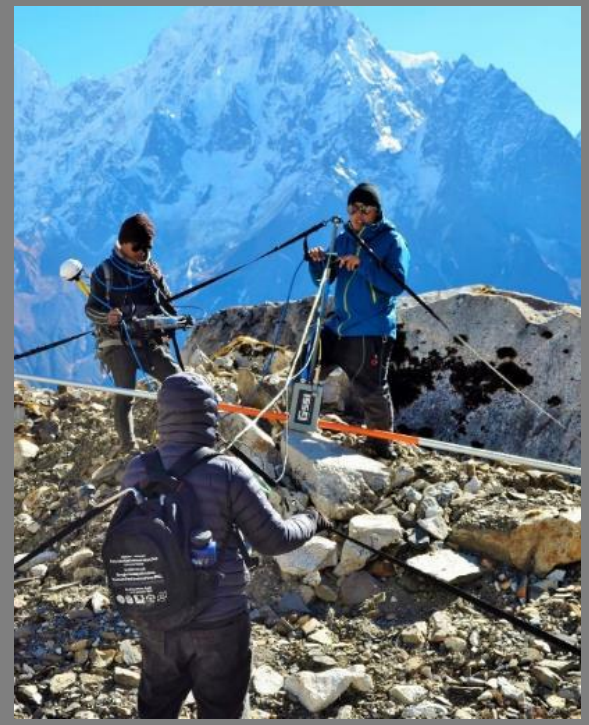
Education

- Bachelors in Environmental Science (2010-2014)
- M.S. By Research in Glaciology (2014-2016)

Work experience

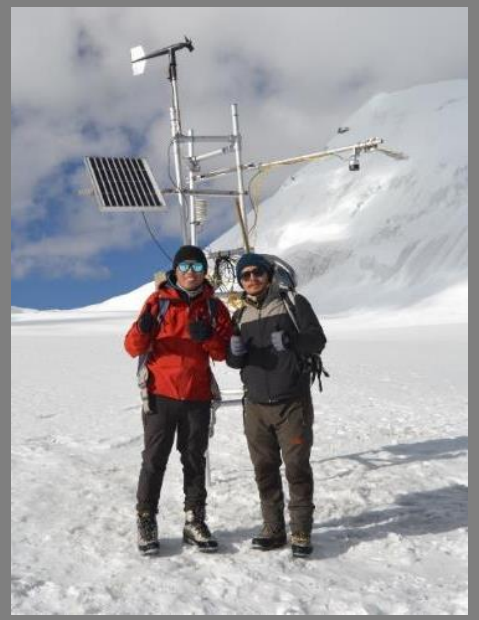
- HiCCDRC (Kathmandu University) (2016-2018)
- GIS and Remote Sensing Research Associate – ICIMOD (2018- present)









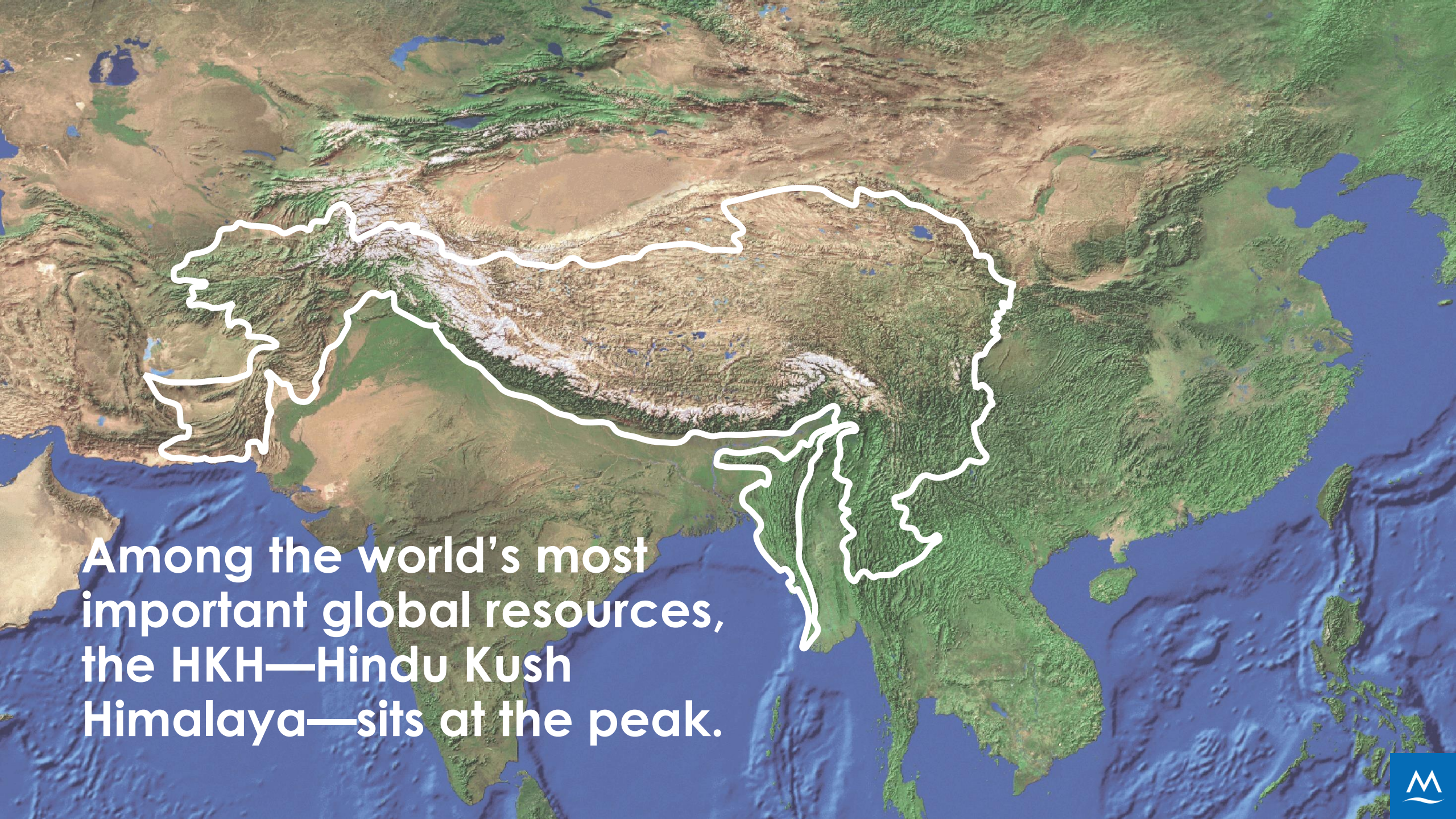


International Centre for Integrated Mountain Development

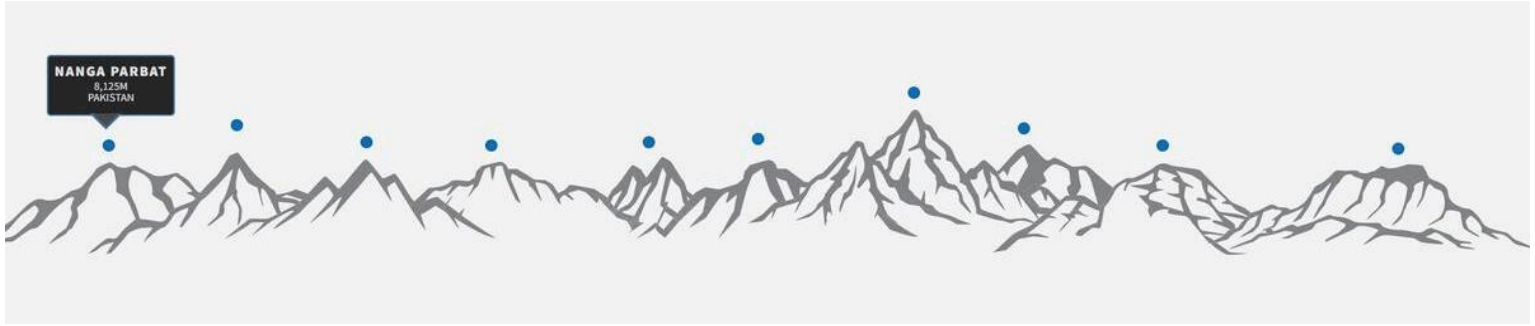


- Intergovernmental International organization working in the Hindu Kush-Himalayan Region
- Established in 1983
- Regional, facilitator with a mountain perspective
- Contributing to country-based knowledge for the region
- Promoting the extension from local to transboundary approaches
- Customizing international knowledge
- Capacity development



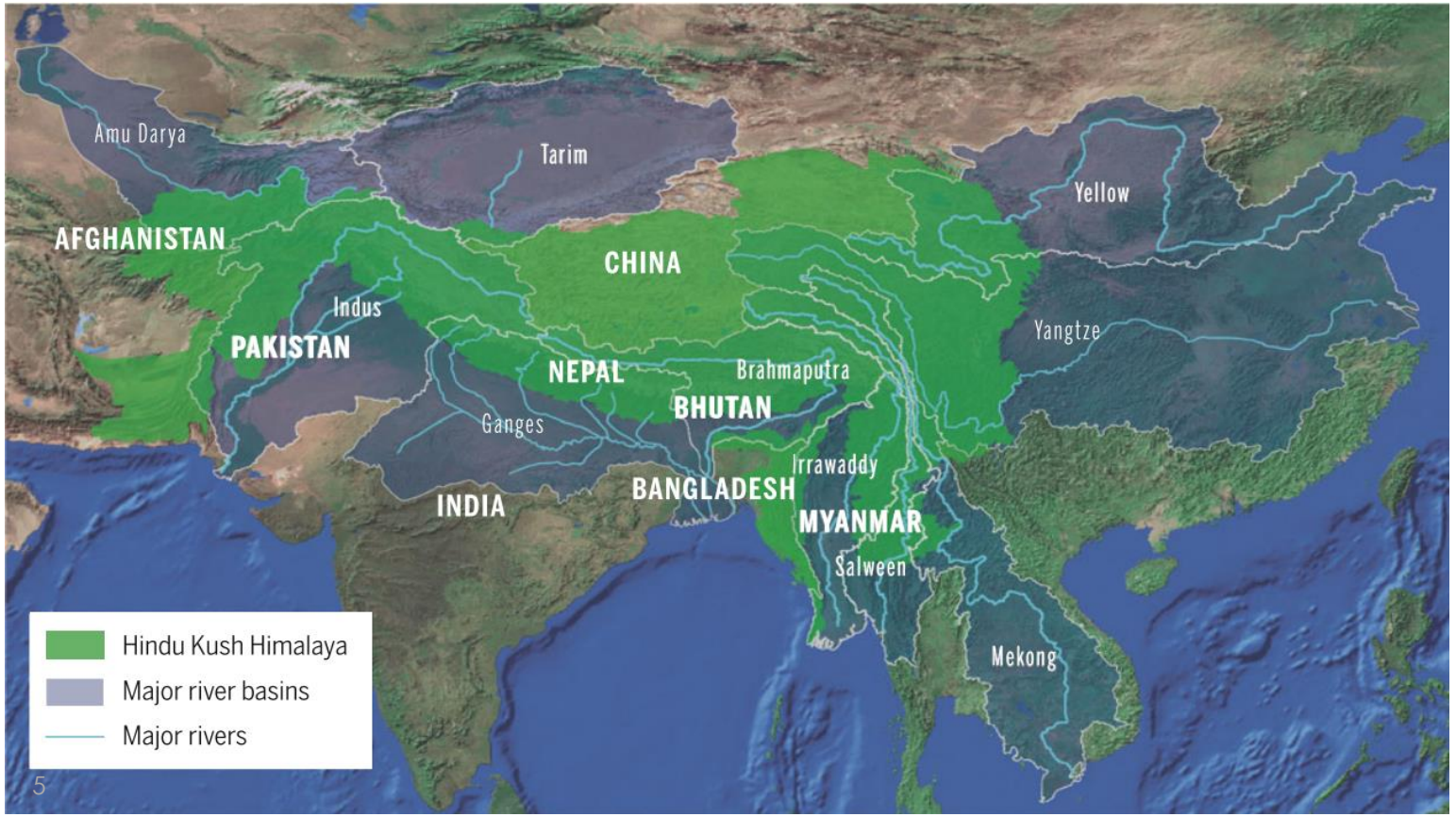

Among the world's most important global resources, the HKH—Hindu Kush Himalaya—sits at the peak.

The Third Pole of the world



14 of the tallest peaks in the world

10	240 M	1.9 B	8
Major river basins	HKH population	River basin population	Countries





Source: OurWorldinData.org

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

Even 1.5 Degrees is Too Hot for the HKH

and amplified by elevation dependent warming

Source: HIMAP climate change and cryosphere chapters and Kraaijenbrink et al. 2017, Nature

Mapping and Limitations

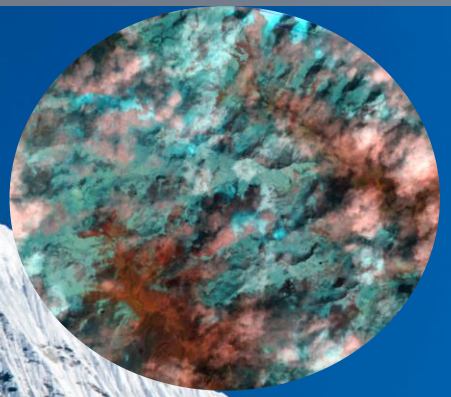
Field based and Remote Sensing

Rugged terrain	Time consuming
High elevation	Manpower
Remote area	Old topographic map
Expensive field survey	Restriction of map

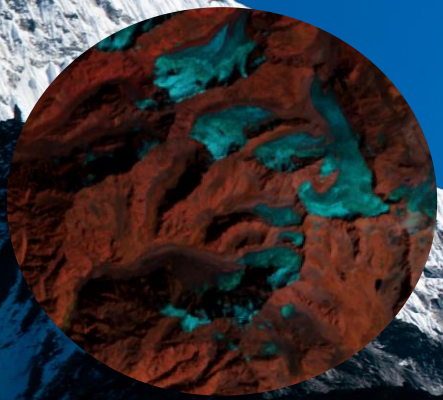
Remote sensing method is the best tool

However!!!

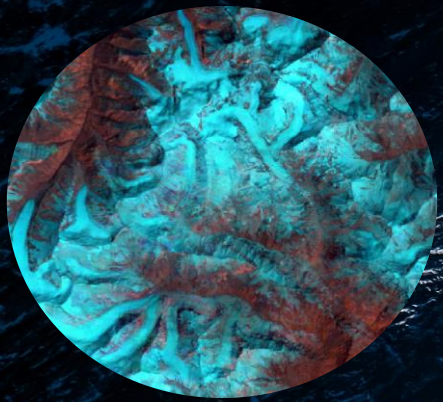
Clouds



Shadows



Snow



Without high-quality training data, even the most efficient machine learning algorithms will fail to perform.

Glaciers

A glacier or perennial snow mass, identified by a single GLIMS glacier ID, consists of a body of ice and snow that is observed at the end of the melt season. This includes, at a minimum, all tributaries and connected feeders that contribute ice to the main glacier, plus all debris-covered parts of it. Excluded is all exposed ground, including nunataks.

--GLIMS Glacier Inventory

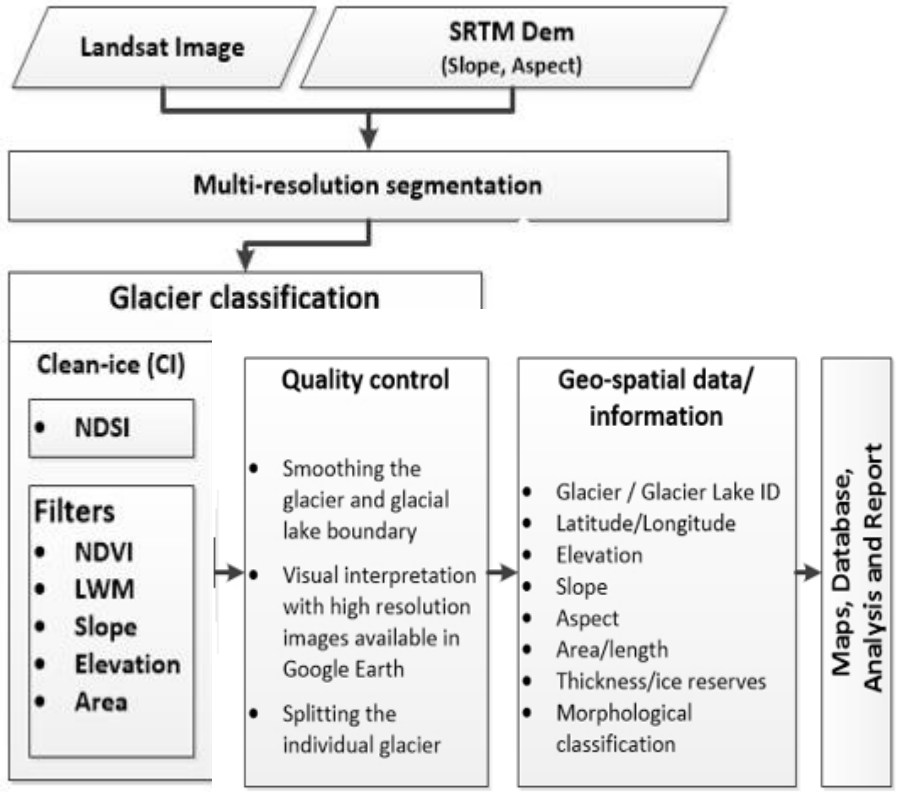




Source: Jakob Małecki

Methodology

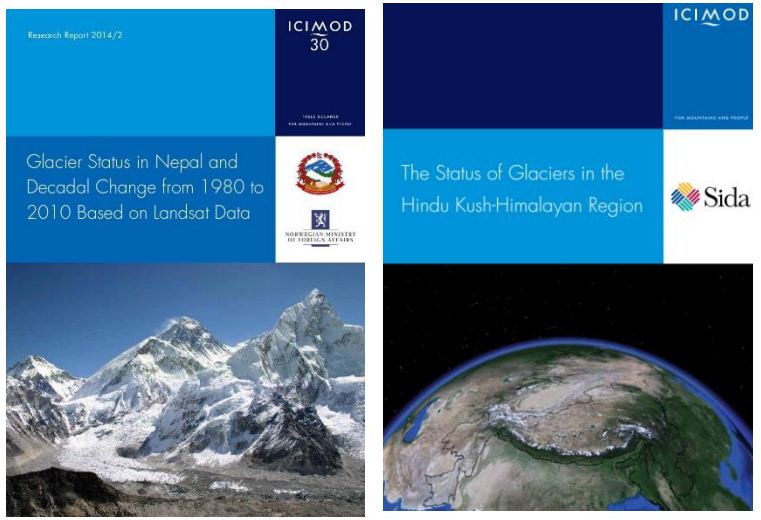
Semi-automatic – Object-based image classification



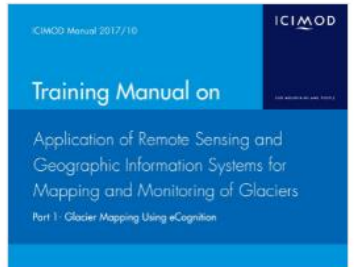
eCognition®

ArcMap

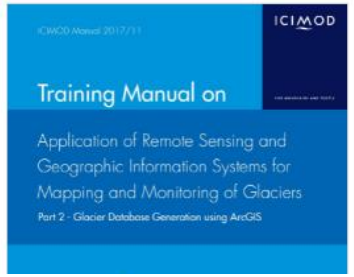
ArcGIS Pro



2017



2017



Annals of Glaciology 55(66) 2014 doi: 10.3189/2014AoG66A125 159

The status and decadal change of glaciers in Bhutan from the 1980s to 2010 based on satellite data

Samjwal Ratna BAJRACHARYA, Sudan Bikash MAHARJAN, Finu SHRESTHA

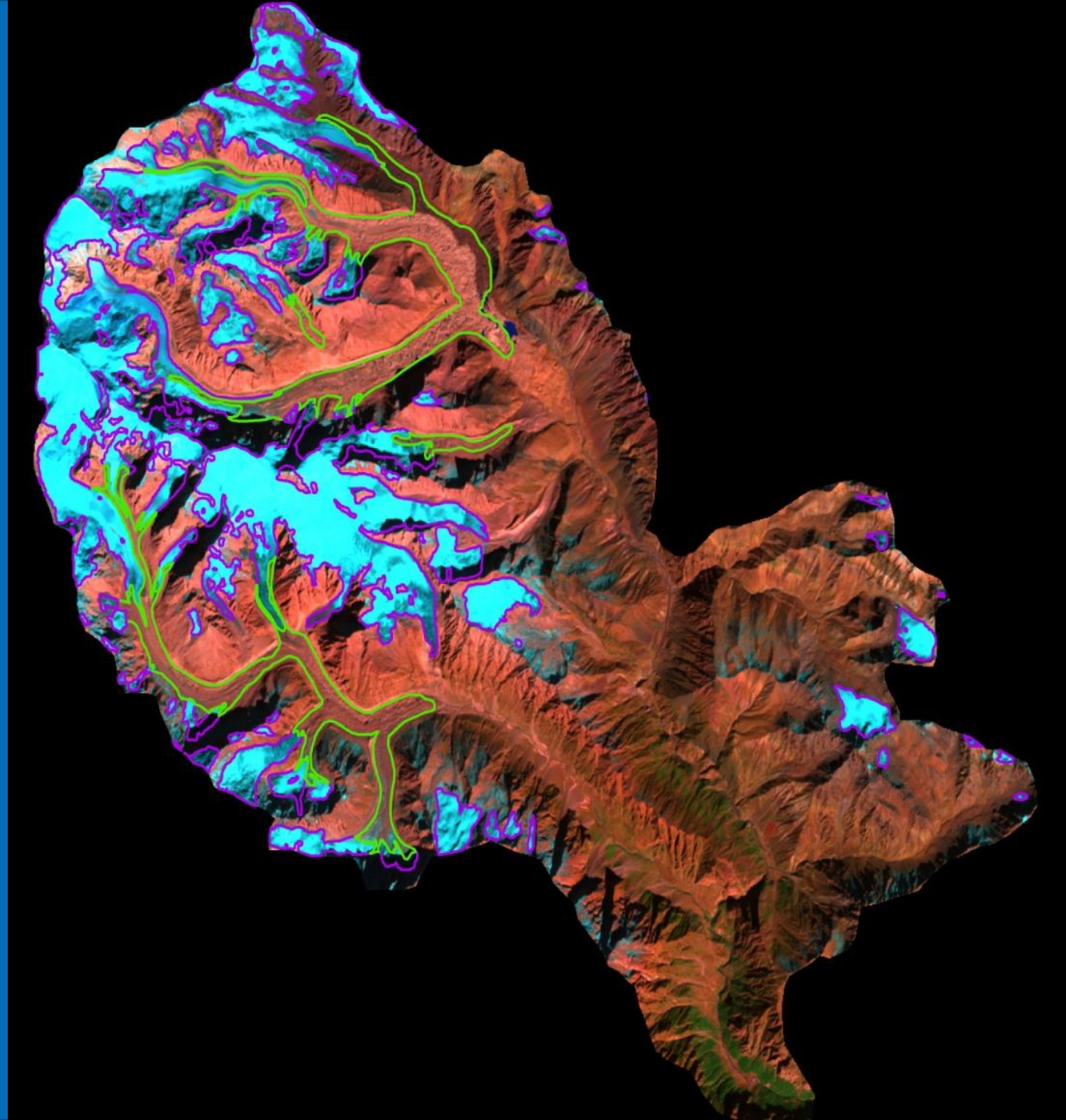
International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal
E-mail: sabajracharya@icimod.org

ABSTRACT. In order to monitor changes in the glaciers in the Bhutan Himalaya, a repeat decadal glacier inventory was carried out from Landsat images of 1977/78 (~1980), 1990, 2000 and 2010. The base map of glaciers was obtained by the object-based image classification method using the multispectral Landsat images of 2010. This method is used separately to delineate clean-ice and debris-covered glaciers with some manual editing. Glacier polygons of 2000, 1990 and ~1980 were obtained by manual editing on 2010 by separately overlaying respective years. The 2010 inventory shows 885 glaciers with a total area of ~642 ± 16.1 km^2. The glacier area is 1.6% of the total land cover in Bhutan. The result of a repeat inventory shows 23.3 ± 0.9% glacial area loss between ~1980 and 2010, with the highest loss (11.6 ± 1.2%) between ~1980 and 1990 and the lowest (6.7 ± 0.1%) between 2000 and 2010. The trend of glacier area change from the 1980s to 2010 is –6.4 ± 1.6%. Loss of glacier area was mostly observed below 5600 m a.s.l. and was greater for clean-ice glaciers. The equilibrium-line altitude has shifted upward from 5170 ± 110 m a.s.l. to 5350 ± 150 m a.s.l. in the years ~1980–2010.

KEYWORDS: glacier mapping, mountain glaciers, remote sensing

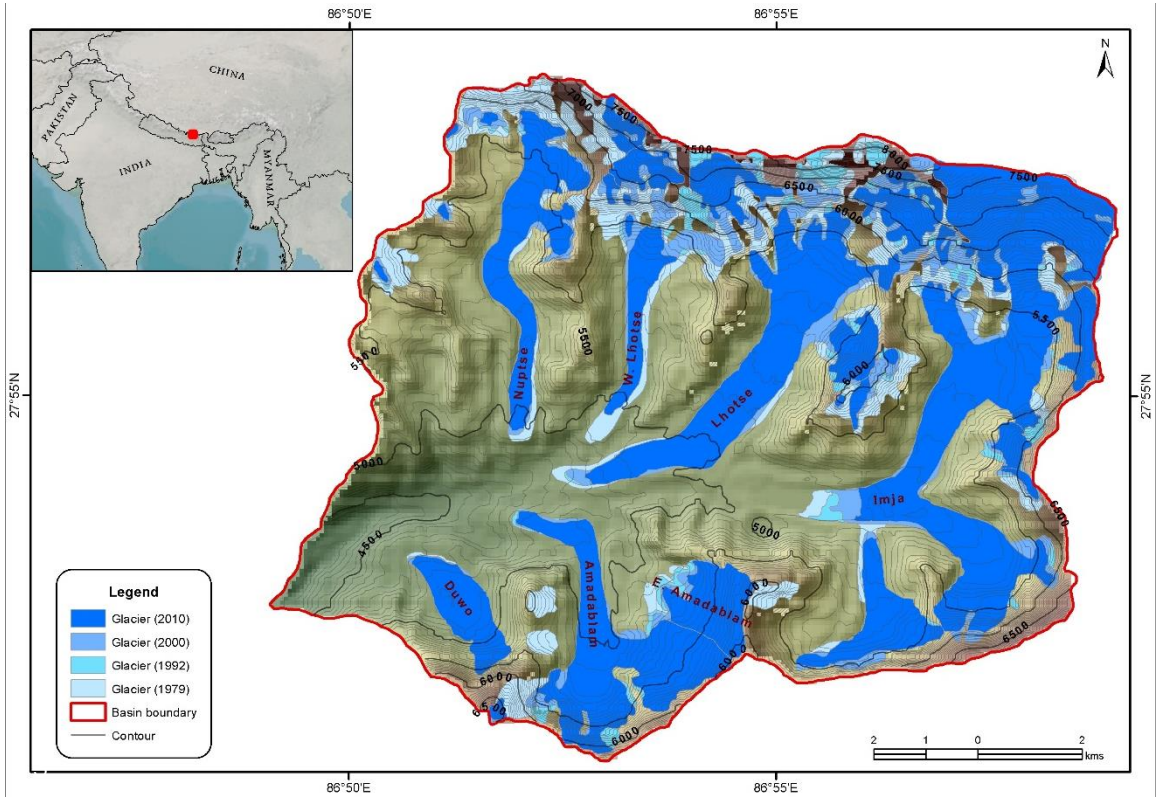
Glacier Inventory

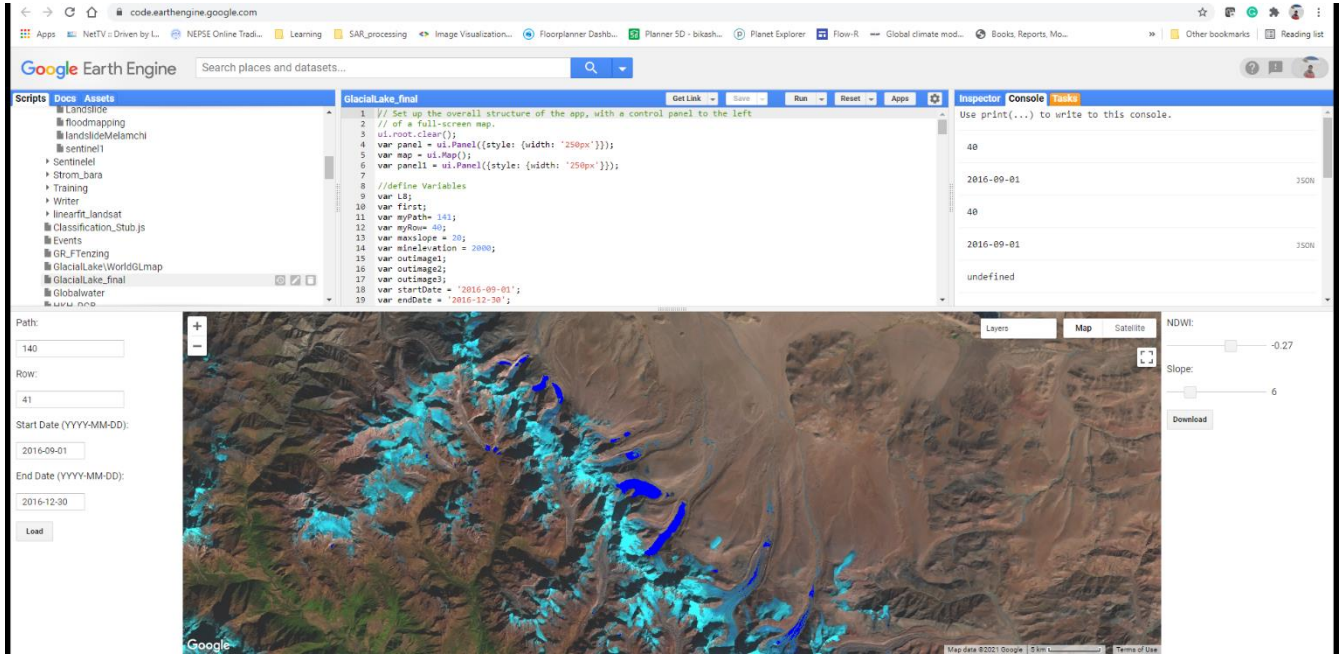
- Glacier Identity
  - GLIMS ID
- Glacier Location
  - Latitude
  - Longitude
- Elevation (Max, Mean, Min)
- Slope (Max, Mean, Min)
- Aspect
- Surface Area (km^2)
- Area-elevation 100m bin
- Area classes
- Mean thickness
- Estimated ice reserves

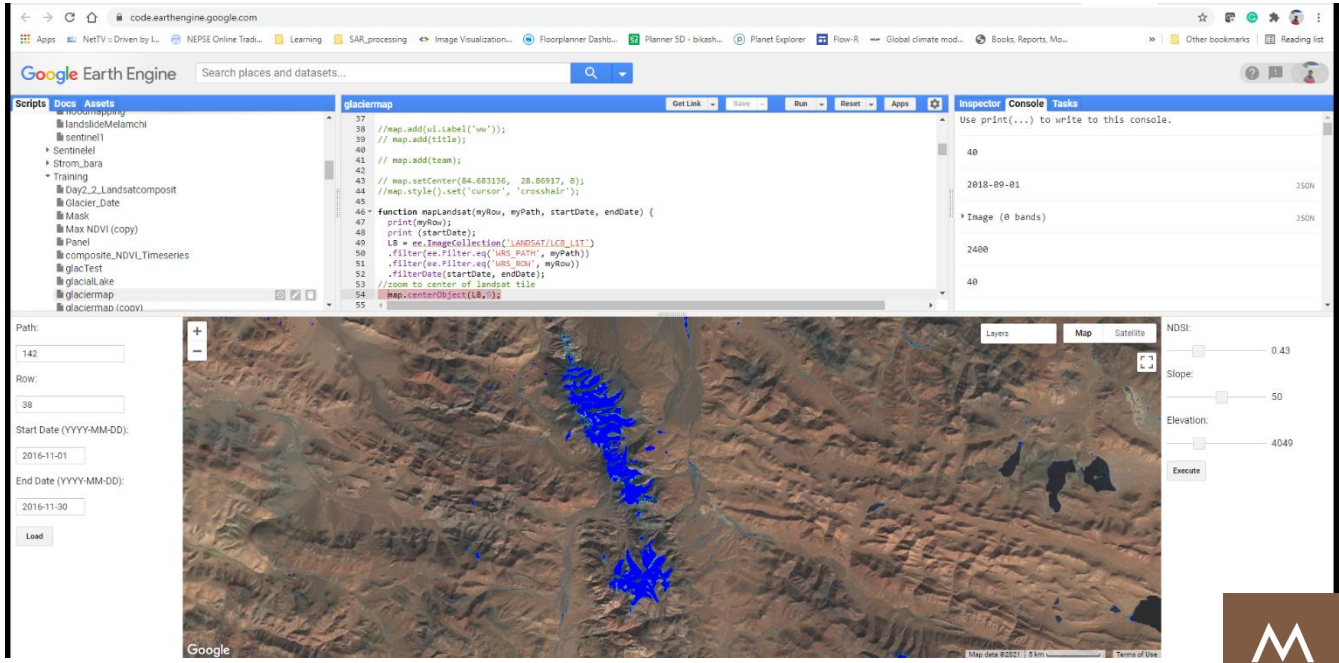


GLIMS Glacier Inventory & WGMS glacier classification system

Mapping Method
using Google earth engine







Uncertainties

1. Quality of the image (with potential issues due to seasonal snow, shadows and cloud cover),
2. Interpretation of glacial features and methodology used
3. Post-processing techniques (Le Bris & Paul, 2013;169 Paul et al., 2013, 2017; Racoviteanu et al., 2009, 2019)

Can be visually identified and corrected but an exact quantification is difficult due to the lack of reference data available from the region *(Racoviteanu et al., 2009; Shukla et al., 2020)*.

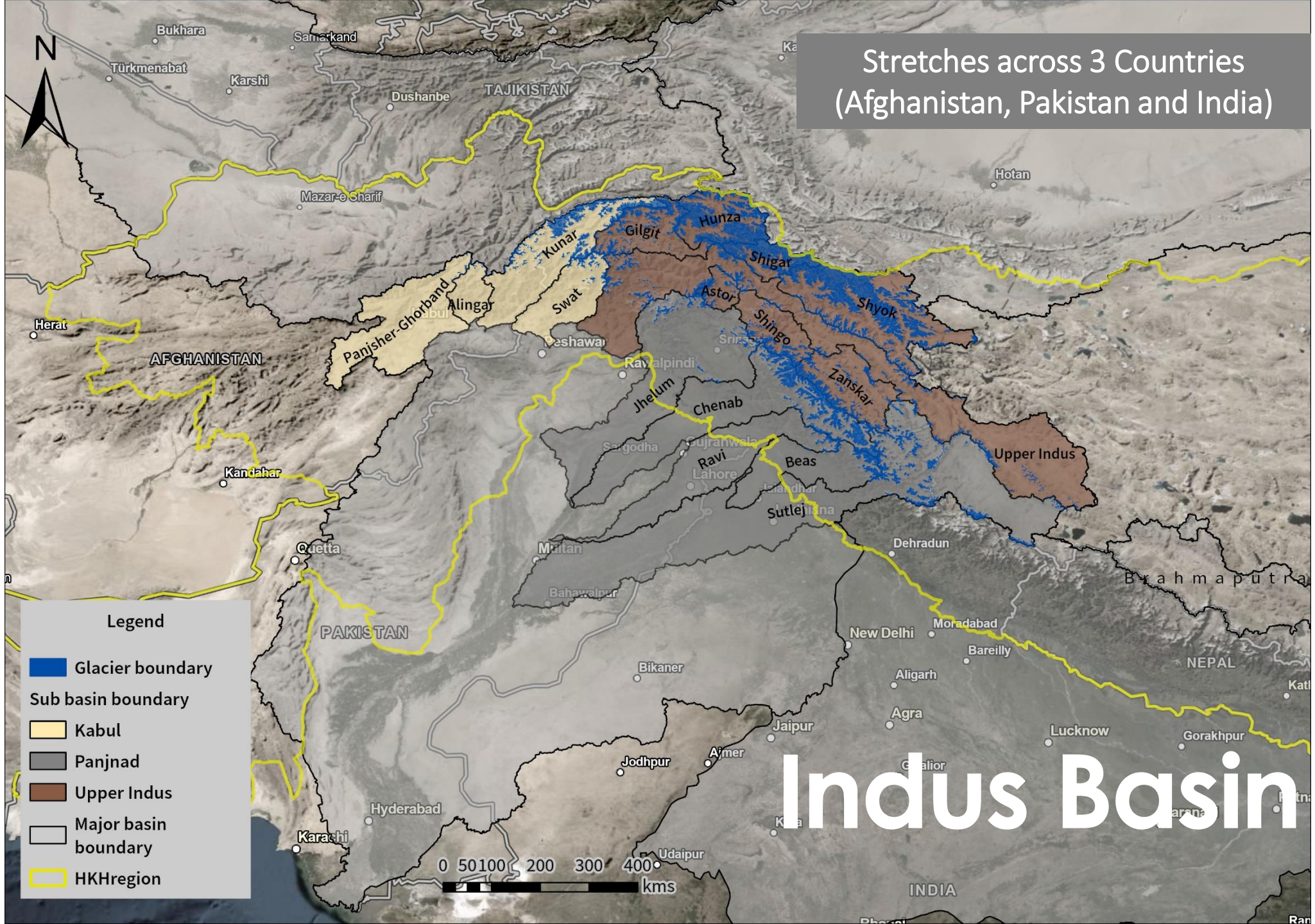
Significant and have an impact on glacier area estimation. Therefore, we applied a buffer-based assessment to glacier areas with the buffer width set to one-pixel (*Bolch et al., 2010; Granshaw 174 & Fountain, 2006; Mölg et al., 2018; Paul et al., 2017; Racoviteanu et al., 2009; Shukla et al., 2020; Tielidze & 175 Wheate, 2018*),

Uncertainty

The buffer-based method determines the highest and lowest estimates of glacier size uncertainty using factors such as glacier size and imagery spatial resolution. This method is more suited for a specific dataset and is recommended when no dependable reference data exists *(Paul et al., 2017; Racoviteanu 179 et al., 2009; Shukla et al., 2020)*.

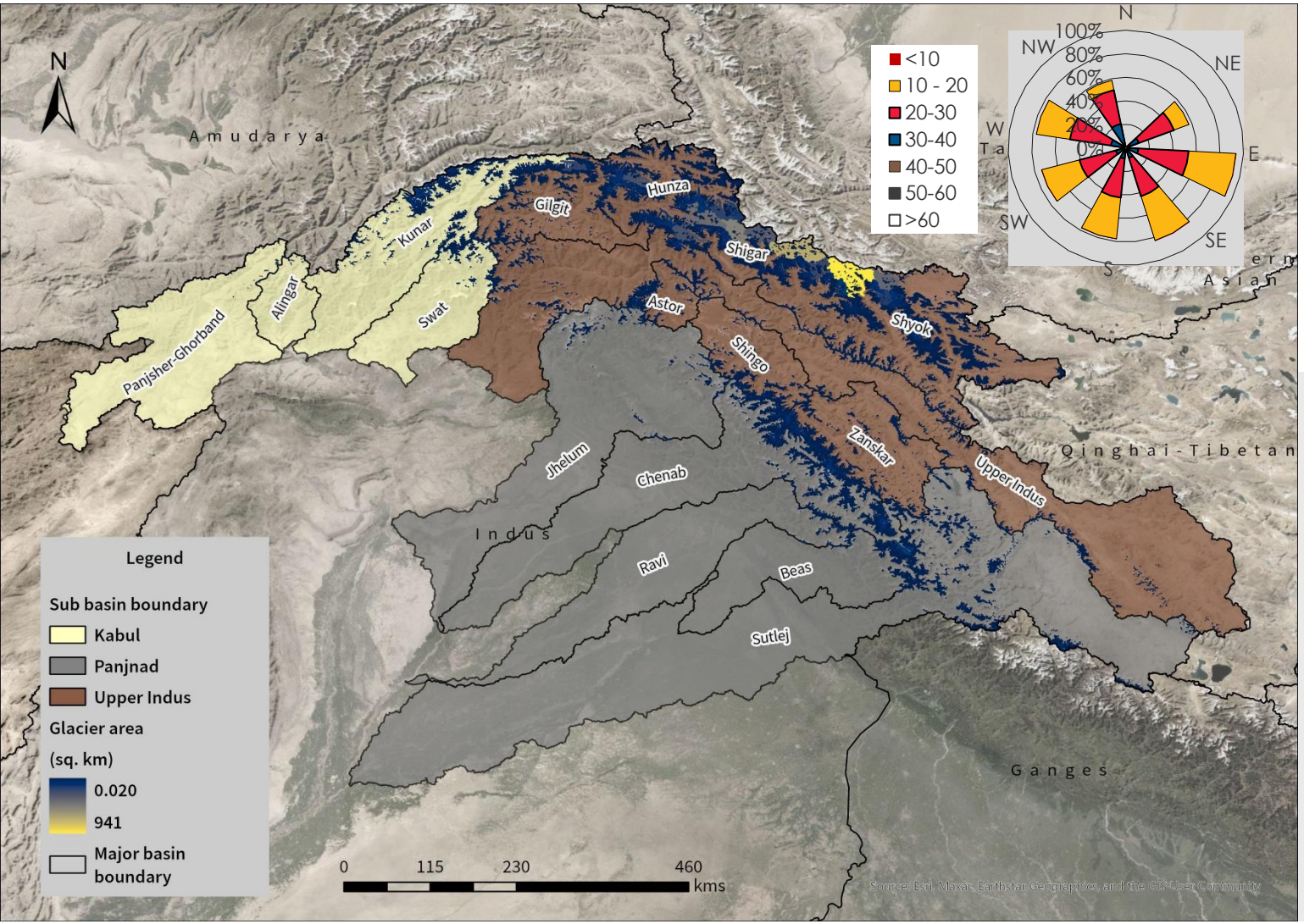
The uncertainty of glacier area in the present study:

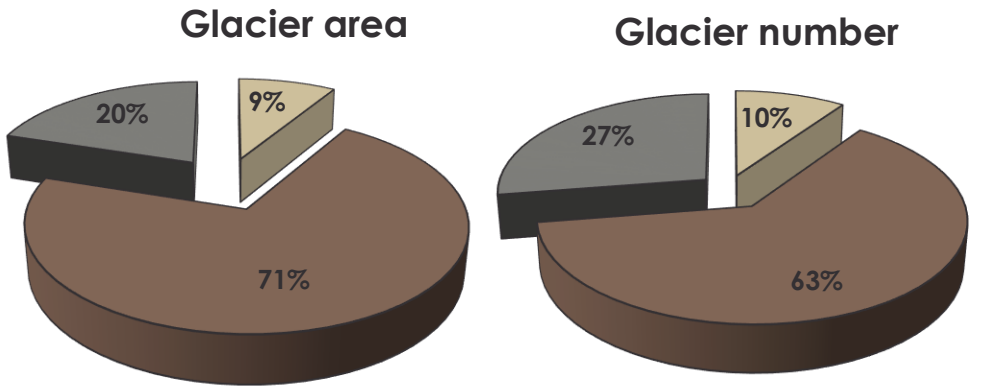
2.5%, 2.4% , 2.5%, 2.5 % for the years 1990, 2000, 2010 and 2020 respectively

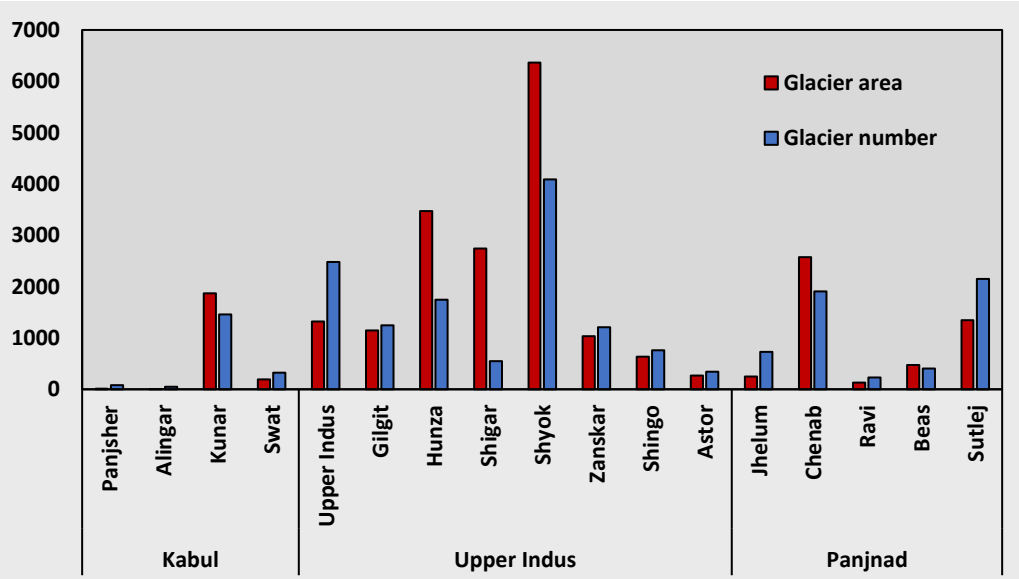

Stretches across 3 Countries
(Afghanistan, Pakistan and India)
Indus Basin
N
Legend
Glacier boundary
Sub basin boundary
Kabul
Panjnad
Upper Indus
Major basin boundary
HKHregion
0 50100 200 300 400 kms
Bukhara
Samarkand
Türkmenabat
Karshi
Dushanbe
TAJIKISTAN
Mazar-e Sharif
Herat
AFGHANISTAN
Kandahar
Quetta
PAKISTAN
Karachi
Hyderabad
Bikaner
Jodhpur
Jaipur
Ajmer
Udaipur
INDIA
Hotan
Gilgit
Hunza
Kunar
Shigar
Astor
Shyok
Shingo
Zanskar
Swat
Alingar
Panjsher-Ghorband
Jhelum
Chenab
Ravi
Beas
Sutlej
Upper Indus
Dehradun
Brahmaputra
New Delhi
Moradabad
Bareilly
Aligarh
Agra
Lucknow
Gorakhpur
NEPAL

Indus Basin

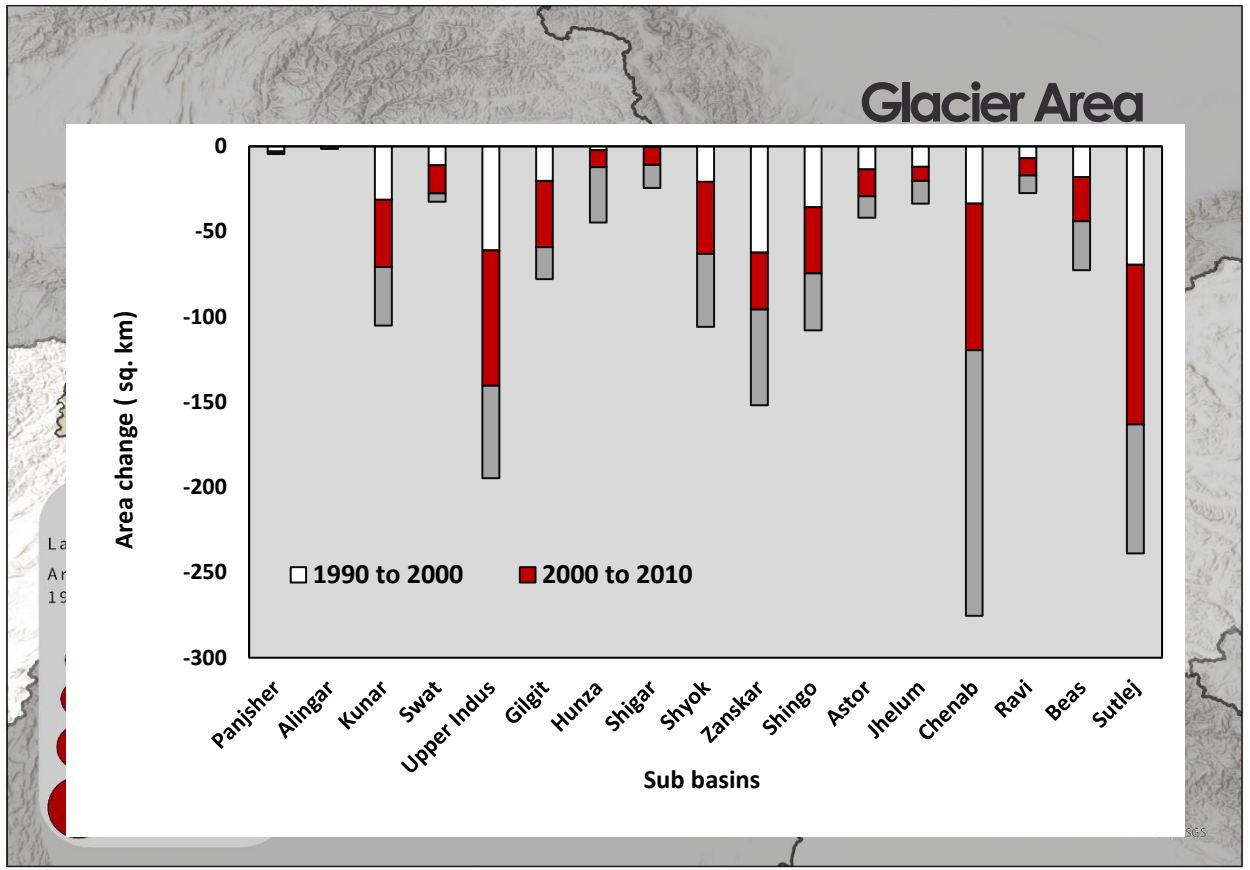
19,789 glaciers encompassing a surface area: 23,860 ± 596.5 sq. km (2020)

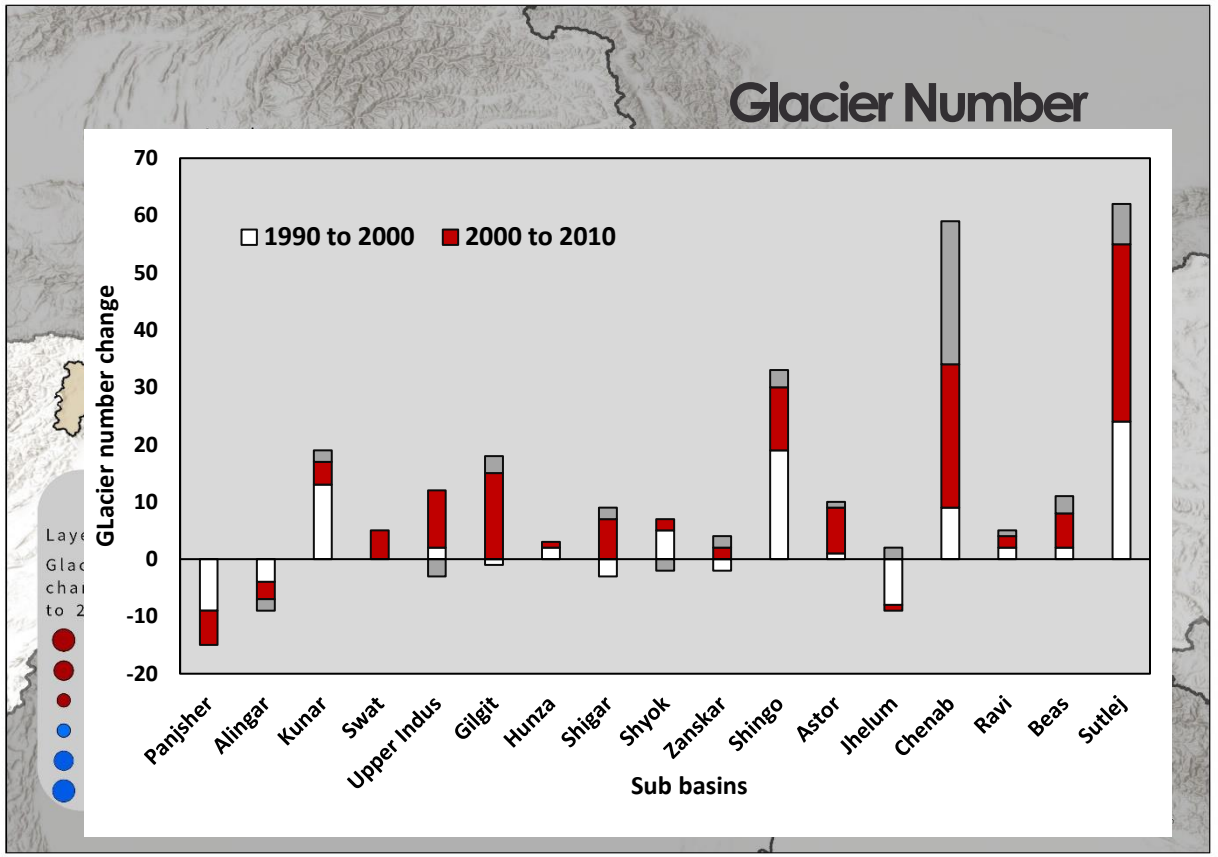




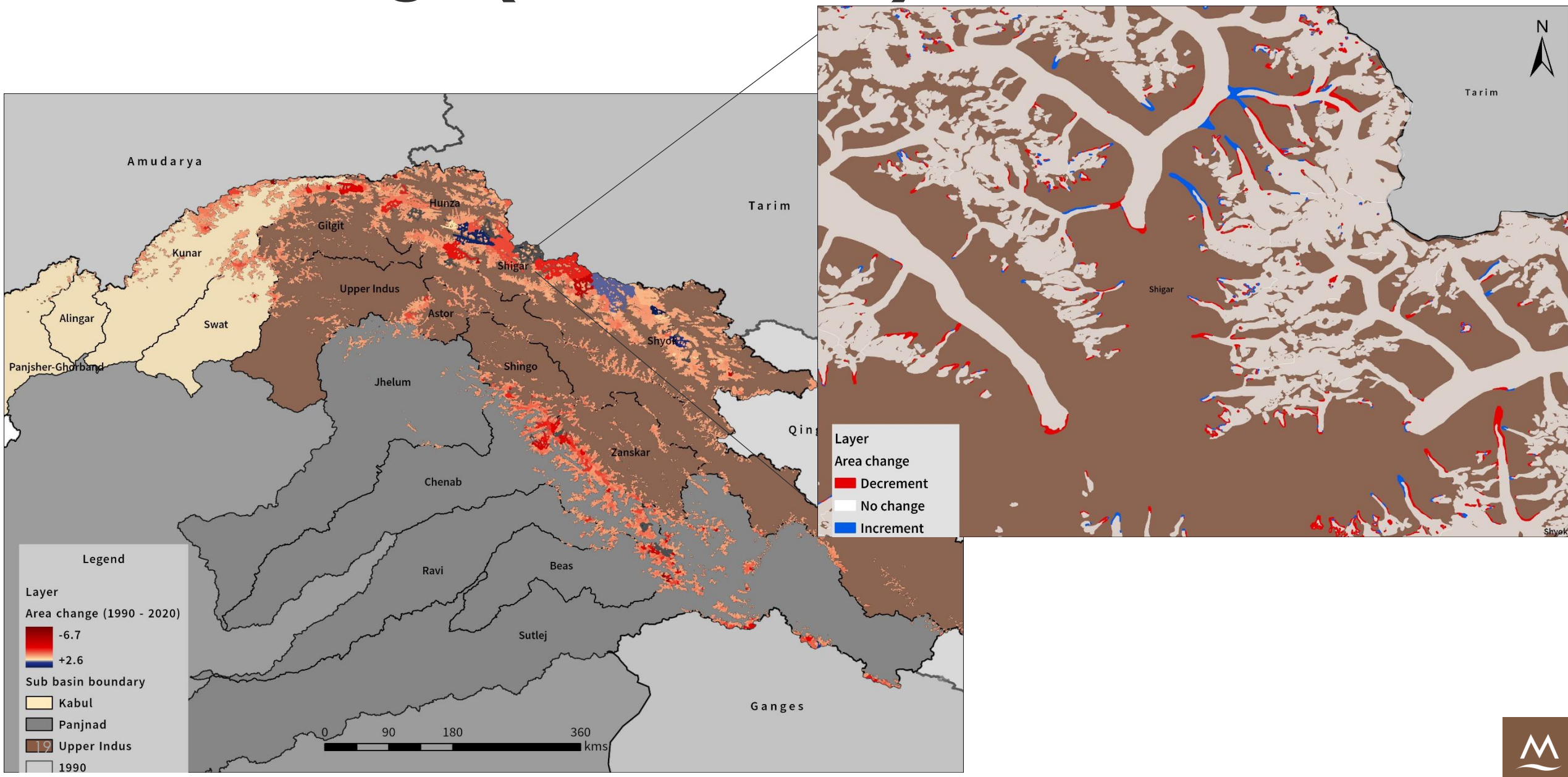


Basin wise change (1990 – 2020)

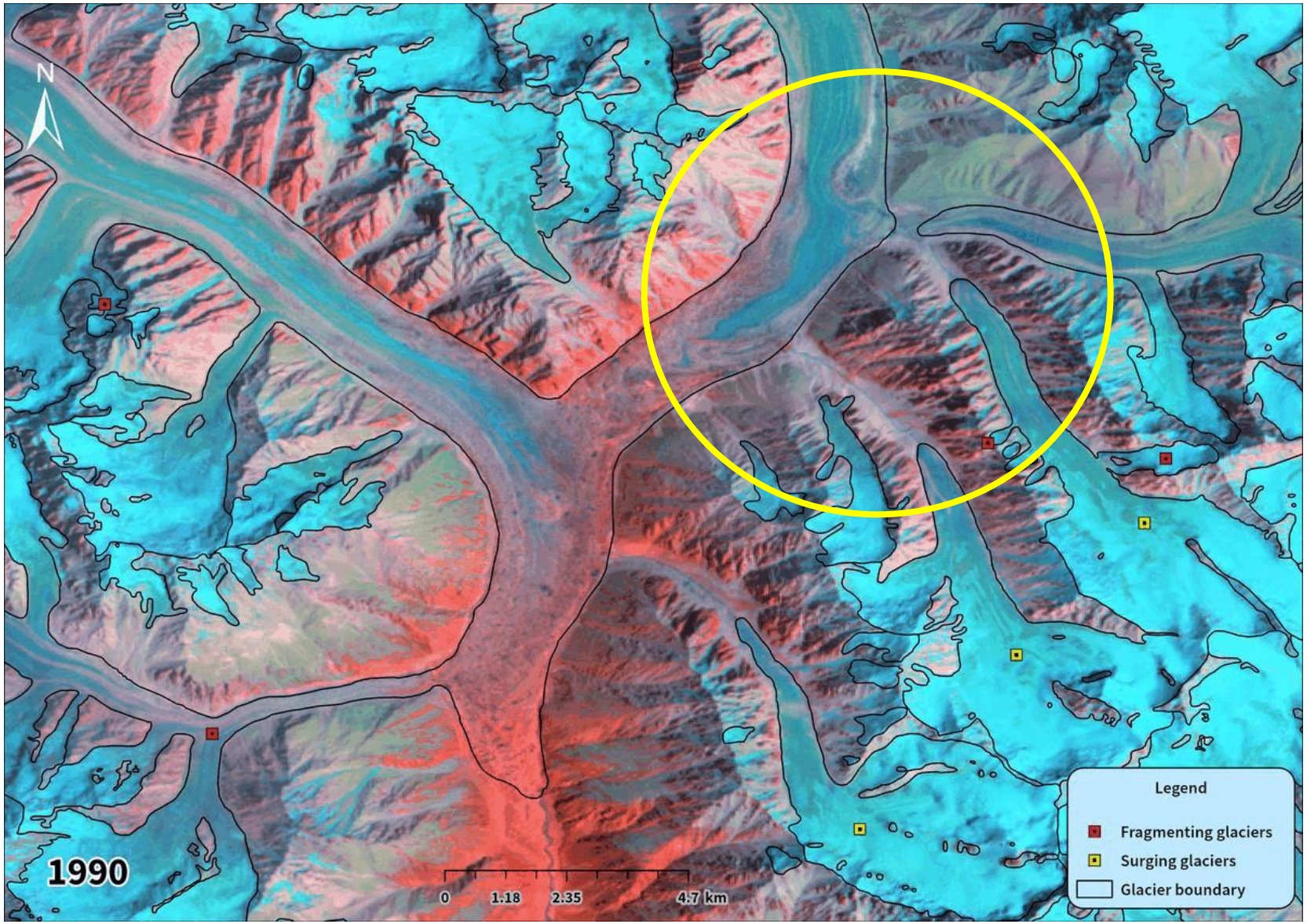




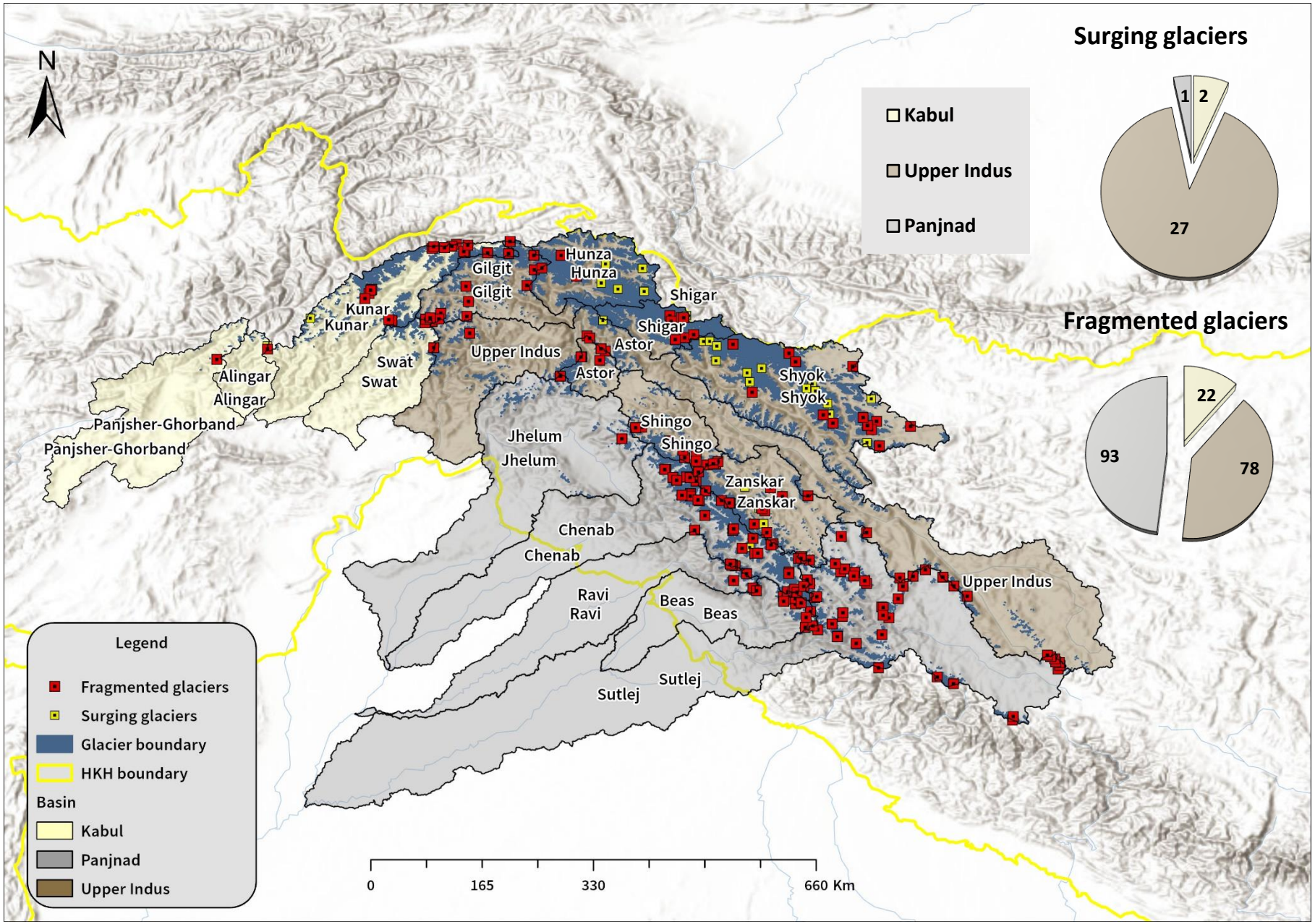
Area change (1990 – 2020)



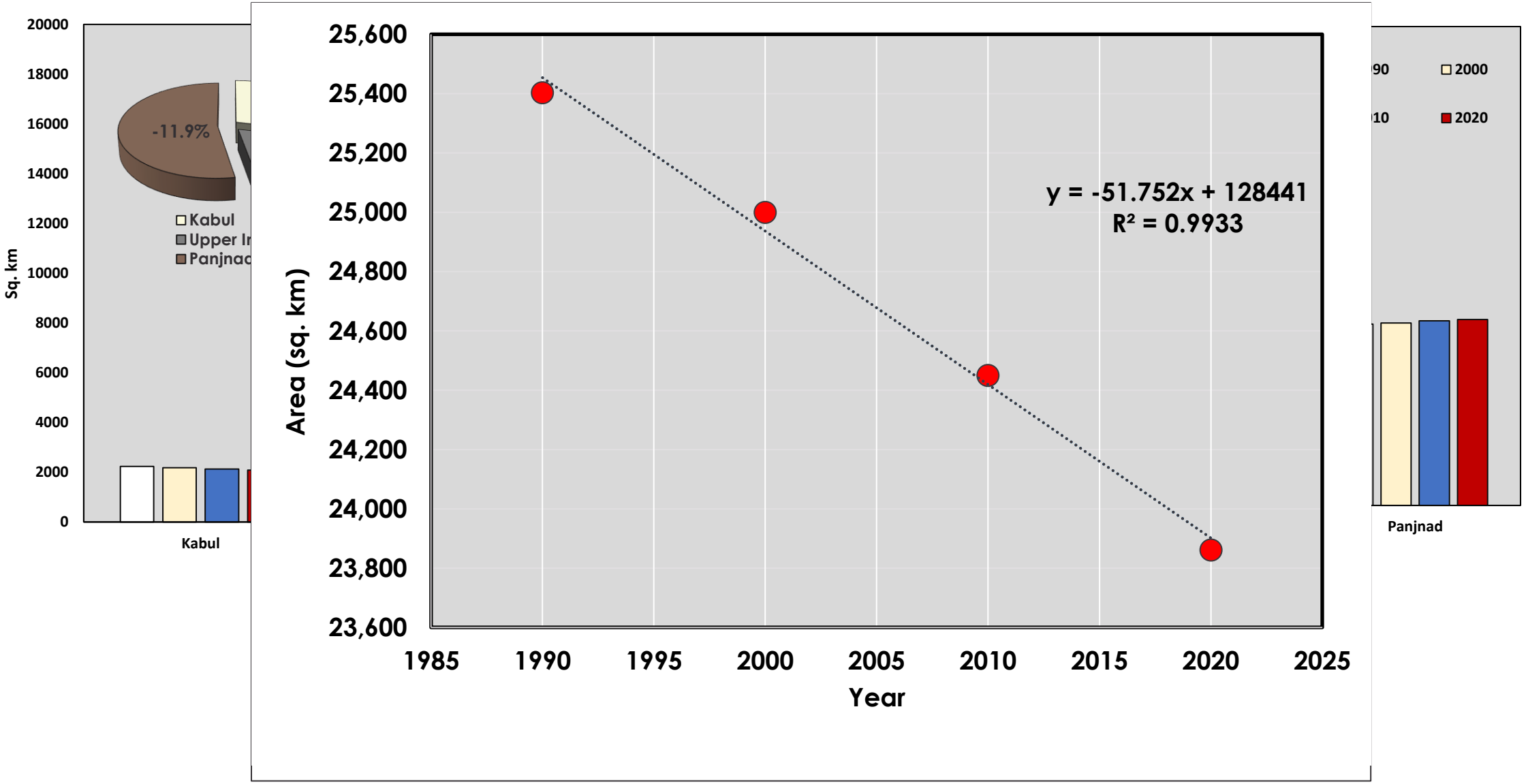
Surging and fragmenting of glaciers



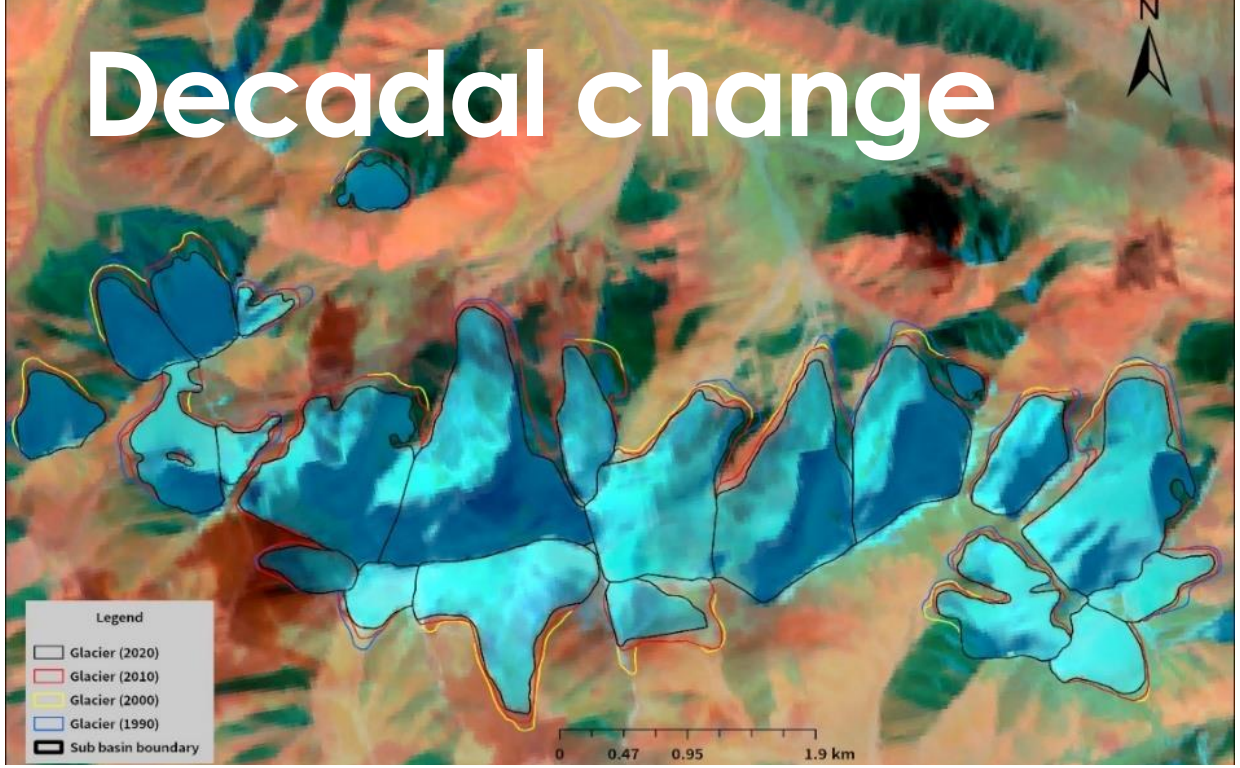
Surging and fragmenting of glaciers

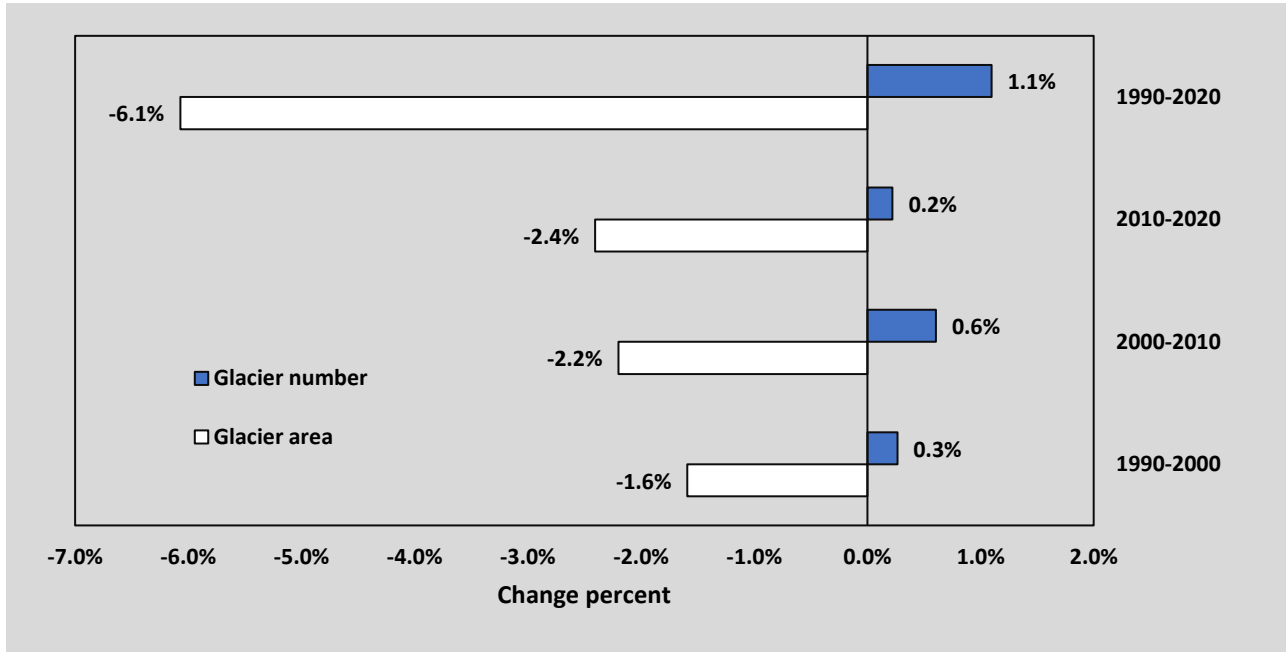


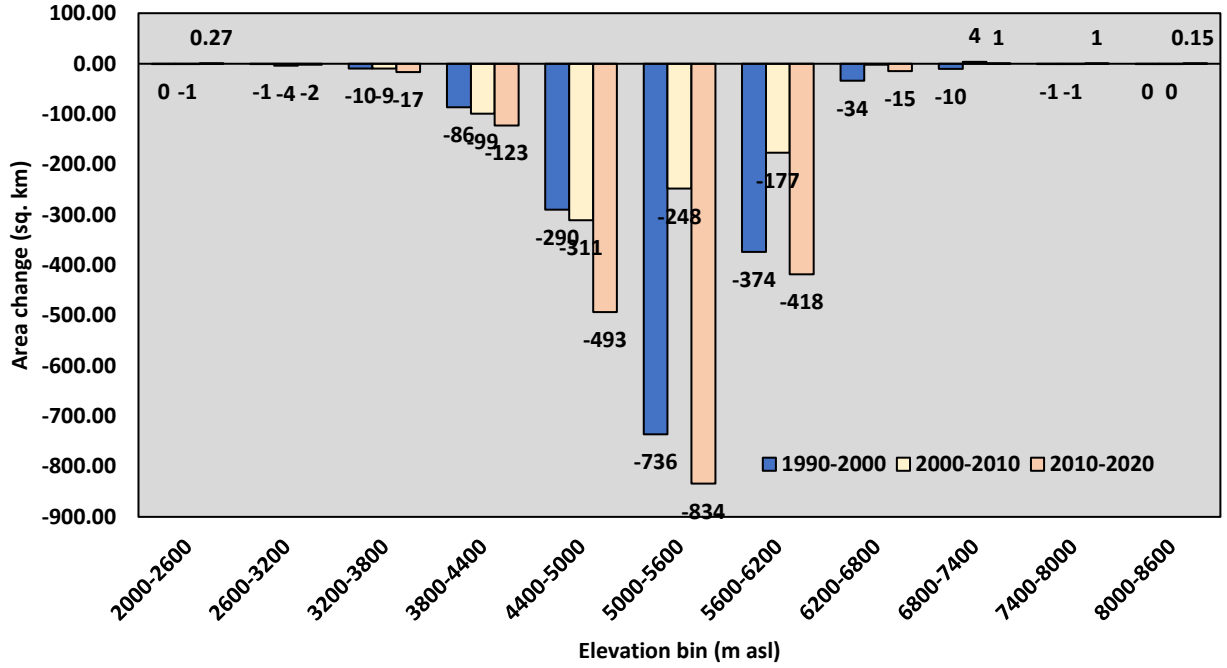
Basin wise change (1990 – 2020)

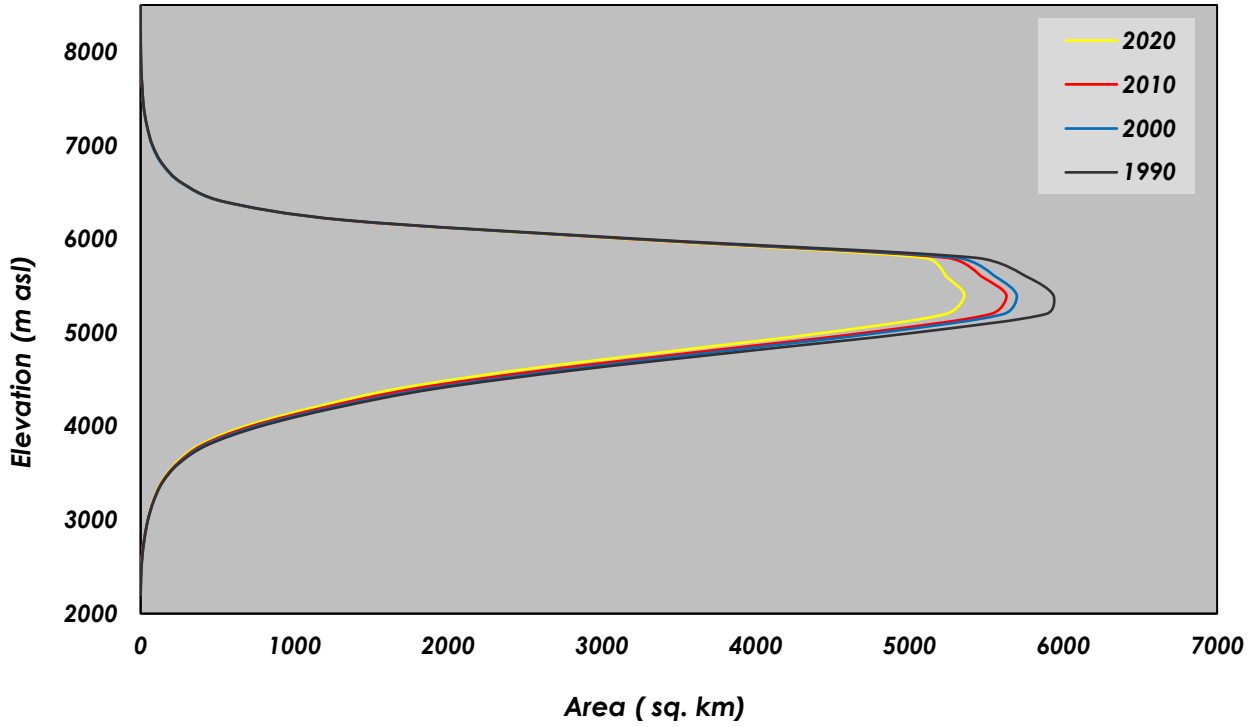


Decadal change

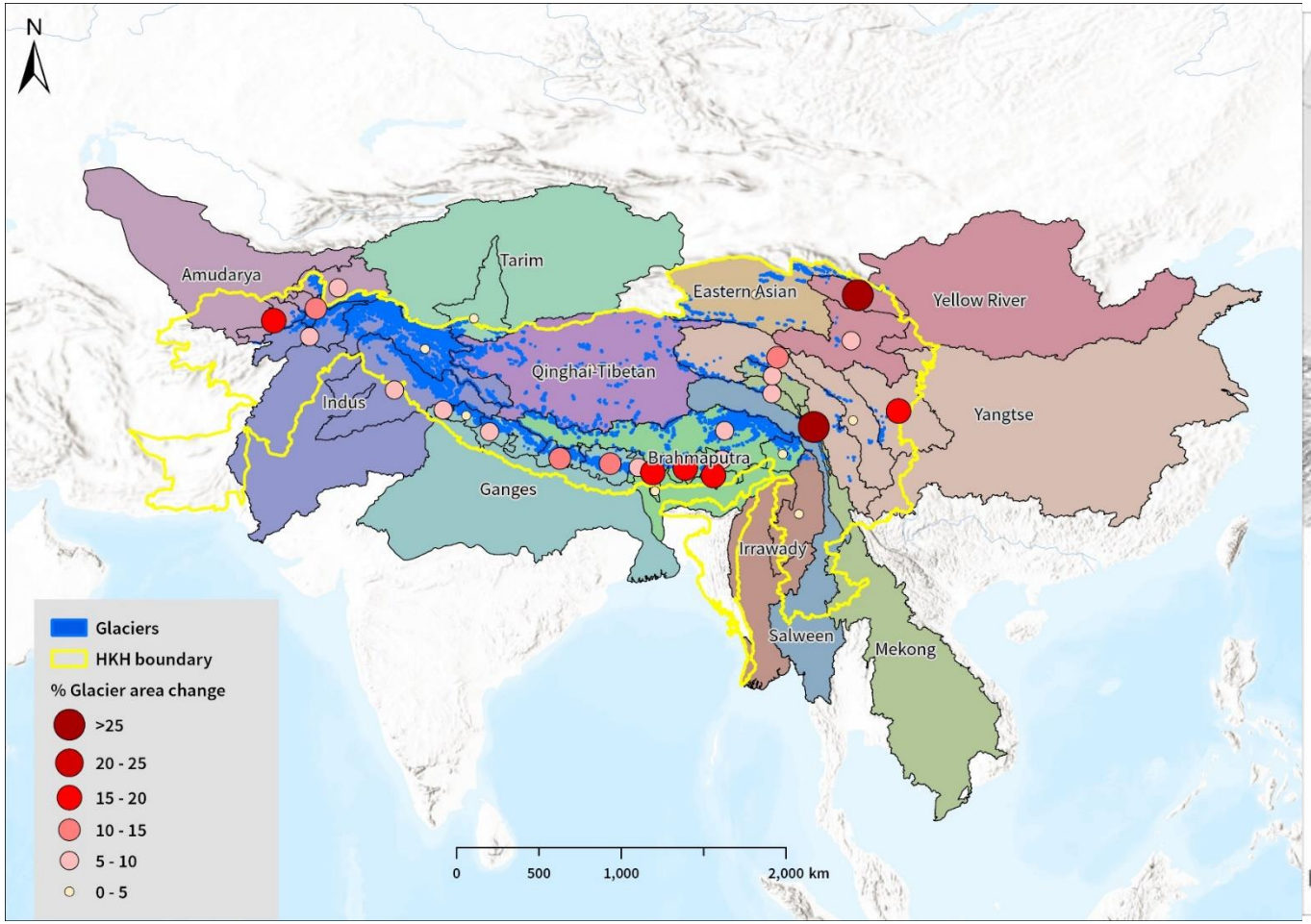


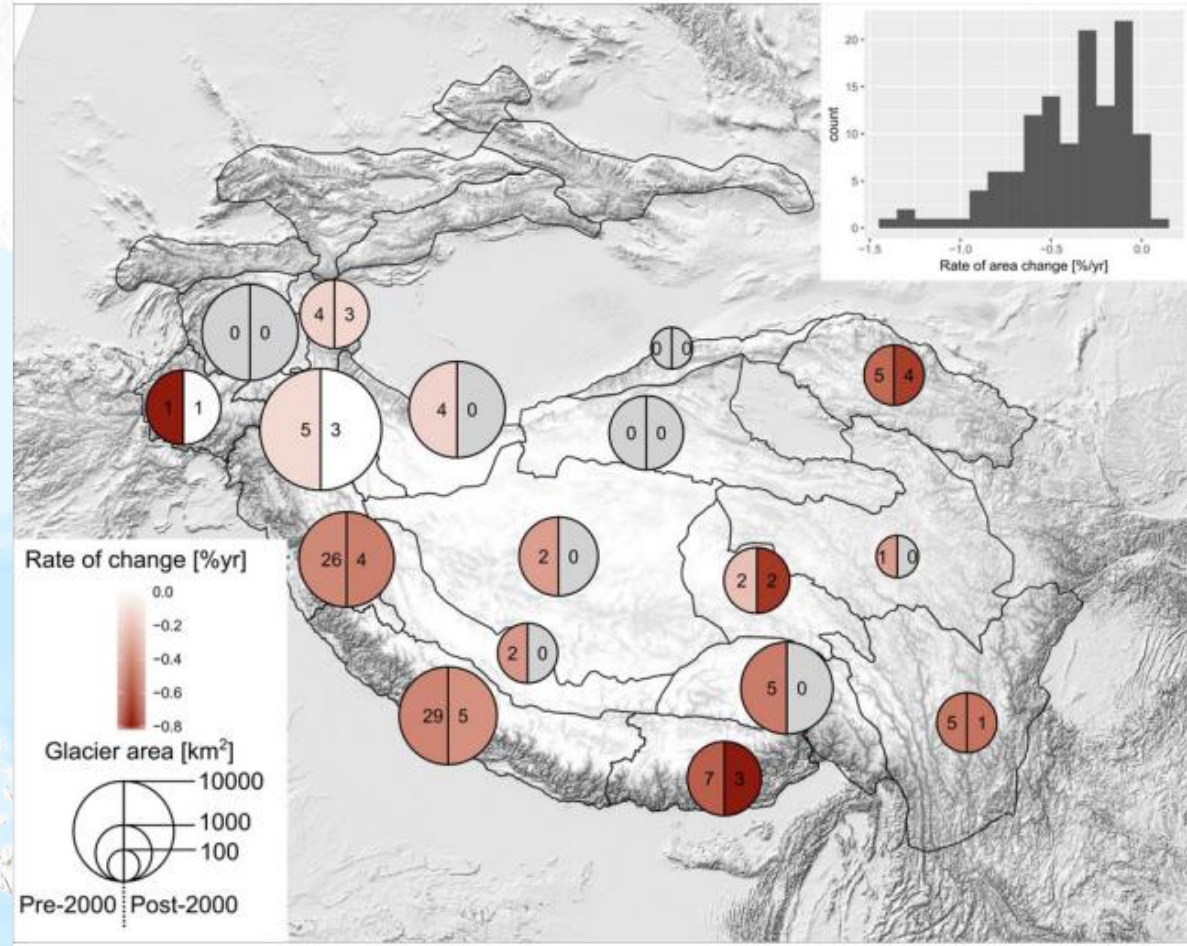






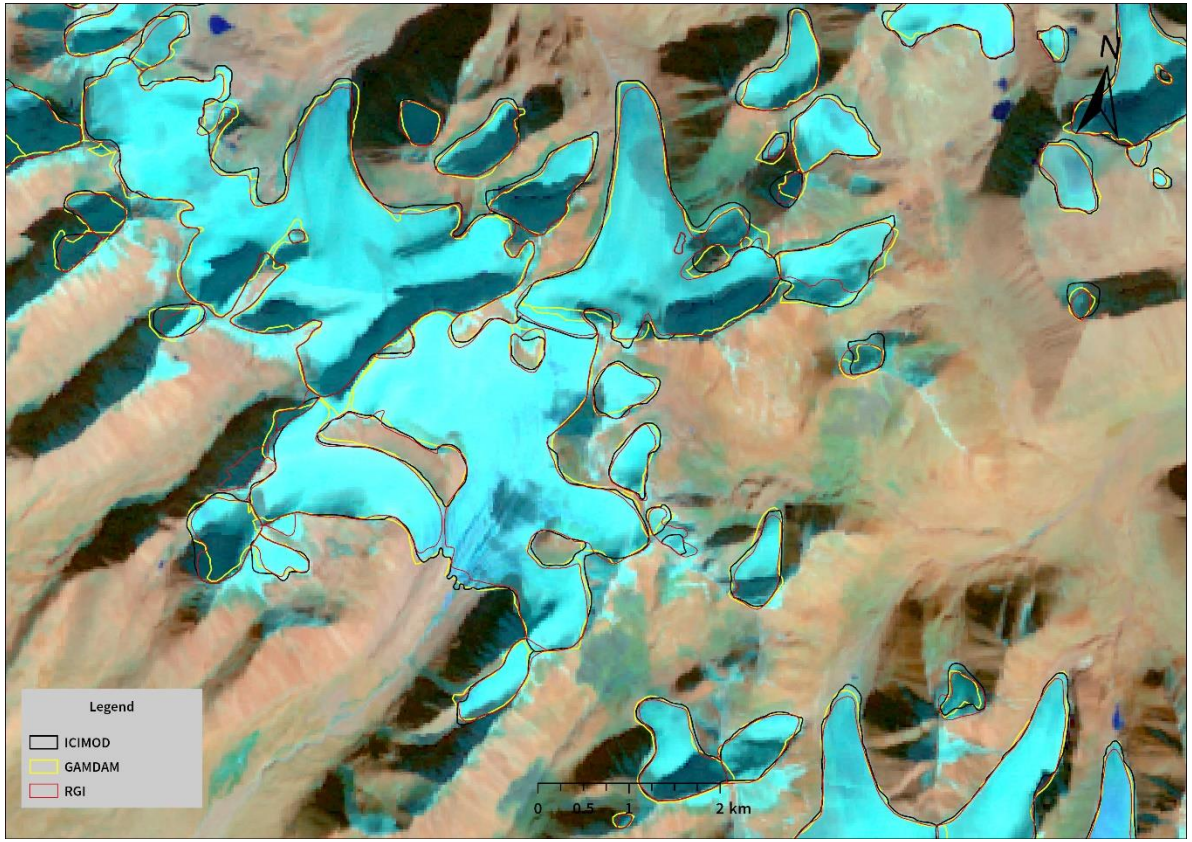
Decadal Glacier change in the HKH (1990 – 2020)



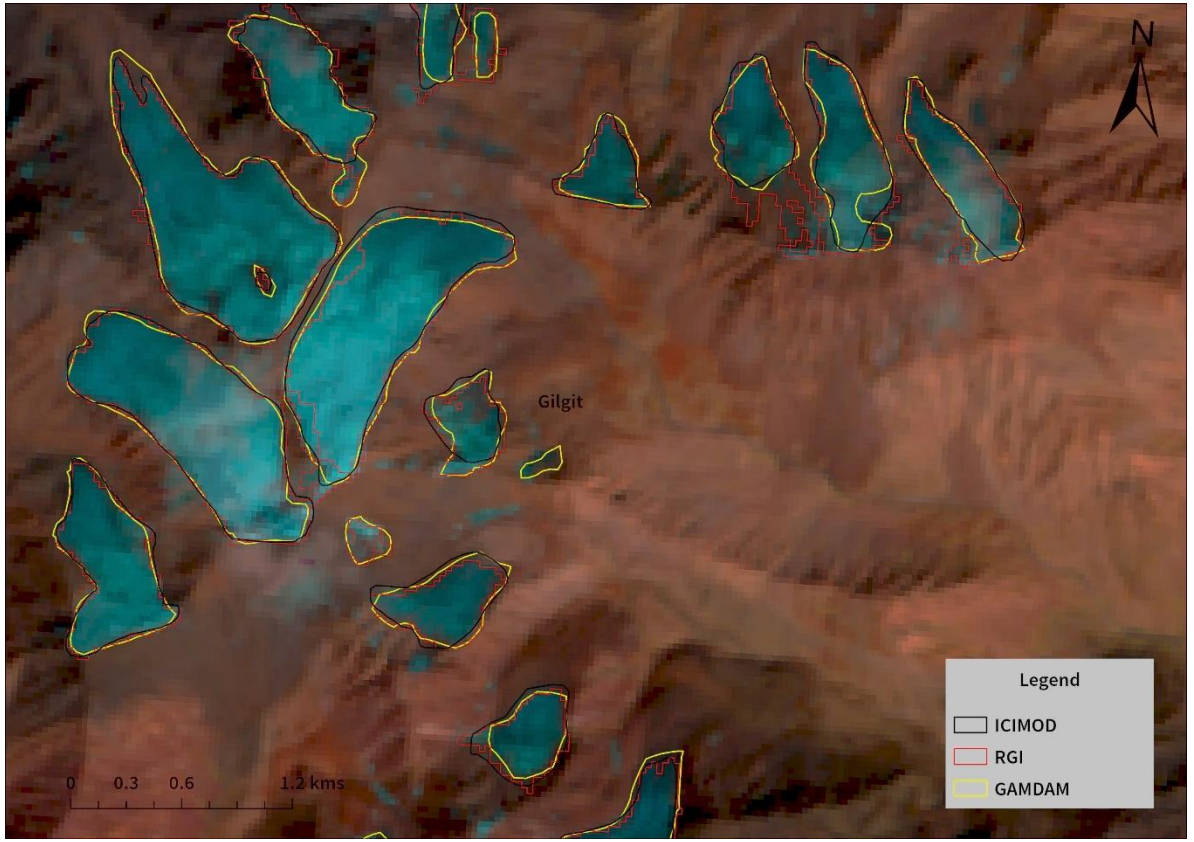


Wester et al., 2019

Comparison to other inventories



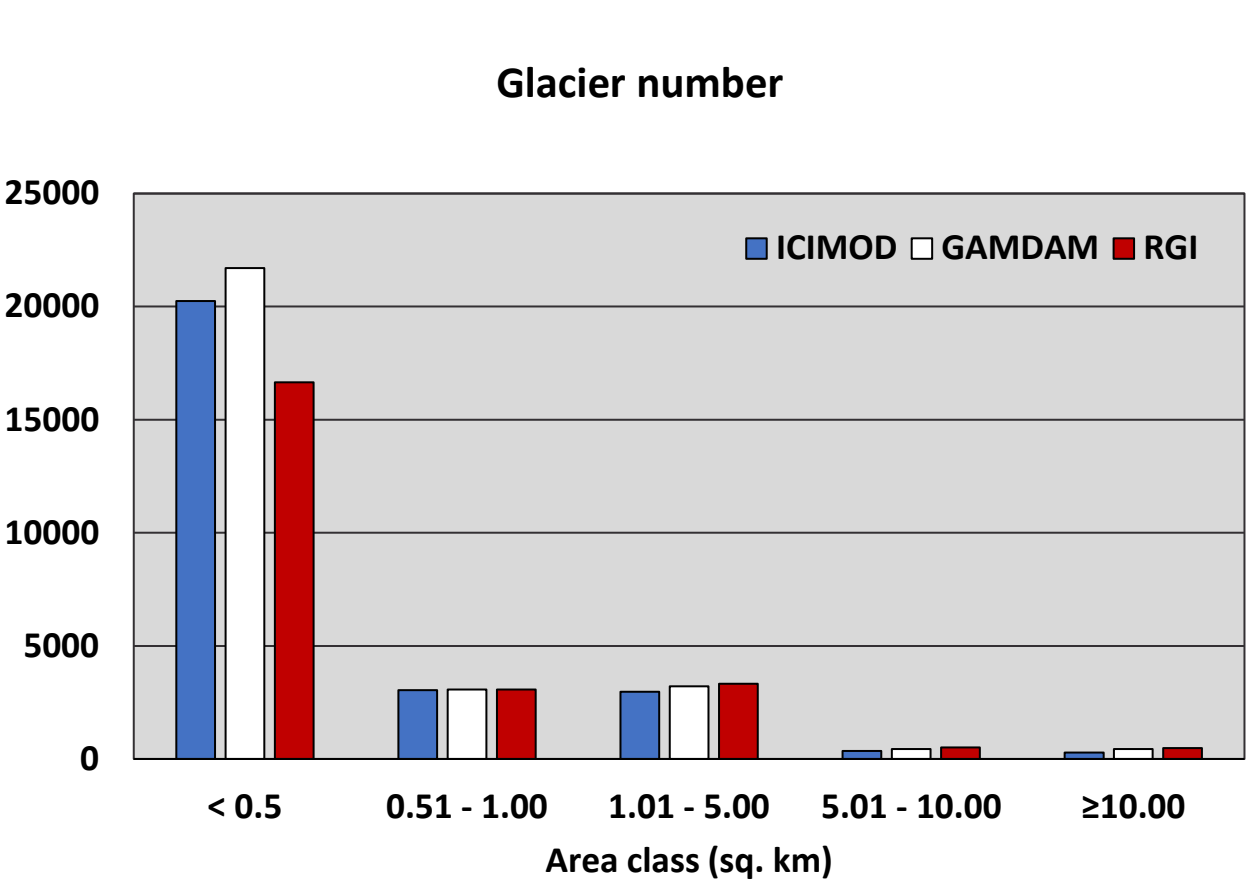
-25% in glacier area from GAMDAM 2018 inventory

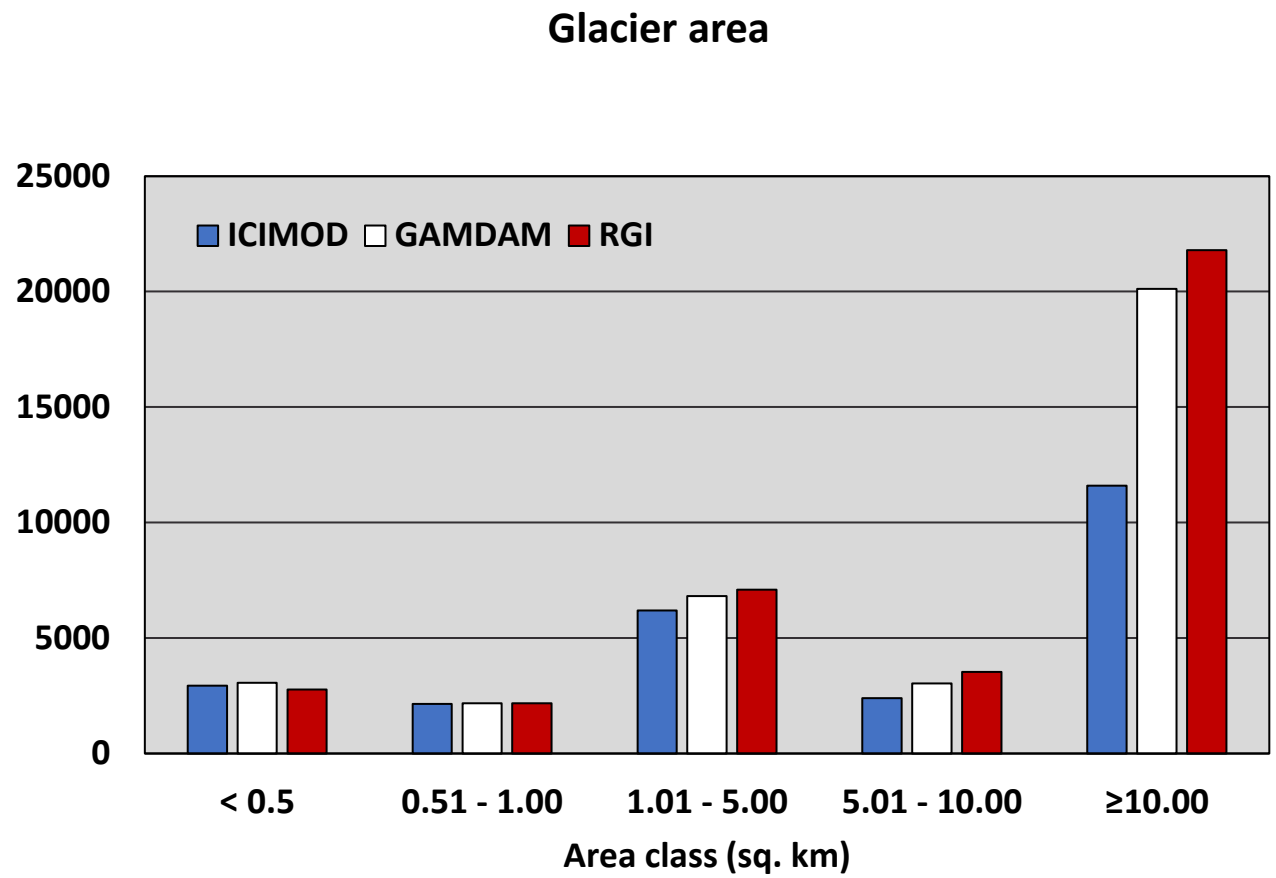


-7% in glacier number from GAMDAM 2018 inventory

Similar differences in Bhambri et al., 2022 and Soheb et al., 2022

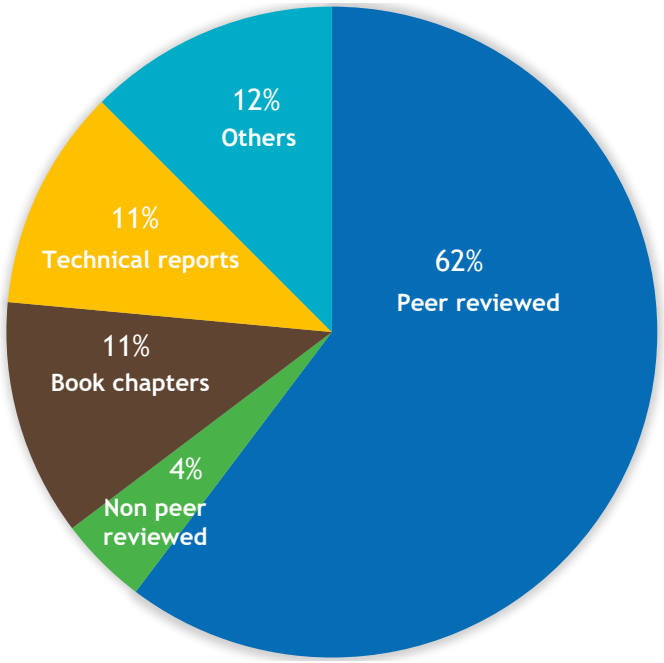
Comparison to other inventories

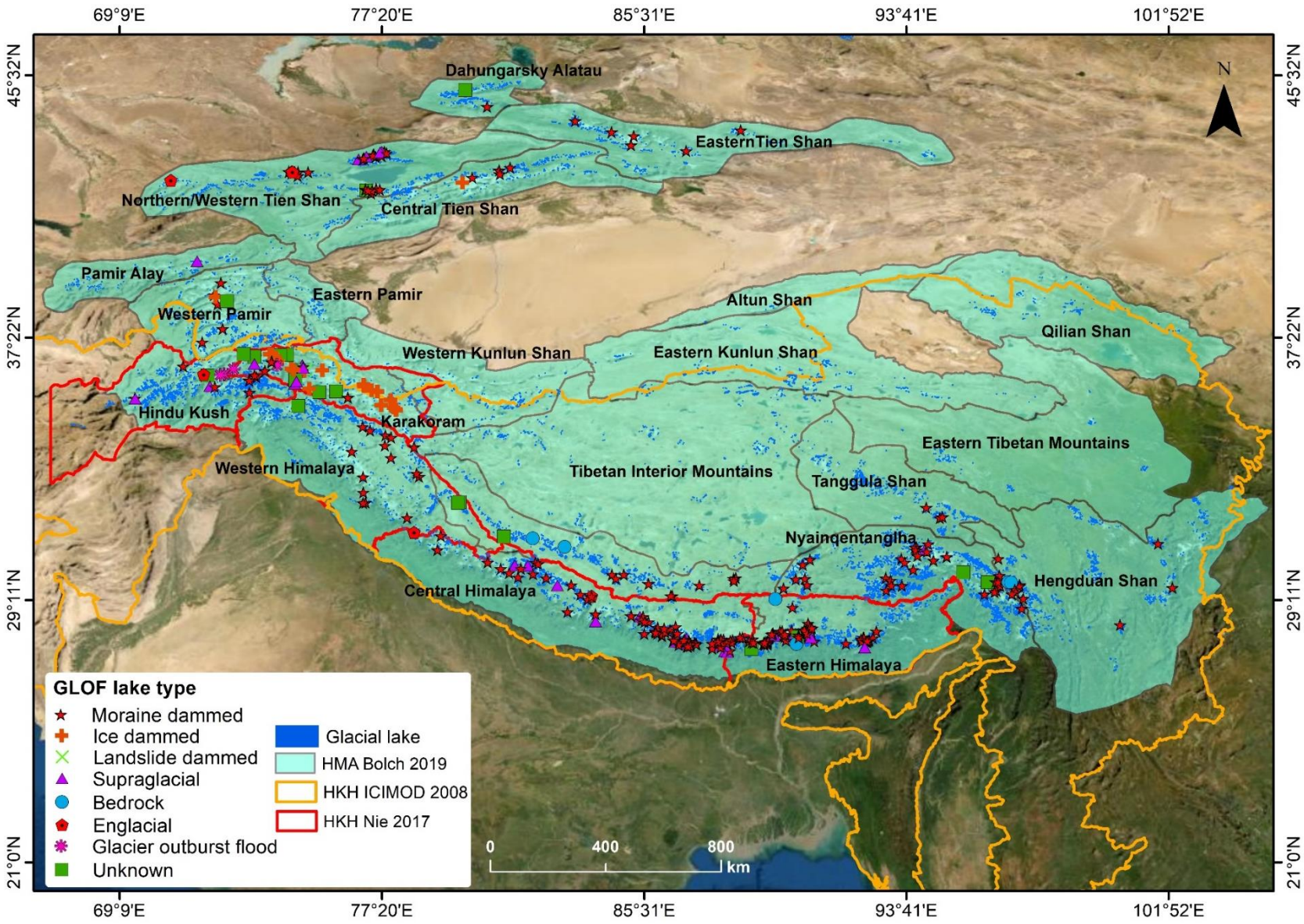




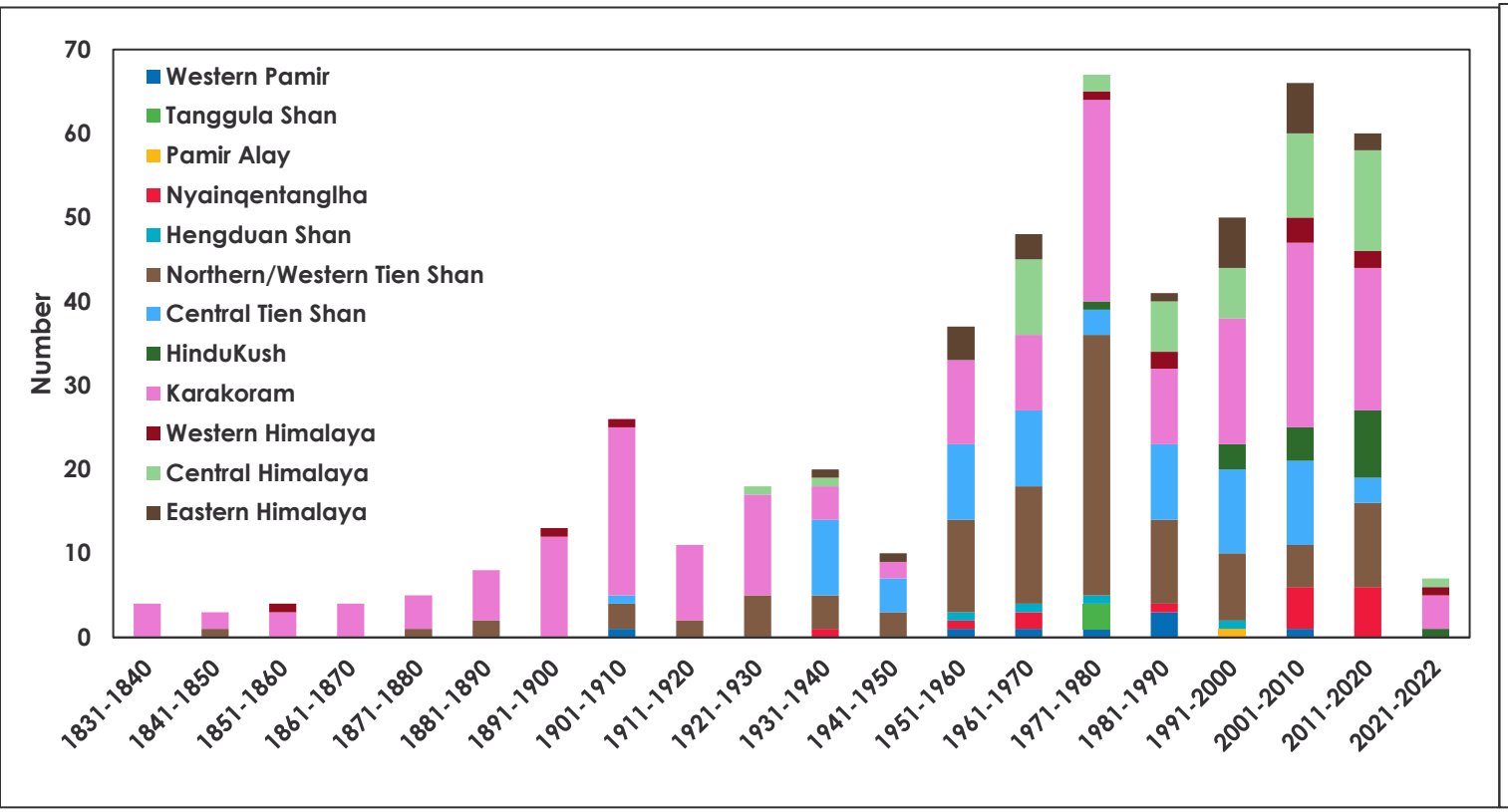
GLOF DATABASE

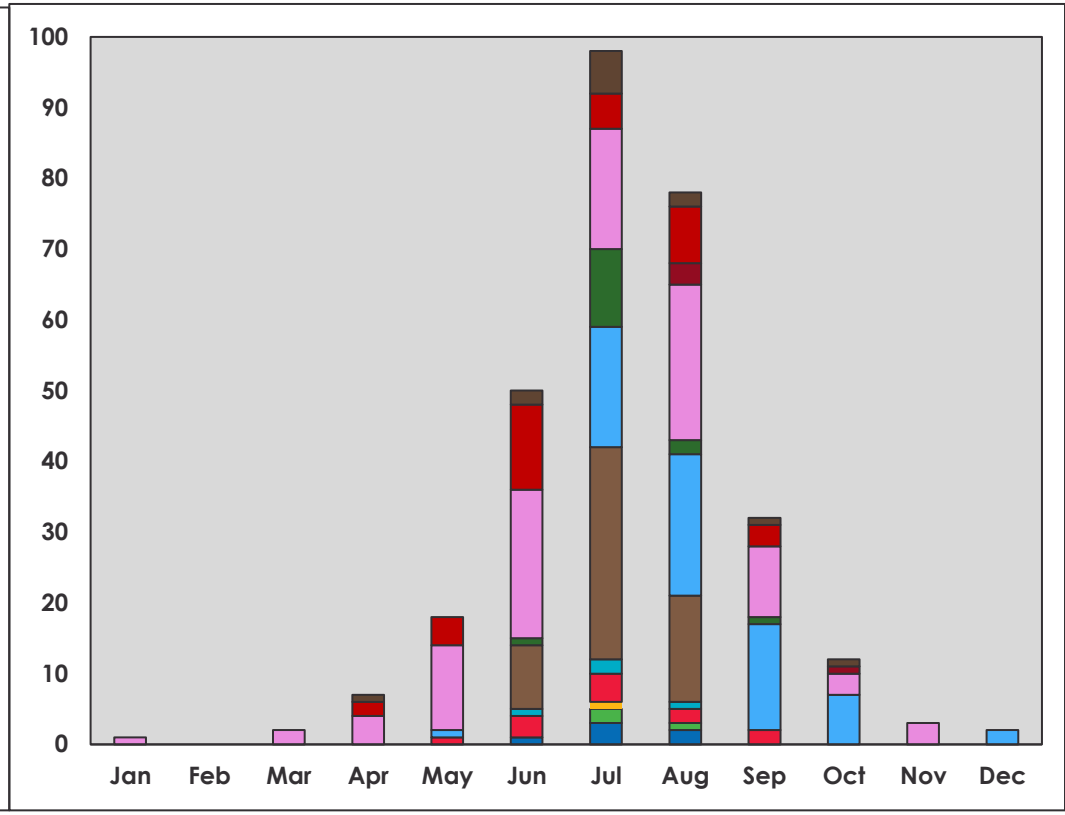
682 GLOFs recorded between 1833 (with 4 historic events before that date) and 2022 from 142 publications





GLOF distribution in HMA





ICIMOD

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Regional Database System

Search

Advanced Search

GLOF database of High Mountain Asia

UPDATED DATE: 10/21/2022 12:07:12 PM

DOWNLOAD

Glacier lake outburst floods (GLOFs) have been intensely investigated in high mountain Asia (HMA) in recent years and are often the first hazard related to the cryosphere mentioned in the region. As glaciers are receding and surrounding slopes become increasingly unstable such events are expected to increase, although so far, no evidence exists for the same. Many studies have investigated individual events and some regional inventories exist however they either do not cover all types of GLOF, do not cover the entirety of the region and none generally discuss downstream impacts. Previous inventories also do not rely on non-academic sources and are not combined with already existing inventories of glaciers and lakes. In this study we present a first comprehensive inventory of GLOFs in HMA, including the time of their occurrence, processes of lake formation and drainage involved as well as downstream impacts. We find 660 individual GLOFs that occurred between 1833 (with 4 historic events before that date) and 2022, 20% of which occurred from repeated events at just three ephemeral ice dammed lakes. All events resulted in 6907 fatalities, of which 6000 were caused by just one event that included a number of other drivers of the eventual flood. The combination of the database with previous inventories of glaciers and lakes allows future assessments of potential drivers of GLOFs, allowing more robust future projections of their evolution. The presented database and its future updated versions are traceable, version controlled and can be directly incorporated into further analysis.



https://rds.icimod.org/

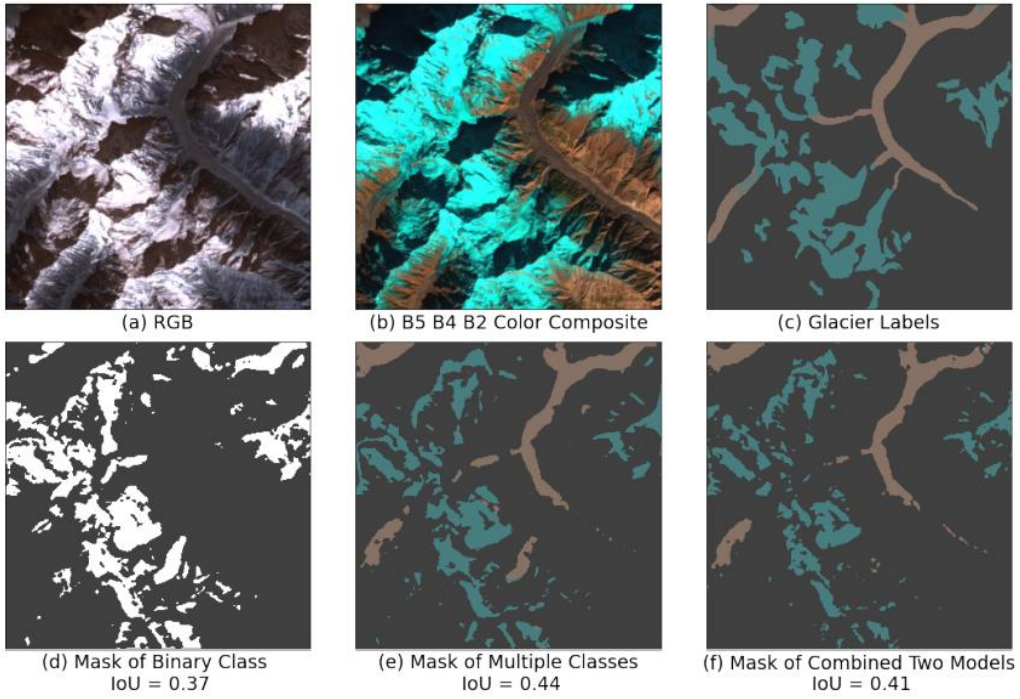
Schema	iso19139
Purpose	This database provide a first comprehensive dataset of GLOFs in HMA including their location, timing, associated processes and downstream impacts; which can

Application of the data

Machine Learning for Glacier Monitoring in the Hindu Kush Himalaya

Shimaa Baraka[1,*], Benjamin Akera[1,*], Bibek Aryal[2,*], Tenzing Sherpa[3], Finu Shresta[3], Anthony Ortiz[4], Kris Sankaran[5], Juan Lavista Ferres[4], Mir Matin[3], and Yoshua Bengio[1]

[1]Mila
[2]University of Texas at El Paso
[3]Integrated Centre for Mountain Development
[4]Microsoft AI for Good Research Lab
[5]University of Wisconsin - Madison
[*]Equal Contribution



Mapping Glacial Lakes Using Historically Guided Segmentation Models

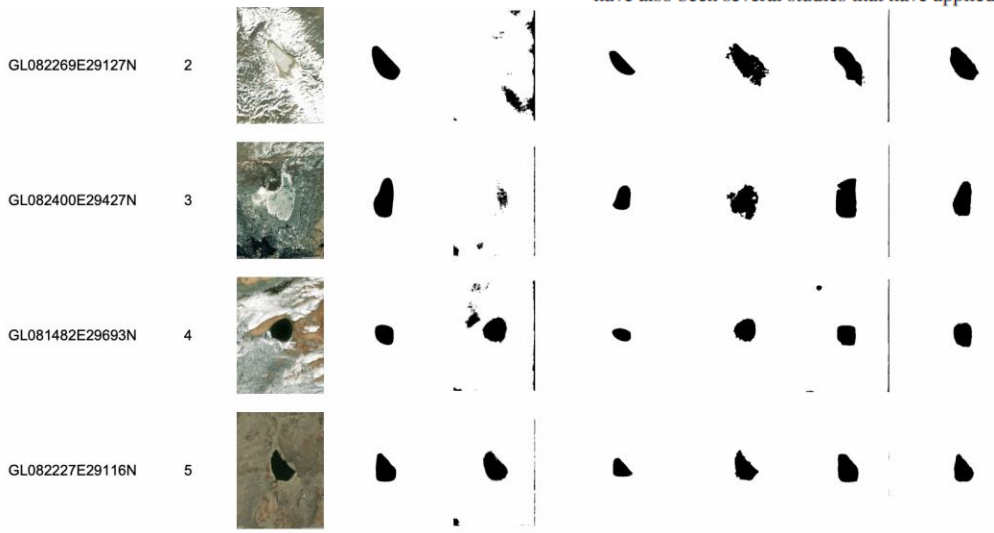
Anthony Ortiz, Weiyushi Tian, Tenzing Chogyal Sherpa, Finu Shrestha, Mir Matin, Rahul Dodhia, Juan M. Lavista Ferres, and Kris Sankaran

***Abstract*—In this article, we compare several approaches to segmenting glacial lakes in the Hindu Kush Himalayas in order to support glacial lake area mapping. More automatic mapping could support risk assessments of Glacial Lake Outburst Floods, a type of natural hazard that poses a risk to communities and infrastructure in valleys below glacial lakes. We propose and evaluate several approaches that incorporate labels from a 2015 survey using Landsat 7 ETM+ SLC-off imagery to guide segmentation on newer higher resolution satellite images such as Sentinel 2 and Bing Maps imagery, comparing them also to approaches that do not use this form of weak prior. We find that a guided version of U-Net and a properly initialized form of morphological snakes are most effective for these two datasets, respectively, each providing between an 8–10% intersection-over-union improvement over existing U-Net segmentation approaches. An error analysis highlights the strengths and limitations of each method. We design visualizations to support the discovery of lakes of potential concern, including an interactive exploratory interface. All the codes supporting our study are released in public repositories.**

***Index Terms*—Climate change, deep learning, glacial lakes, glacier mapping, morphological snakes.**

These lakes are dammed by moraine complexes, which are often unstable and have a potential to breach. A *Glacial Lake Outburst Flood (GLOF)* event occurs when a dam holding a glacial lake collapses. The resulting rush of water and accumulated debris can cause significant damage to nearby communities destroying human lives and infrastructure. GLOFs have led to more than 12 000 deaths and destroyed roads, bridges, hydroelectric developments, and entire villages [4], [20]. The accurate delineation and mapping of glacial lakes across multiple timepoints is required for determining the risks of such GLOF events [8] and developing GLOF mitigation strategies.

Different organizations around the world, including the International Centre for Integrated Mountain Development (ICIMOD), have been working on creating glacial lake inventories [3], [8], [11], [12], [14], [18], [22], [24], [26], [30]. Until now, most of these inventories have been opting for manual methods of delineating glacial lakes using optical or synthetic aperture radar (SAR) imagery [3], [8], [12], [15], [24]. There have also been several studies that have applied semiautomated



Thank you

Protect the pulse.