Observation of cryosphere

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ICIMOD

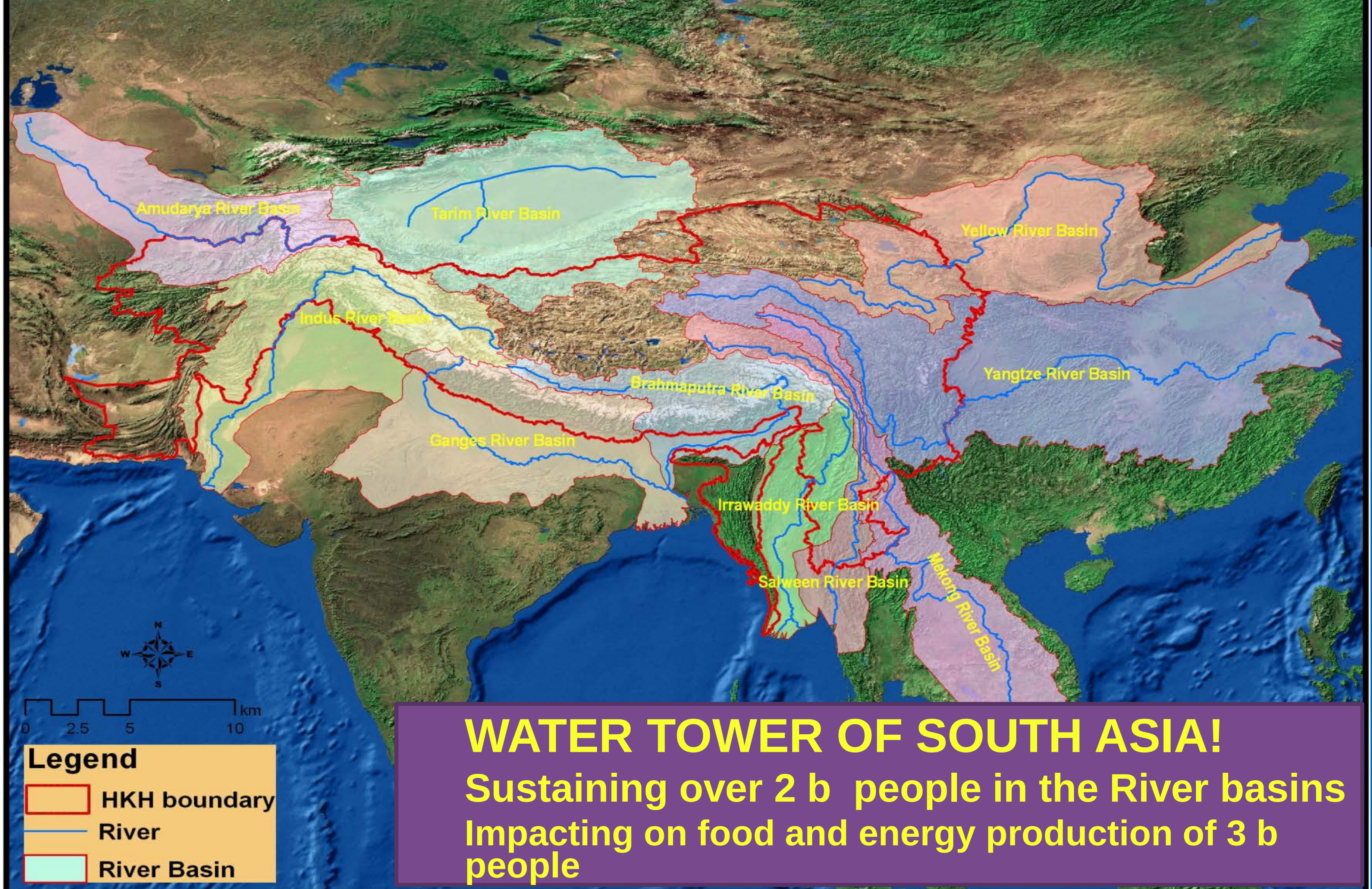
FOR MOUNTAINS AND PEOPLE

Regional Stakeholder Consultation on Climate Services for the Third Pole Region
Jaipur, Rajasthan, India
9-11 March 2016

ICIMOD – an intergovernmental learning and knowledge sharing centre serving 8 member countries

- **Vision:** ***The mountain population of the greater Himalayas enjoys improved well-being in a sustainable global environment***
- **Mission:** ***To enable and facilitate the equitable and sustainable well-being of the people of the Hindu Kush-Himalayas by supporting sustainable mountain development through active regional cooperation.***

ICIMOD aims to assist mountain people to understand climate changes, adapt to them, and make the most of new opportunities, while addressing upstream-downstream issues.



WATER TOWER OF SOUTH ASIA!

Sustaining over 2 b people in the River basins

Impacting on food and energy production of 3 b people

The HKH region is one of the most dynamic and complex mountain systems in the world. It contains the largest amount of snow, glacier and permafrost found outside the Polar Regions, including more than 50,000 square km of glacier cover. This vast accumulation of snow and glaciers acts as a natural water reserve, feeding ten major Asia river systems. The mountain system, stretching 3,500 km through some of the world's wettest and driest environments, rising eight vertical kilometers through nearly every life zones existing on Earth, and at the geographical centre of the largest and densest concentration of humanity, is recognized as an extremely fragile environment vulnerable to global warming.

Cryosphere Monitoring Approach

Develop and implement cryosphere monitoring activities at ICIMOD. Categorized into three main components:

1. Field-based snow and glacier monitoring
2. Field-based hydro-meteorological observations and monitoring
3. Remote sensing-based observations and monitoring

Activities under these three components ensure an interdisciplinary approach to developing comprehensive assessments of glacier water resources and future water availability scenarios.

Field-based Snow and Glacier Monitoring

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The current status of benchmark glaciers and their response to climatic variations is assessed through:

- **Monitoring the glacier mass balance and dynamics of benchmark glaciers**
- **Short-term glaciological measurement campaigns in the region**
- **Glacier mass balance and dynamics modelling**

Field-based Snow and Glacier Monitoring

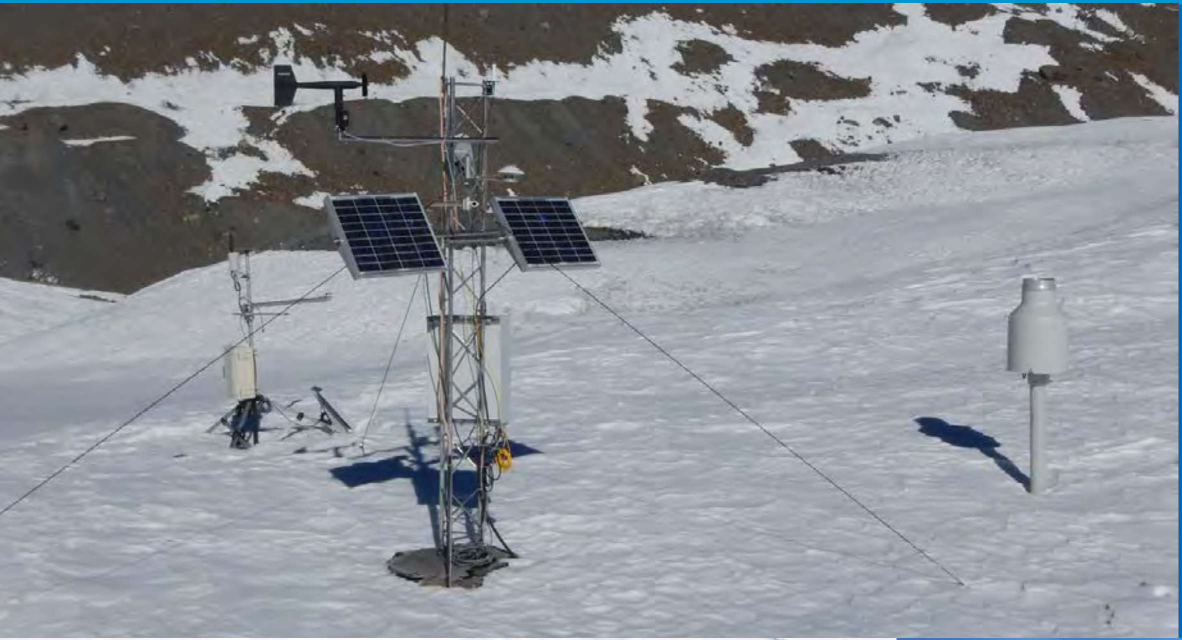

Photo: SR Joshi ICIMOD

Field-based hydro-meteorological observations and monitoring

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Assessments of current and future water resources at the catchment and sub-basin scales are carried out through:

- Meteorological monitoring
- Short-term hydrological monitoring
- Glacio-hydrological and snow melt model development
- Modelling future changes in glacier meltwater contributions to overall discharge

Field-based hydro-meteorological observations and monitoring

Photo: SR Joshi ICIMOD

Remote Sensing-based Snow and Glacier Monitoring

ICIMOD maintains a multi-level remote sensing based observation system for snow and glacier monitoring in basins and sub-basins, including:

- Mapping and monitoring of glaciers and glacial lakes using Landsat and other high resolution satellite images
- Snow cover monitoring using MODIS
- Using unmanned aerial vehicles (UAV) and high resolution stereopair satellite images to monitor glacier mass change
- Detailed investigations of glaciers in representative basins/sub-basins

MODIS receiving station in ICIMOD

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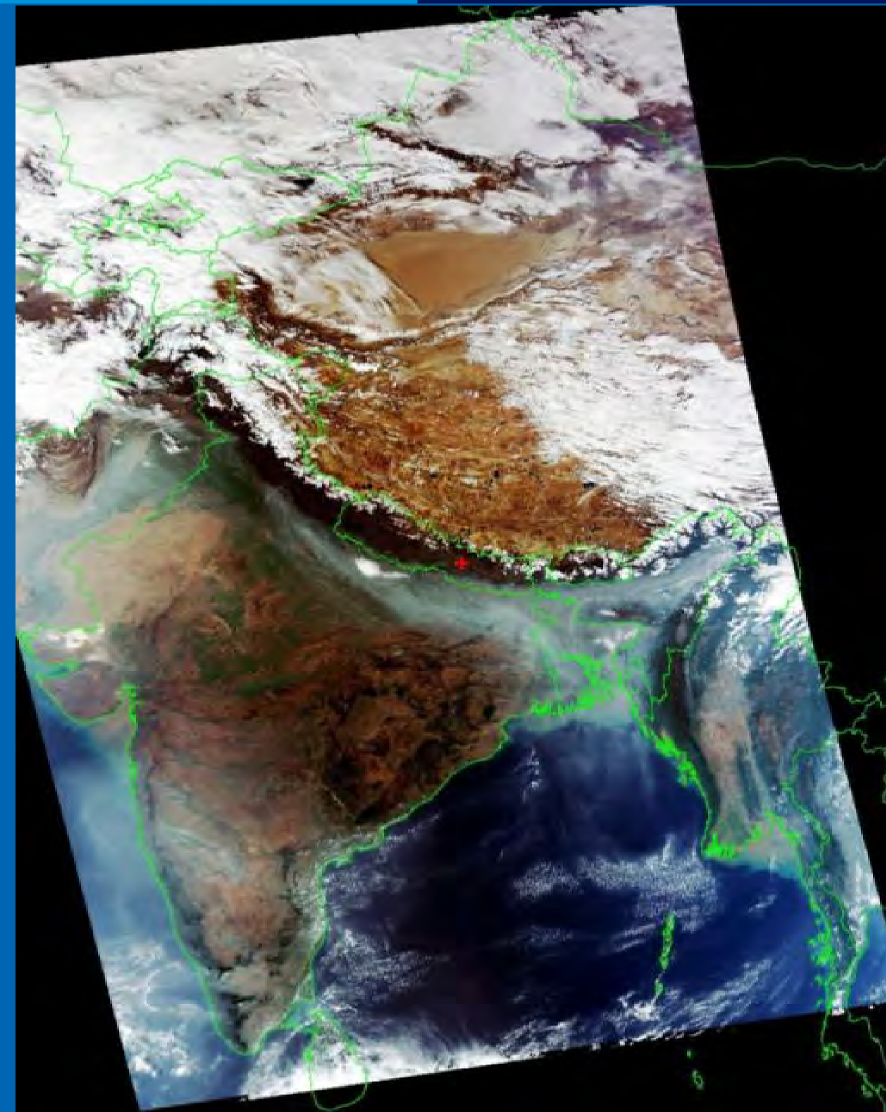
Installing MODIS receiving station at ICIMOD



Receiving MODIS images since January 2013

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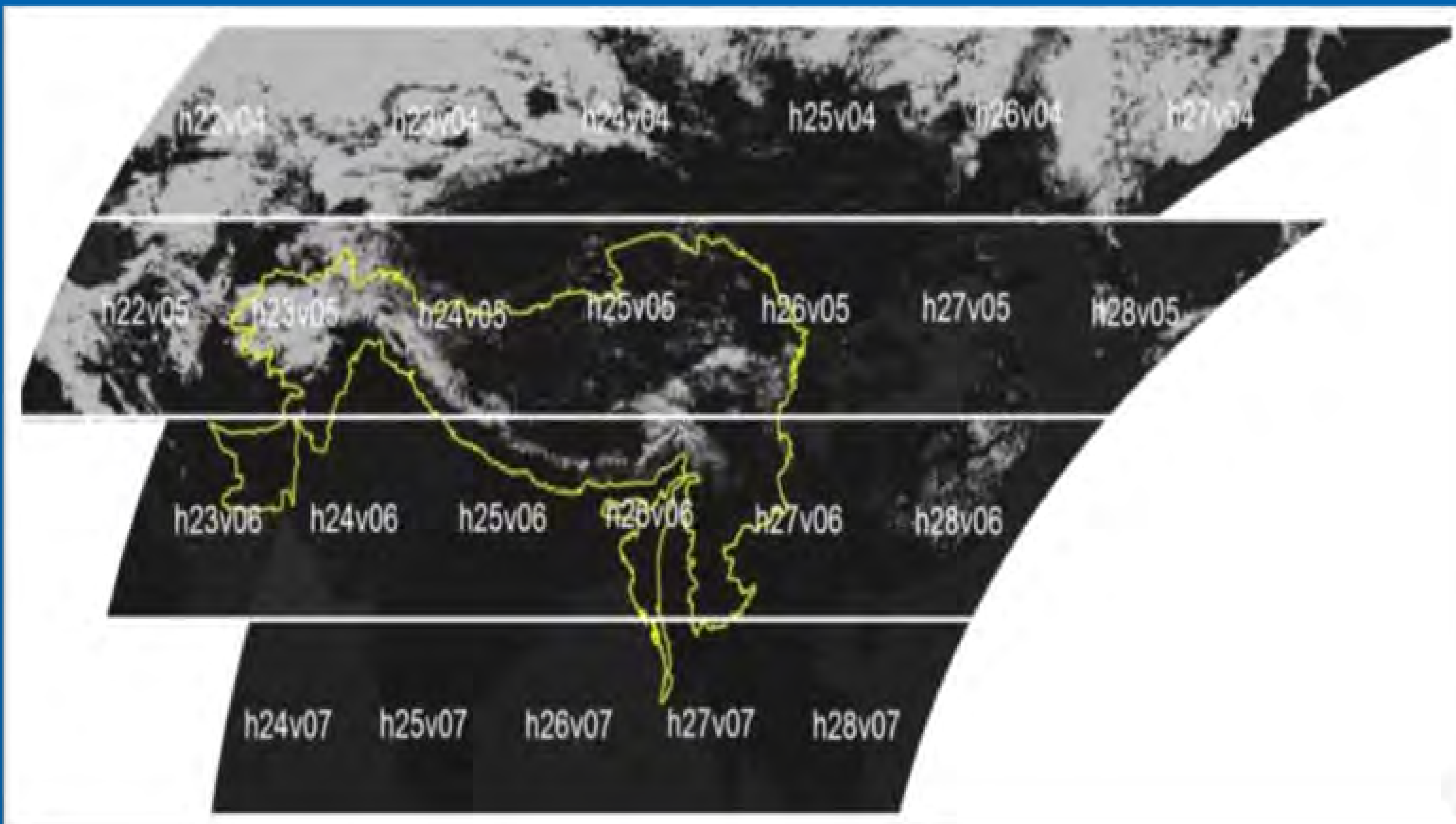

Capacity Building

Capacity building features strongly within the Cryosphere Initiative and its activities, including:

- **Support for a two year MSc programme in glaciology at Kathmandu University**
- **Scholarships for MSc and PhD students**
- **Short-term training courses and study tours**
- **Short-term personnel exchange and on-the-job training for professionals from the region**

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Photo: SR Joshi ICIMOD

But the cryosphere in the HKH is changing….

Changes in the glaciers may have a significant impact on the quantity and timing of water availability. A comprehensive understanding of the extent and nature of changes in glaciers will support downstream hydrological planning and water resource management.

Changing Mountain Environment

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Fast retreating Gangapurna glacier at the northern slope of Annapurna Range, Manang Lake and Manang Village, Nepal

Glaciers in
The Hindu Kush – Himalaya Region

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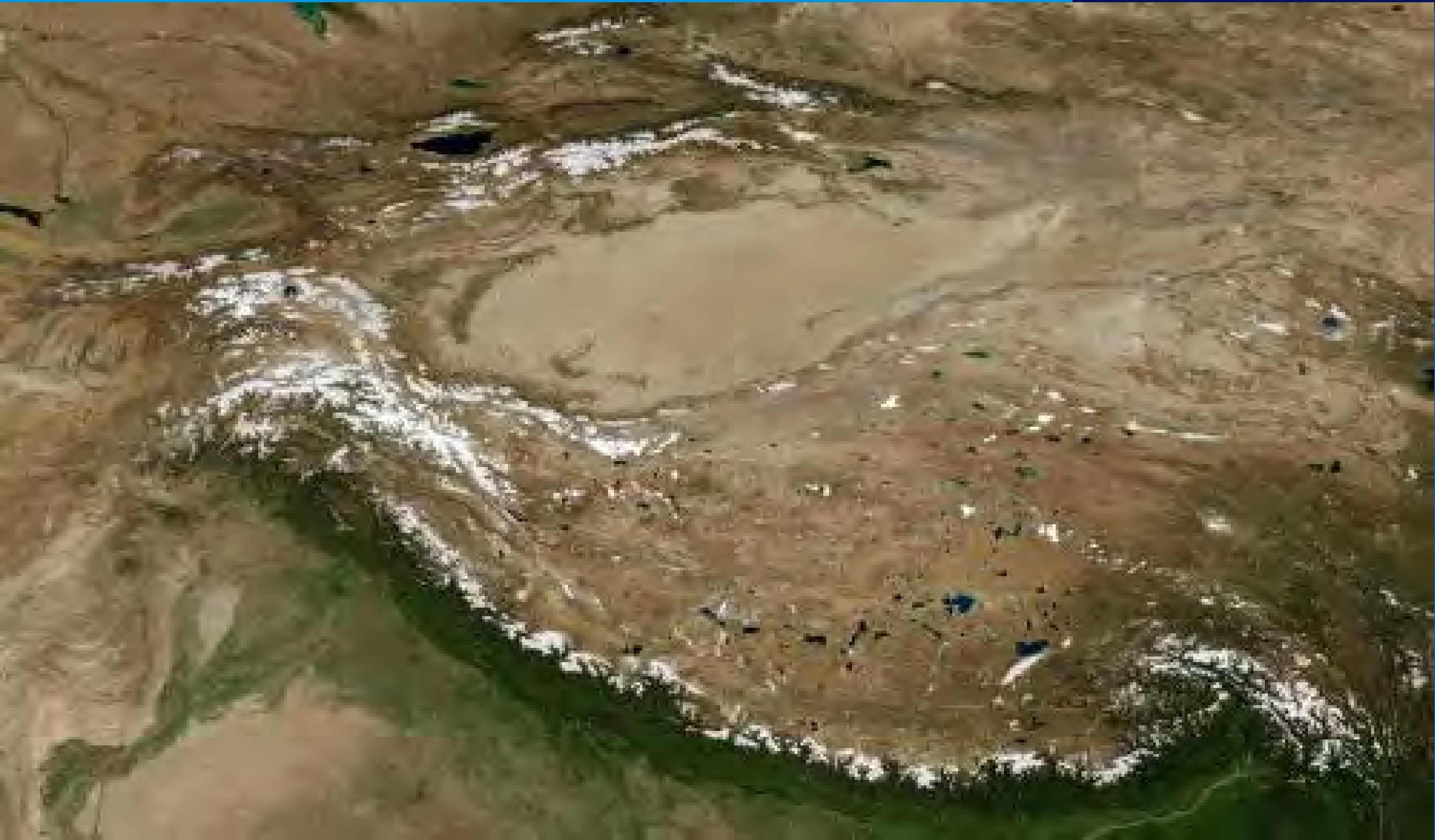
The Himalaya alone have nearly 60,054 km^2 of snow and ice



Snow cover in HKH region

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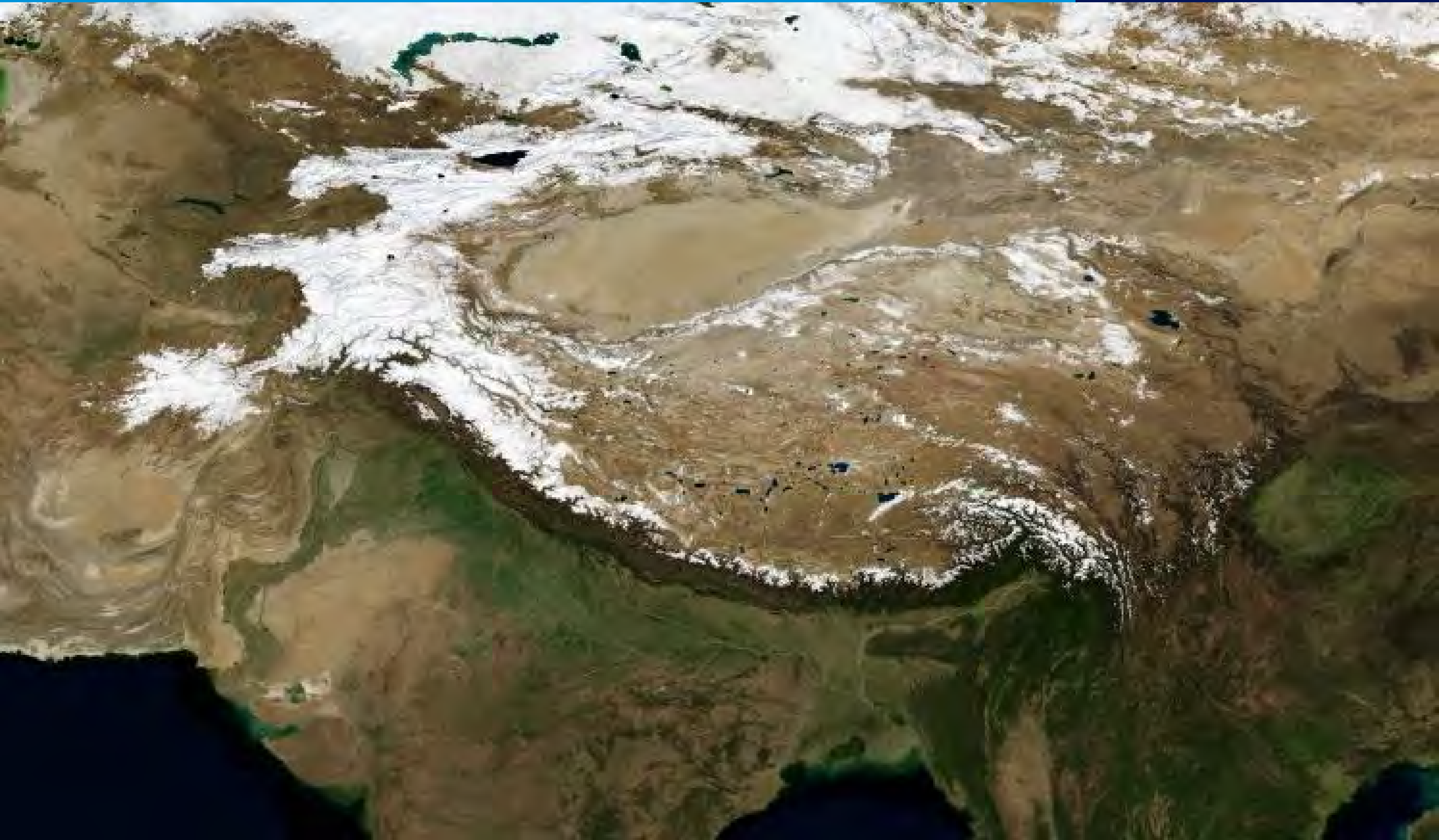

Glaciers are retreating fast

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Most of glacial lakes in the region are formed/developing since last half century

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)

Imja Glacier and formation of Imja glacial lake, Nepal – Repeat Photography

Need to monitor the glacier changes

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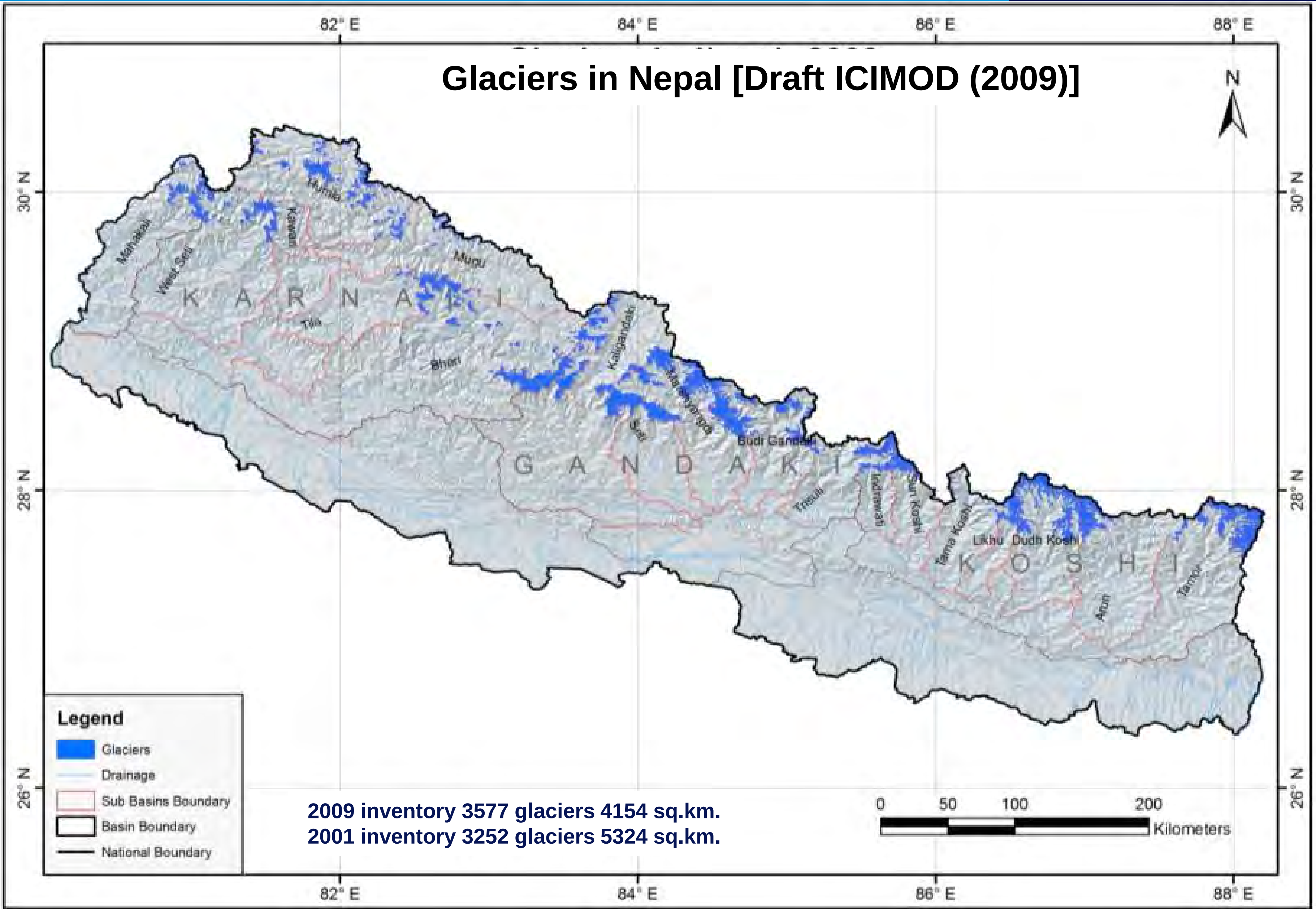

2009 inventory 3577 glaciers 4154 sq.km.
2001 inventory 3252 glaciers 5324 sq.km.

Results: HKH region

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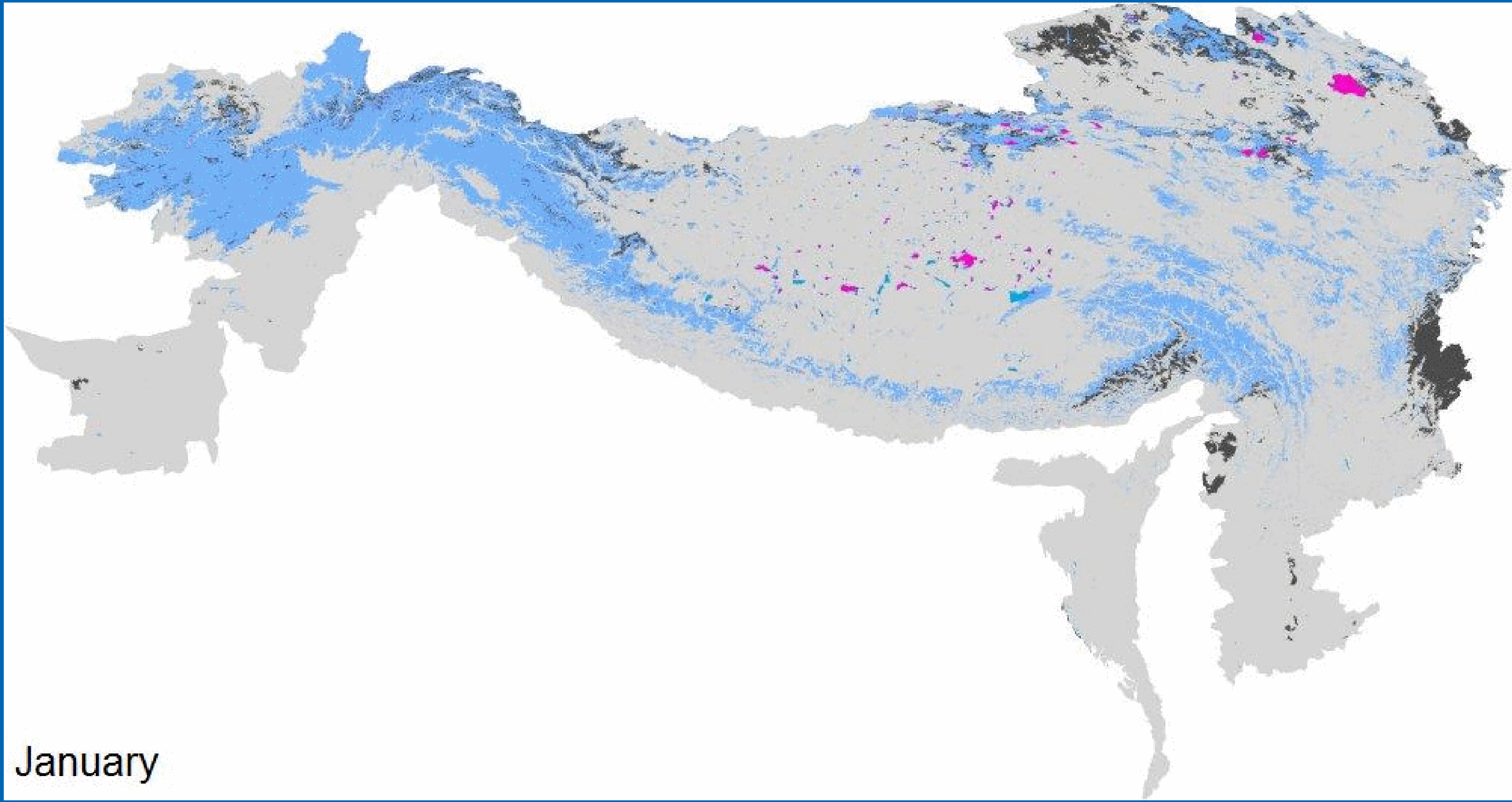
Temporal variation of snow cover area (SCA) of HKH – 8 Days composite of 2005



Snow cover change from 2002 - 2010

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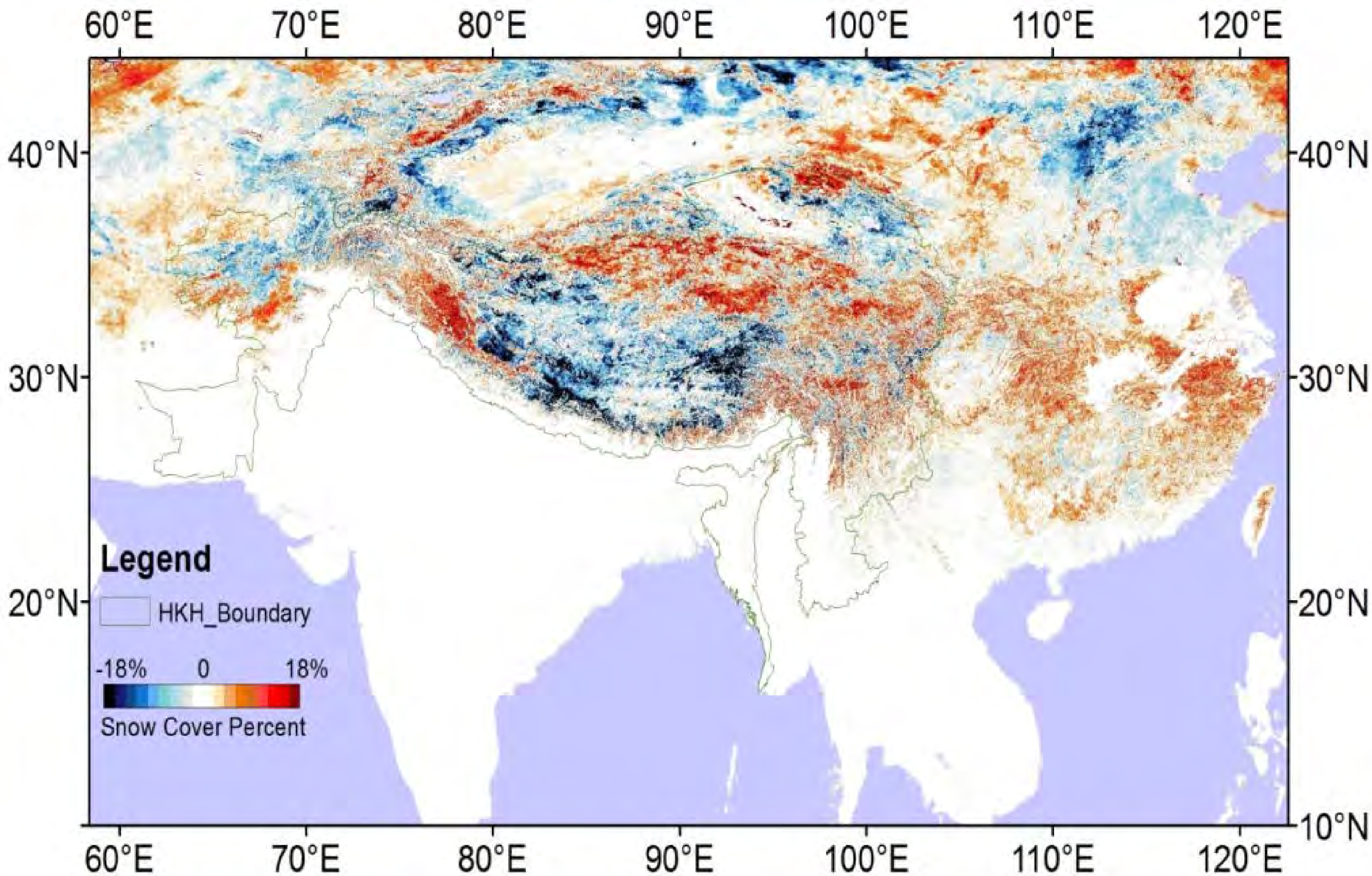

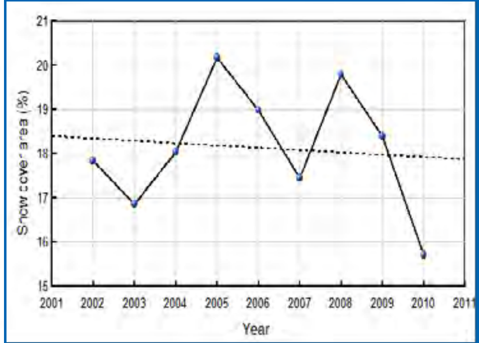

Linear regression (trend) indicate decline of snow cover trend for last decade

Seasonal Snow Cover

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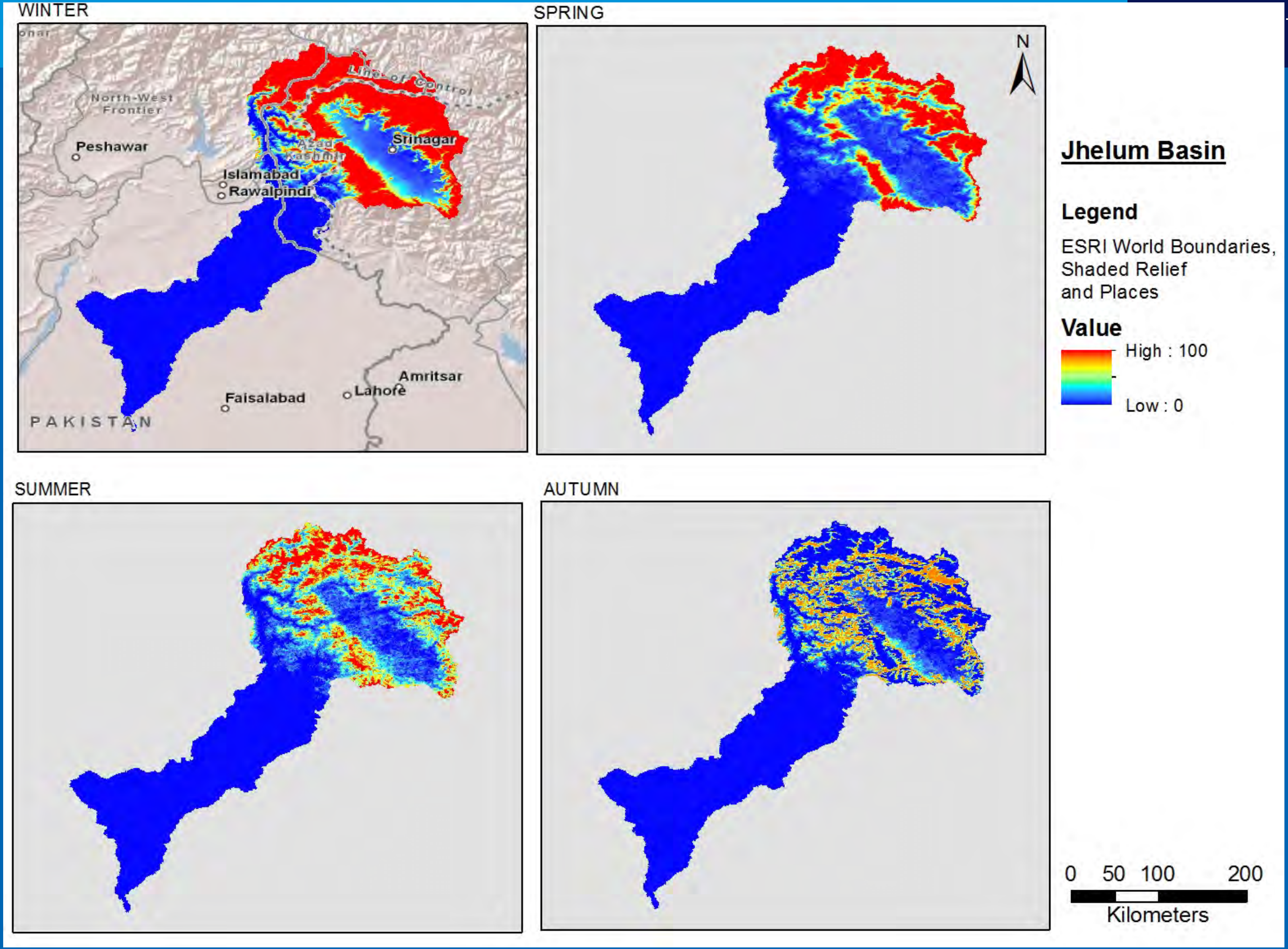

Additional risks are created …….

The risk of GLOF has increased

GLOF risk assessment

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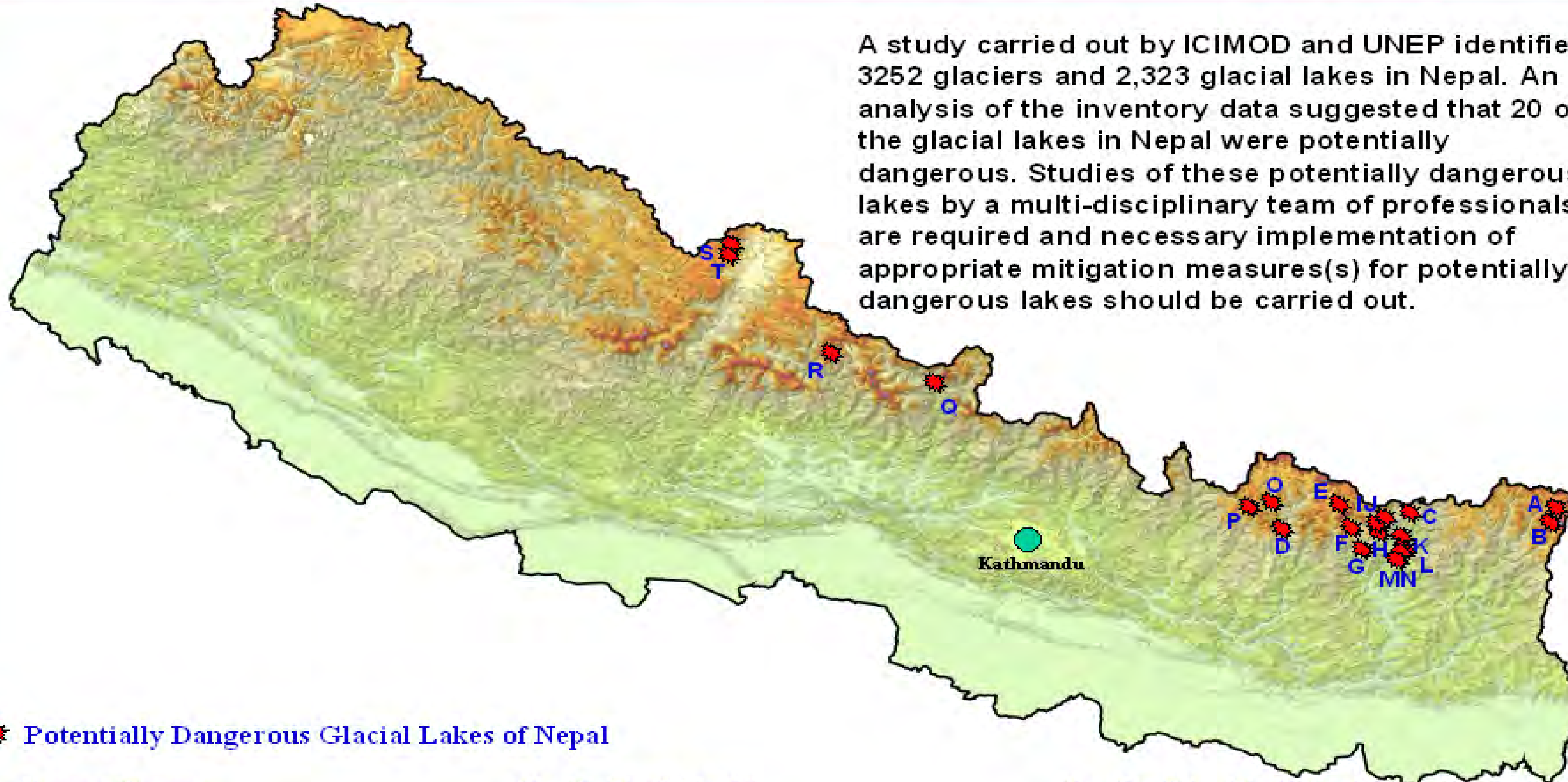
Potentially Dangerous Glacial Lakes of Nepal

A study carried out by ICIMOD and UNEP identified 3252 glaciers and 2,323 glacial lakes in Nepal. An analysis of the inventory data suggested that 20 of the glacial lakes in Nepal were potentially dangerous. Studies of these potentially dangerous lakes by a multi-disciplinary team of professionals are required and necessary implementation of appropriate mitigation measures(s) for potentially dangerous lakes should be carried out.



Potentially Dangerous Glacial Lakes of Nepal

A= Nagma (Tamor)
B= (?) (Tamor)
C= Lower Barun (Arun)
D= Lumding (Dudh Koshi)
E= Imja (Dudh Koshi)
F= Tam Pokhari (Dudh Koshi)
G= Dudh Pokhari (Dudh Koshi)
H= (?) (Dudh Koshi)
I= (?) (Dudh Koshi)
J= Hungu (Dudh Koshi)
K= East Hungu 1 (Dudh Koshi)
L= East Hungu 2 (Dudh Koshi)
M= (?) (Dudh Koshi)
N= West Chamjang (Dudh Koshi)
O = Dig Tsho (Dudh Koshi)
P= Tsho Rolpa (Tama Koshi)
Q= (?) (Budhi Gandaki)
R= Thulagi (Marsyangdi)
S= (?) (Kali Gandaki)
T= (?) (Kali Gandaki)

? No name

The status of Glaciers in 2010 of the Hindu Kush Himalayan region

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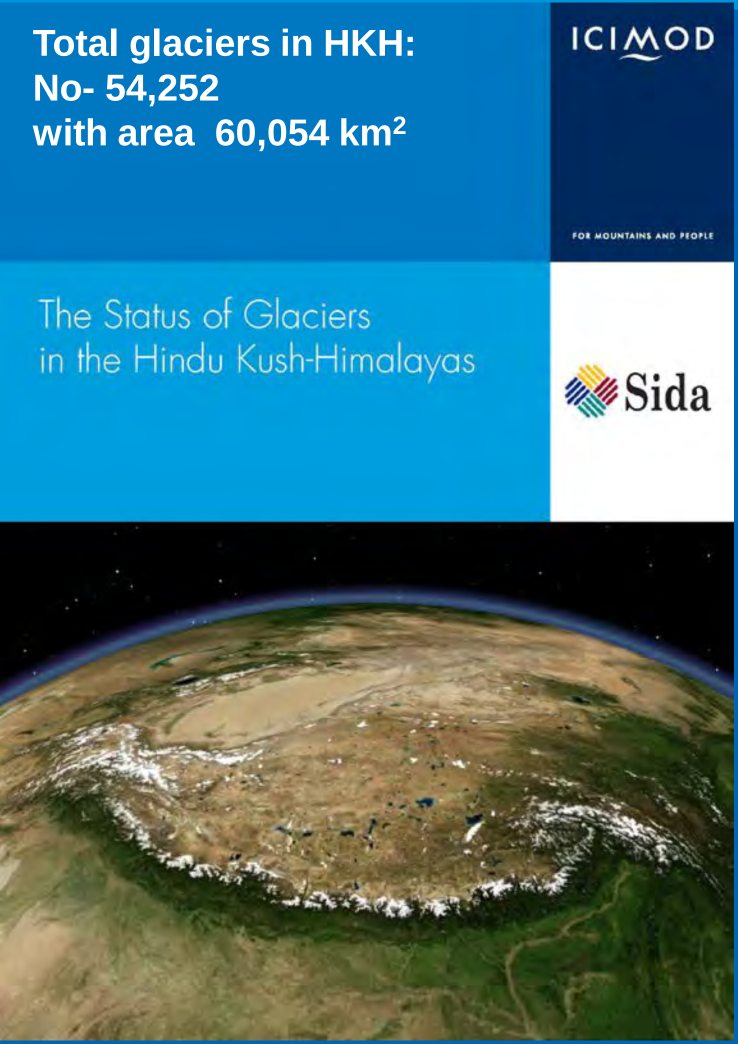
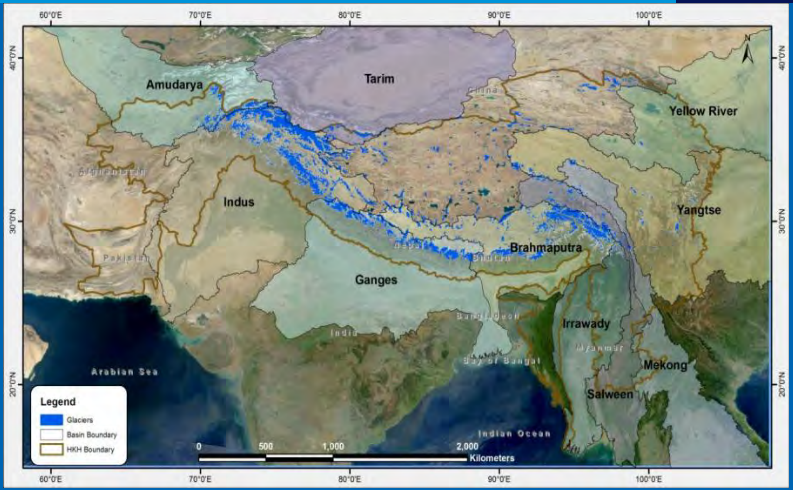
Total glaciers in HKH:
No- 54,252
with area 60,054 km²





Basins	Number	Area (km²)
Amu Darya	3,277	2,566
Indus	18,495	21,192
Ganga	7,963	9,011.53
Brahmaputra	11,497	14,019
Irrawaddy	133	35
Salween	2,113	1,351
Mekong	482	234
Yangtze	1,661	1,561
Yellow	189	137
Tarim	1,091	2,310
Interior	7,351	7,535
Total	54,252	60,054

Glacier Cover in HKH: 1.4%

Glacier data online

http://geoportal.icimod.org/

http://glims.colorado.edu/glacierdata/

Decadal glacier change from 1980's to 2010 of Nepal, Bhutan and some basins of Afghanistan, Pakistan and India

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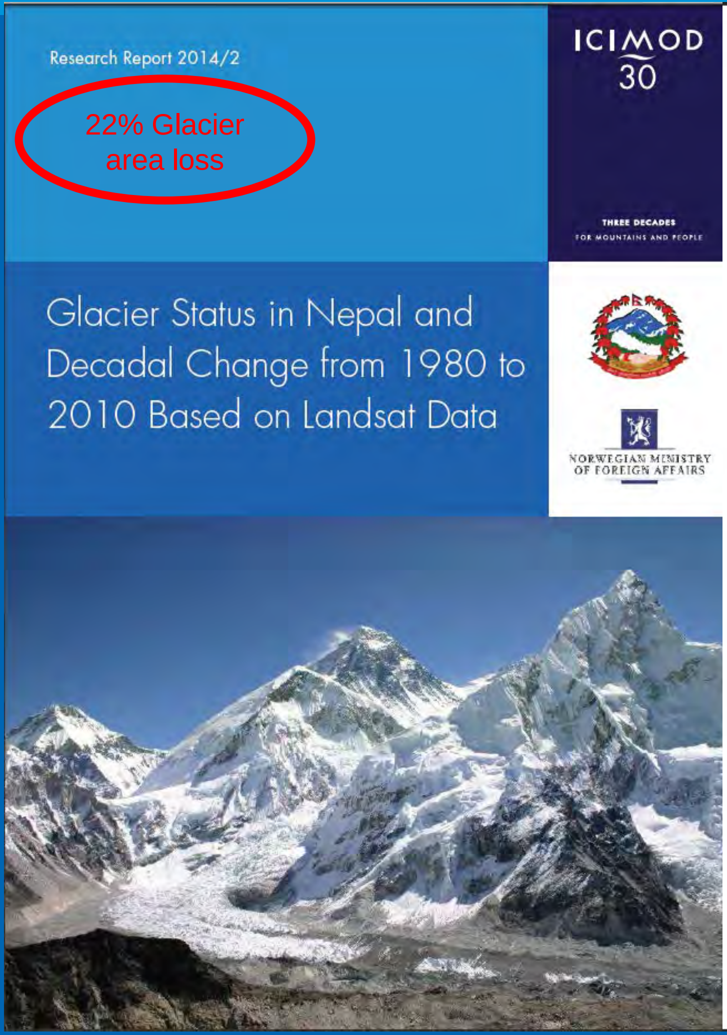

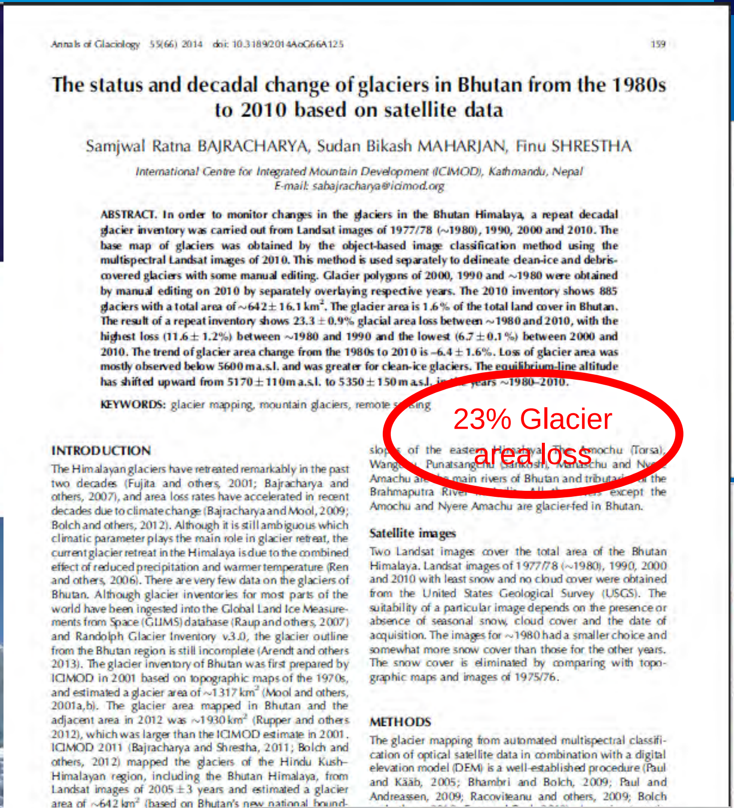

Annals of Glaciology 55(66) 2014 doi: 10.3189/2014AoG66A125 159

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

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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 km². 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

23% Glacier area loss

INTRODUCTION

The Himalayan glaciers have retreated remarkably in the past two decades (Fujita and others, 2001; Bajracharya and others, 2007), and area loss rates have accelerated in recent decades due to climate change (Bajracharya and Mool, 2009; Bolch and others, 2012). Although it is still ambiguous which climatic parameter plays the main role in glacier retreat, the current glacier retreat in the Himalaya is due to the combined effect of reduced precipitation and warmer temperature (Ren and others, 2006). There are very few data on the glaciers of Bhutan. Although glacier inventories for most parts of the world have been ingested into the Global Land Ice Measurements from Space (GLIMS) database (Raup and others, 2007) and Randolph Glacier Inventory v3.0, the glacier outline from the Bhutan region is still incomplete (Arendt and others 2013). The glacier inventory of Bhutan was first prepared by ICIMOD in 2001 based on topographic maps of the 1970s, and estimated a glacier area of ~1317 km² (Mool and others, 2001a,b). The glacier area mapped in Bhutan and the adjacent area in 2012 was ~1930 km² (Rupper and others 2012), which was larger than the ICIMOD estimate in 2001. ICIMOD 2011 (Bajracharya and Shrestha, 2011; Bolch and others, 2012) mapped the glaciers of the Hindu Kush–Himalayan region, including the Bhutan Himalaya, from Landsat images of 2005 ± 3 years and estimated a glacier area of ~642 km² (based on Bhutan's new national bound-ary). The Bhutan data are based on late … difference in area with the present inven…

This study will help us to understand … change in the decades from ~1980 to 20… glaciers in Bhutan in the coming years.

STUDY AREA AND DATA

Study area

Bhutan is a small, landlocked and m… located at 26°45′–28°10′ N, 88°45′–92°1…

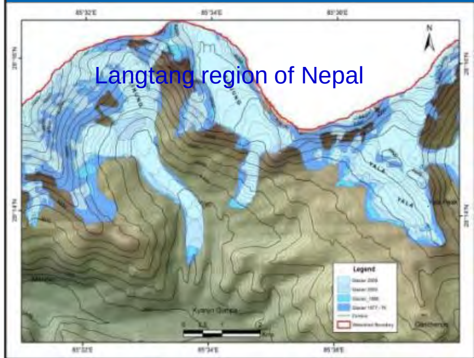
slop… of the eastern Himalaya… The Amochu (Torsa), Wang… Punatsangchu (Sankosh), Manaschu and Ny… Amachu are the main rivers of Bhutan and tributaries of the Brahmaputra River … except the Amochu and Nyere Amachu are glacier-fed in Bhutan.

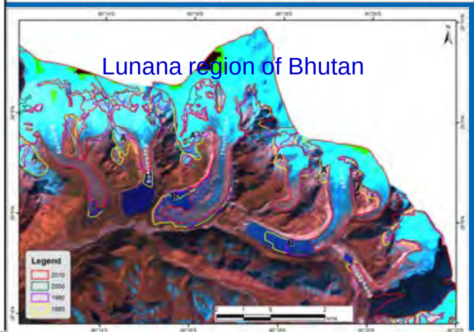
Satellite images

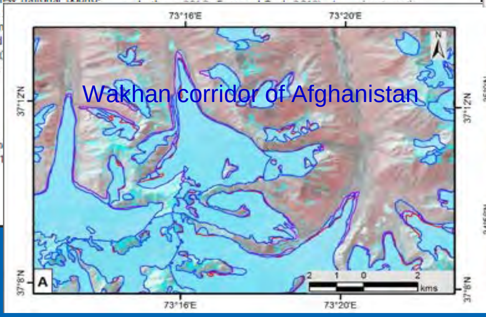
Two Landsat images cover the total area of the Bhutan Himalaya. Landsat images of 1977/78 (~1980), 1990, 2000 and 2010 with least snow and no cloud cover were obtained from the United States Geological Survey (USGS). The suitability of a particular image depends on the presence or absence of seasonal snow, cloud cover and the date of acquisition. The images for ~1980 had a smaller choice and somewhat more snow cover than those for the other years. The snow cover is eliminated by comparing with topo-graphic maps and images of 1975/76.

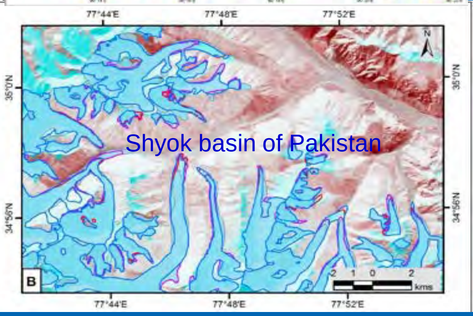
METHODS

The glacier mapping from automated multispectral classification of optical satellite data in combination with a digital elevation model (DEM) is a well-established procedure (Paul and Kääb, 2005; Bhambri and Bolch, 2009; Paul and Andreassen, 2009; Racoviteanu and others, 2009; Bolch …









Decadal Glacier Change

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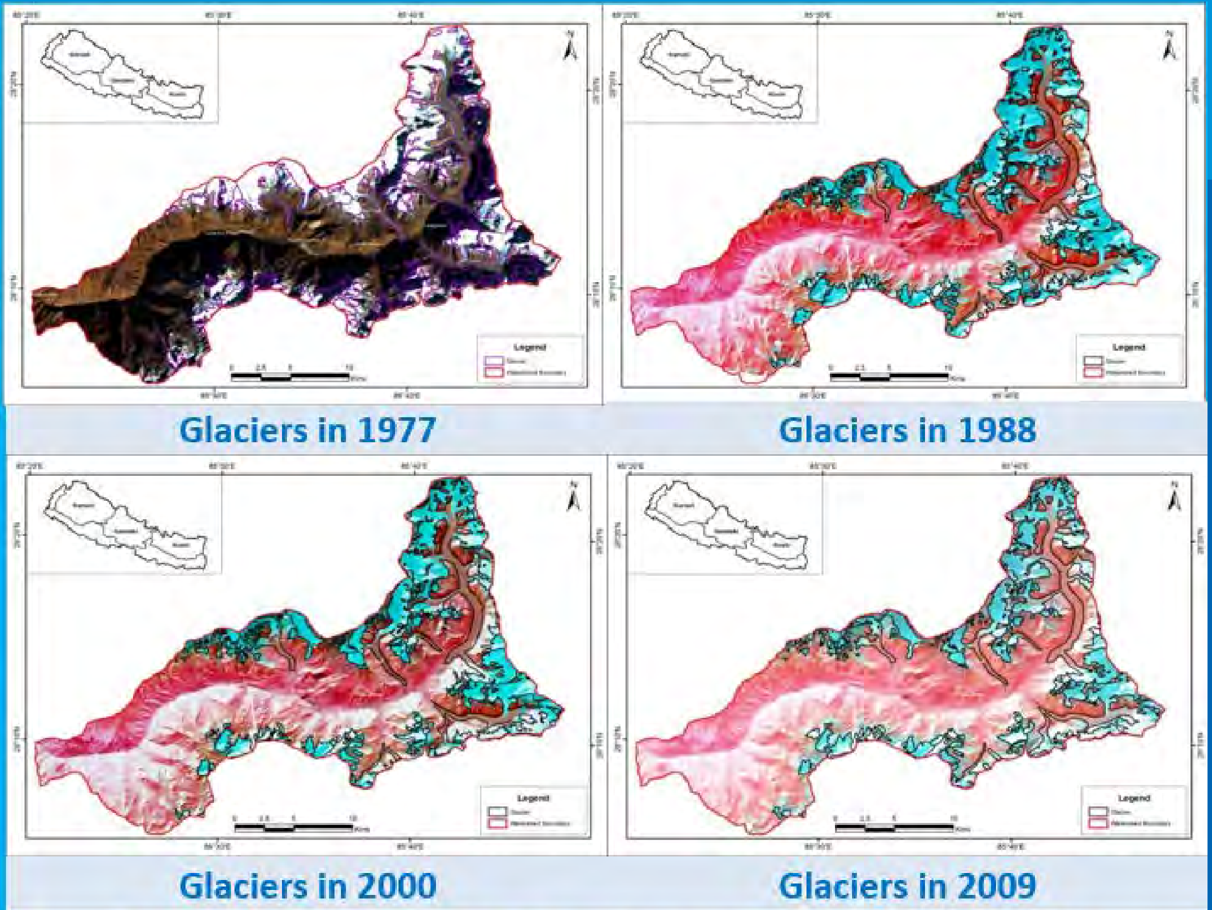

Table: Change in Langtang glacier area over three decades

SN	Data Year	Glacier Number	Glacier Area (Km^2)	Glacier Area (%)	Elevation (m asl) Highest	Elevation (m asl) Lowest
1	2009	106	142.1	28.76	7184	4112
2	2000	102	152.2	30.82	7184	4020
3	1988	102	171.3	34.69	7184	4007
4	1977	73	192.1	38.90	7184	3997

Focus on the development of the glacier area over decades, to understand future change and offer a possible evaluation of future water quantity and availability.

Decadal Glacier Change

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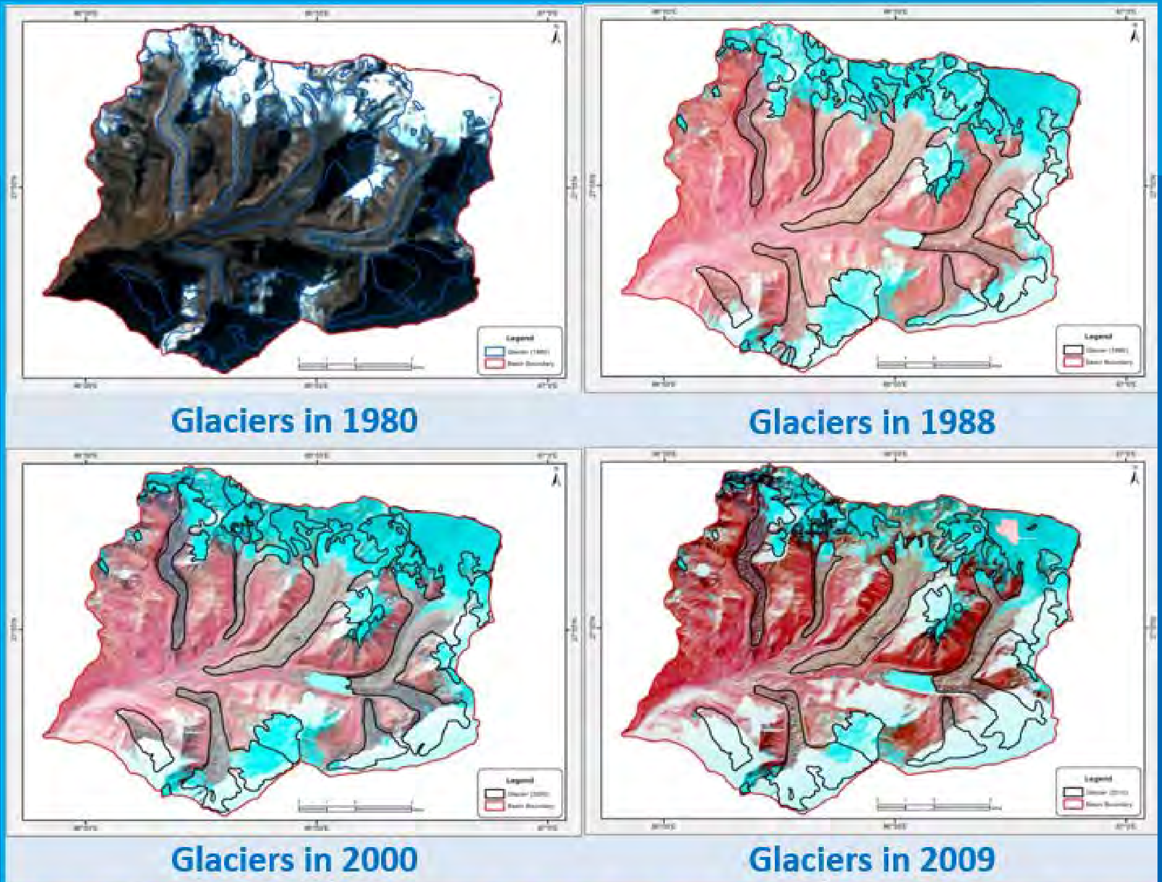
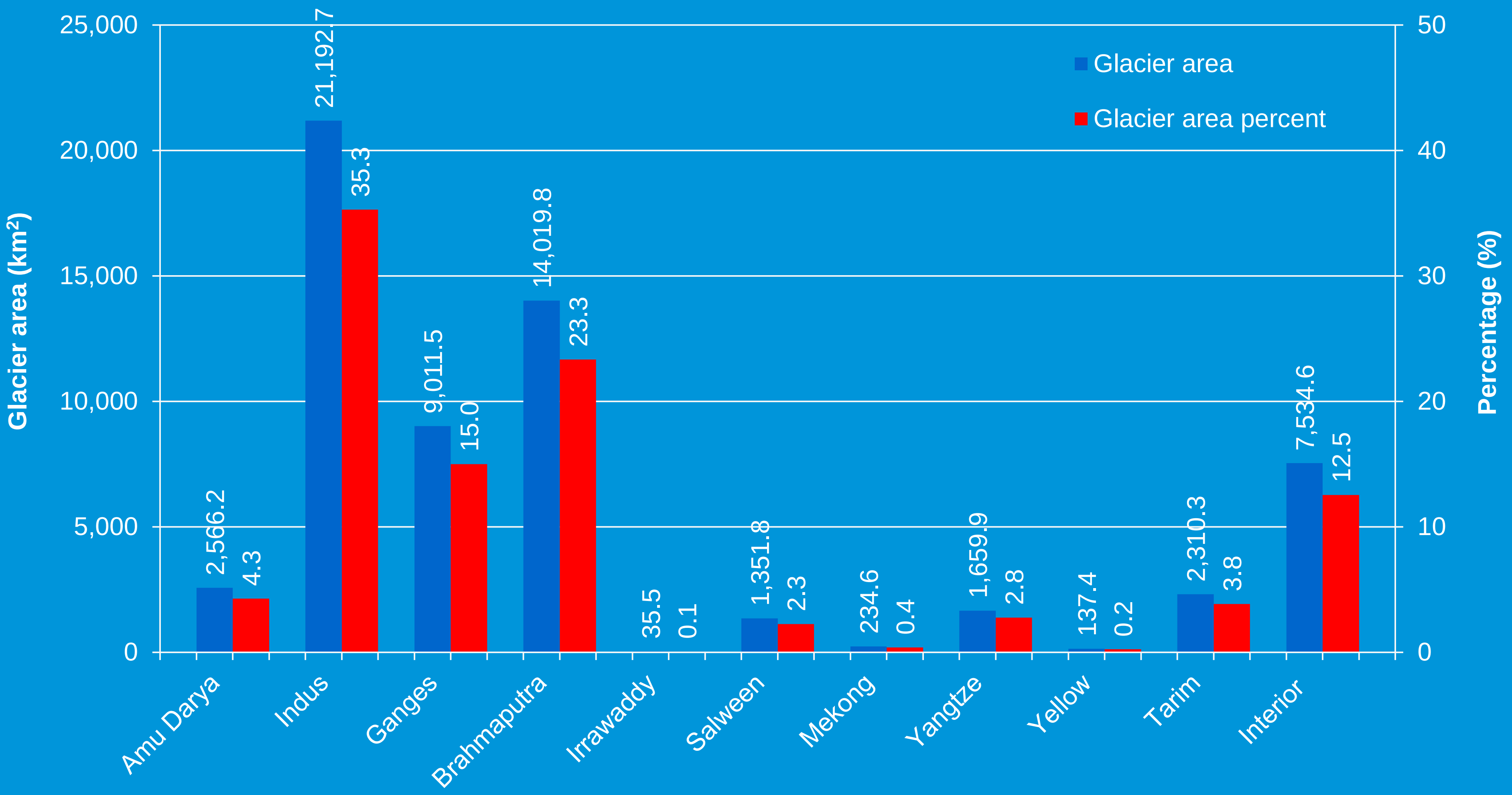


Table: Change in glacier area in Imja valley of Dudh Koshi basin over three decades

SN	Data Year	Glacier Number	Glacier Area (Km^2)	Glacier Area (%)	Elevation (m asl) Highest	Elevation (m asl) Lowest
1	2010	24	45.91	31.67	8018	4693
2	2000	21	51.93	35.83	8329	4689
3	1992	21	53.74	37.08	8329	4689
4	1979	20	63.22	43.62	8427	4675

Glacier Area percentage



Glaciers - Elevation

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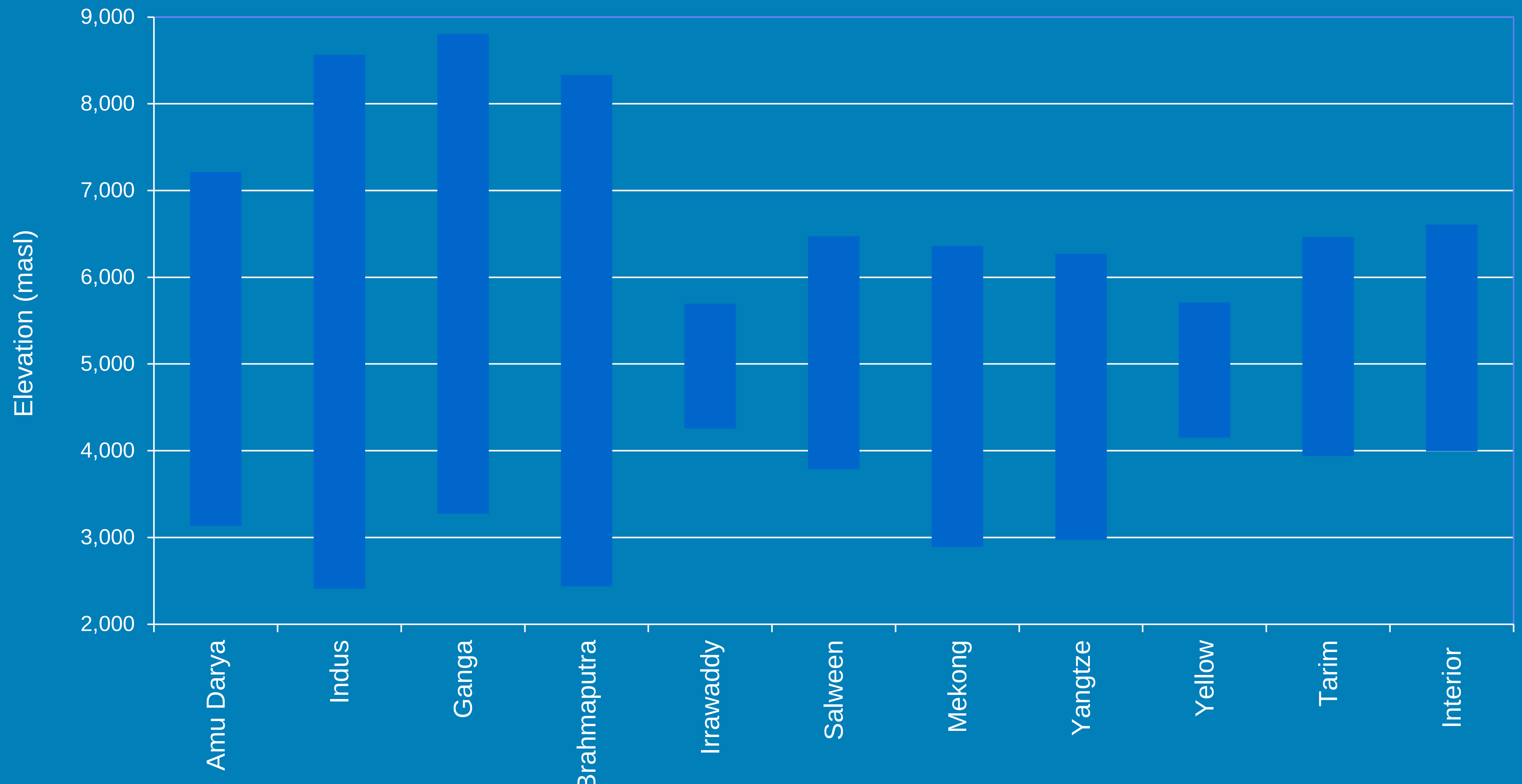
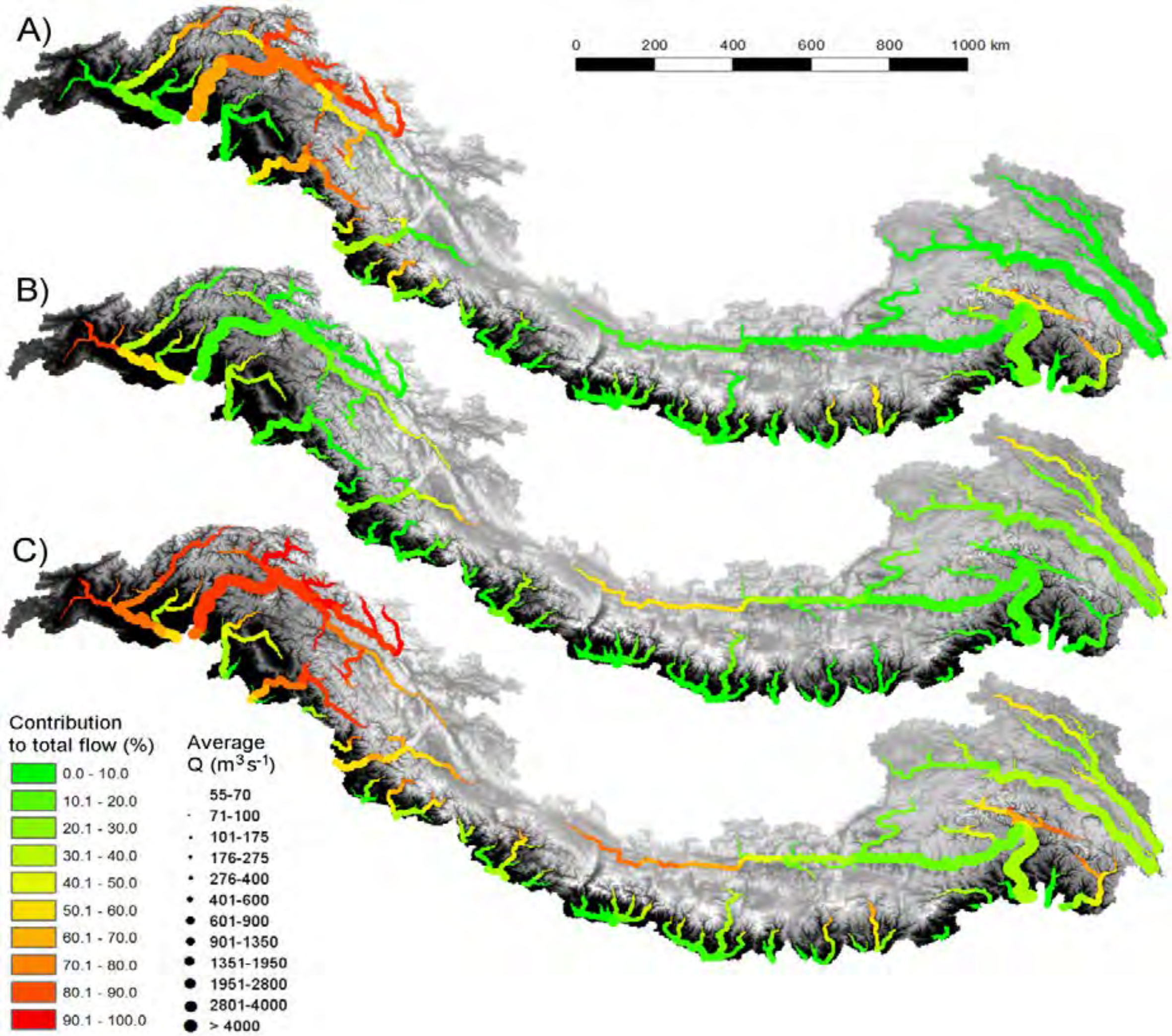
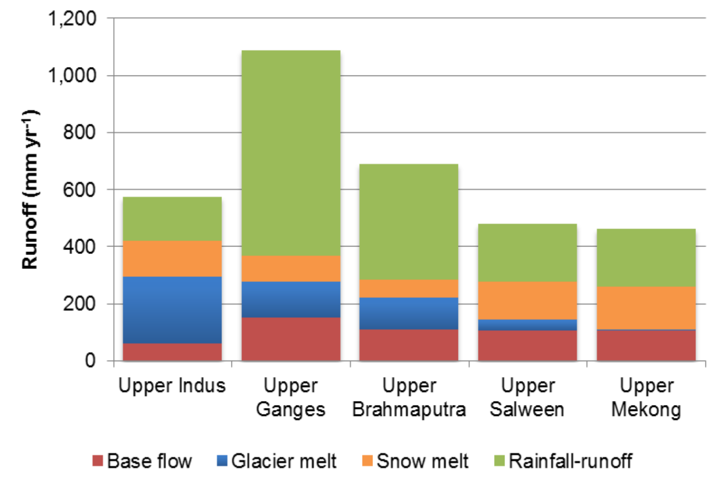


Over 60% of the total glacier area of the HKH is located in the elevation range 5000 – 6000 masl . The glaciers below 5700 masl are particularly sensitive to climate change unless they are covered by thick debris (Bajracharya et al., 2014). The Indus, Ganges and Brahmaputra basins have 79%, 60% and 77% of their total glacier area, respectively, below this critical elevation. CI glaciers at low altitude and small glaciers are the most sensitive glaciers to climate change in the HKH region.





Average contribution of glacier melt (A), snow melt (B), glacier and snow melt combined (C) to total flow during and the average discharge at different stages in major streams in the model domain (all panels) during 1998-2007.

Important of cryosphere

Basin	Annual precipitation (mm)	Glacierized area (%)	Annual runoff (mm)	Contribution to total runoff (%)			
				Glacier melt	Snow melt	Rainfall-runoff	Base flow
Upper Indus	346	4.9	574	40.6	21.8	26.8	10.8
Upper Ganges	900	5.4	1088	11.5	8.6	66.0	13.9
Upper Brahmaputra	573	3.1	691	15.9	9.0	58.9	16.2
Upper Salween	595	1.3	480	8.3	27.5	42.0	22.2

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The snow and glacier meltwater plays a pivotal role in the water supply for those river basins that are arid downstream, in particular where there are large irrigation systems that depend on upstream water resources. Changes in the glaciers may have a significant impact on the quantity and timing of water availability. A comprehensive understanding of the extent and nature of changes in glaciers will support downstream hydrological planning and water resource management.

Regional Cryosphere Knowledge Hub

ICIMOD

The Regional Cryosphere Knowledge Hub is a collaborative effort to share and disseminate cryosphere-related data by:

- **Providing a web-based interactive portal for dissemination and visualization of cryosphere data**
- **Regular publication of quarterly e-bulletin on the cryosphere activities of ICIMOD and its regional member countries**
- **Organizing conferences, seminars, and workshops**
- **Providing a platform for regional knowledge sharing events**

In the end

Although uncertainties about the rate and magnitude of climate change and potential impacts prevail, it is generally agreed that climate change is gradually and powerfully changing the cryosphere, ecological and socio-economic landscape in the HKH region, particularly in relation to water, with significant implications for mountain communities and livelihoods, as well as downstream users, including women.

It is estimated that around 1.3 billion people live in the river basins draining the HKH. Here, more than 20% live below the poverty line, amounting to around 260 million people. Therefore, climate change impact on the HKH region is particularly severe due to the large concentration of people dependent on climate-sensitive livelihoods such as agriculture

Thank you

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Regional Stakeholder Consultation on Climate Services for the Third Pole Region
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9-11 March 2016