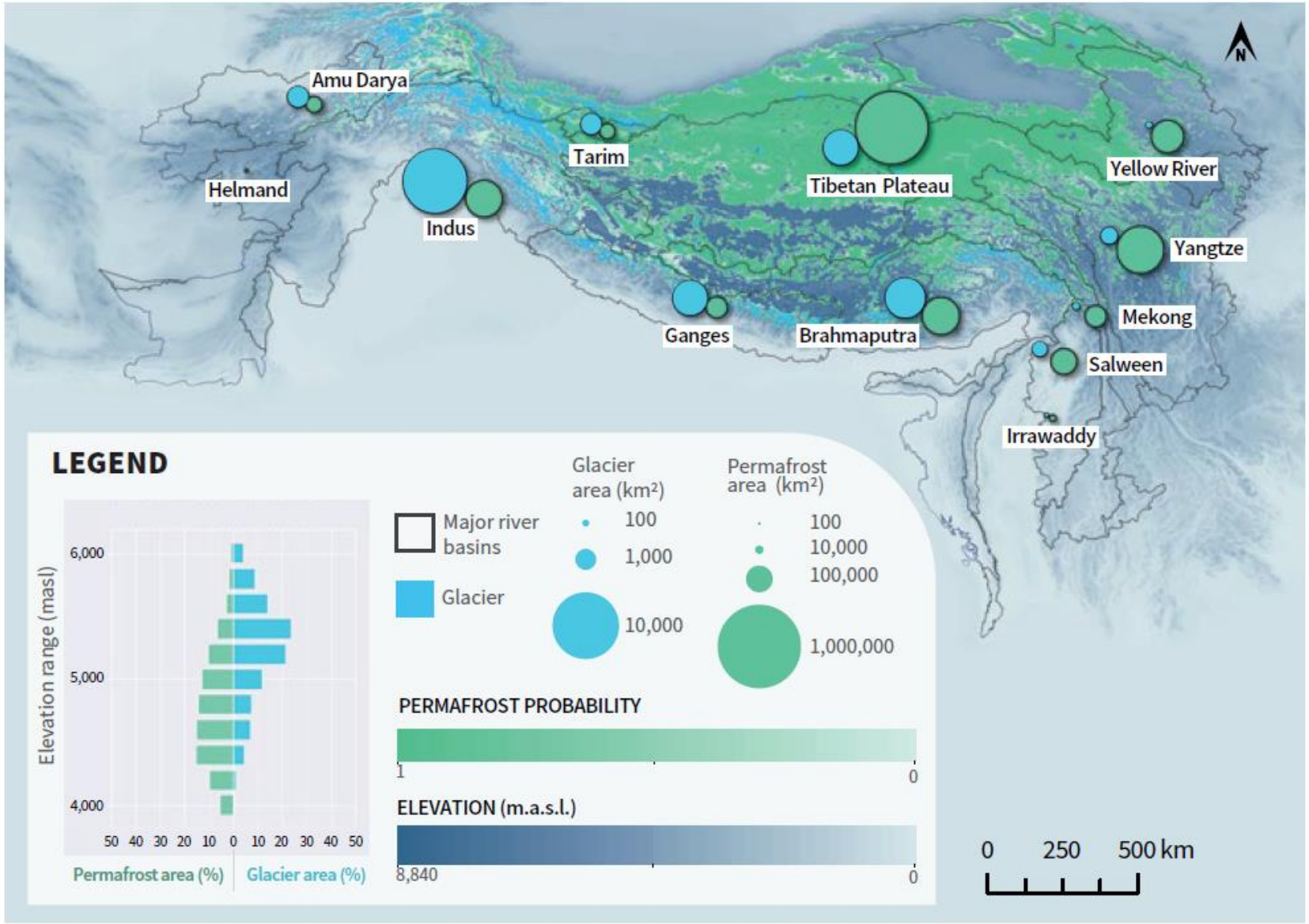
ICIMOD

Permafrost research activities at ICIMOD

Prashant Baral

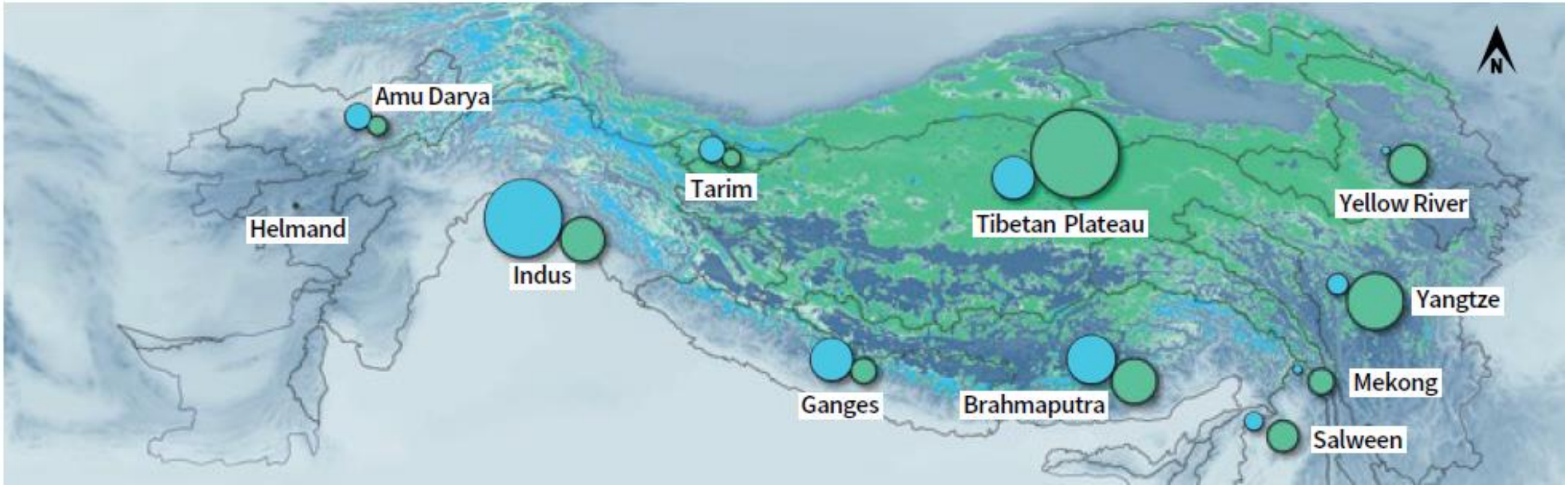
Date: 24 September 2024

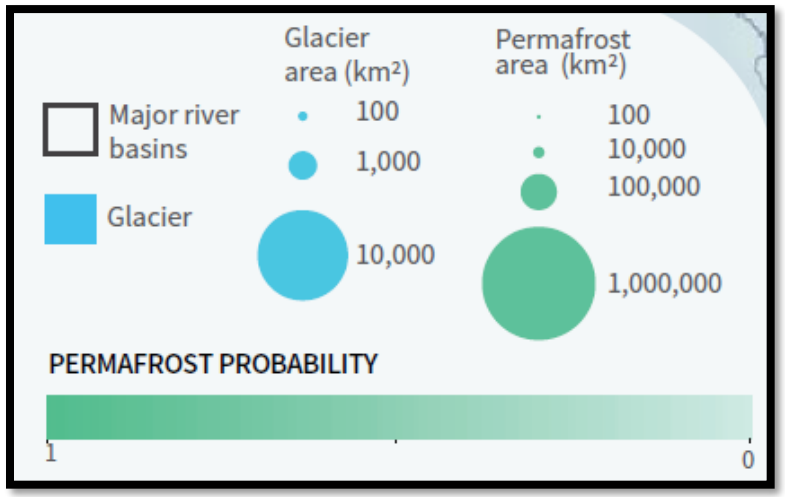
Permafrost distribution



(HI-WISE, 2023)

Permafrost distribution

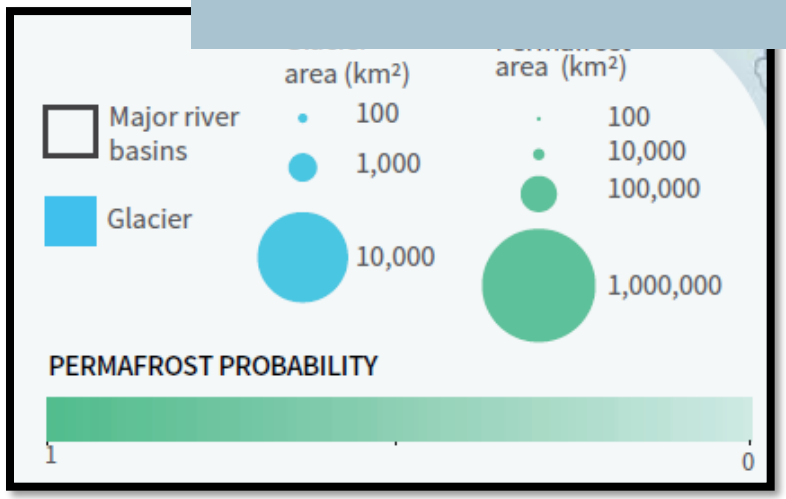




(HI-WISE, 2023)

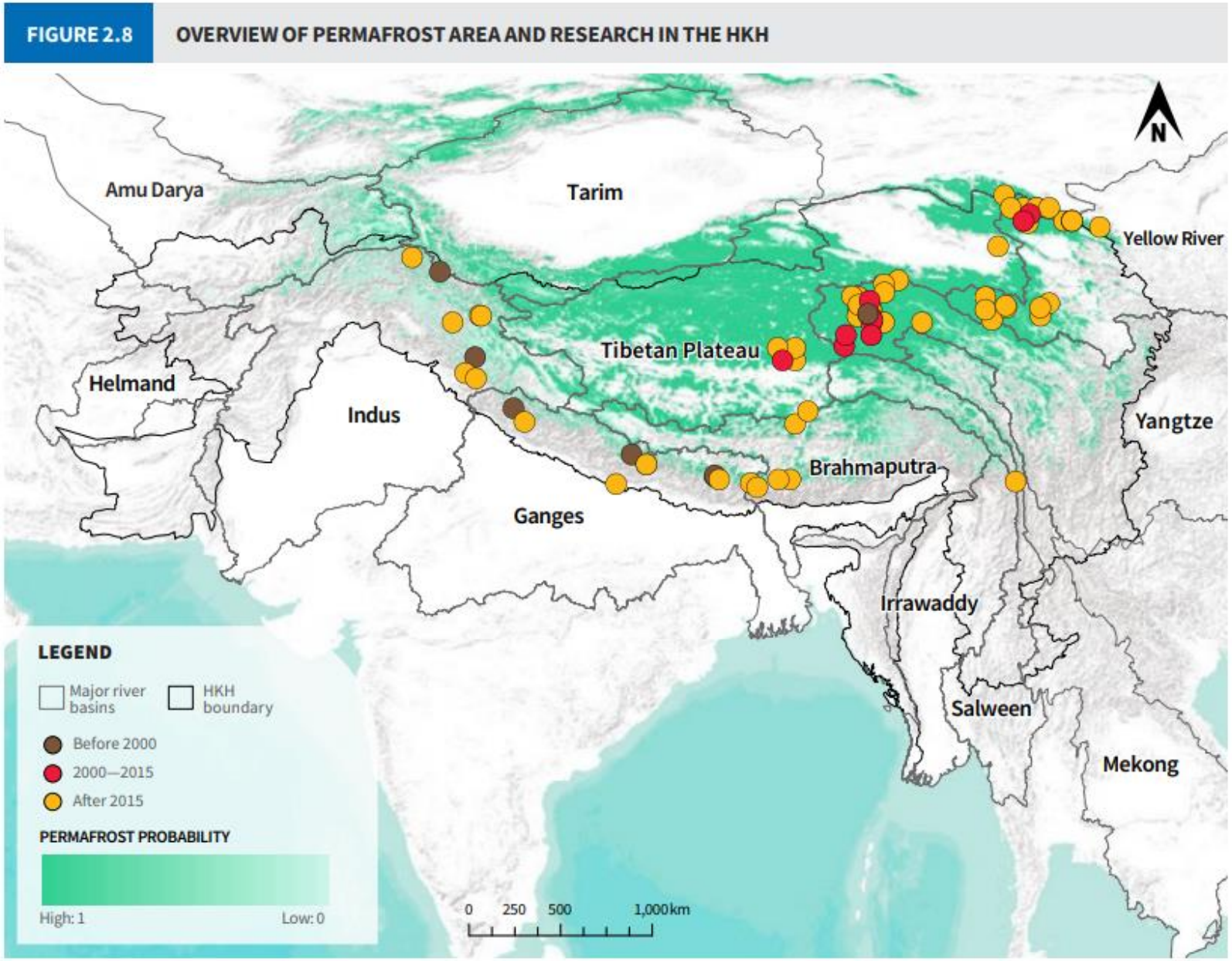
Permafrost distribution

- In the northern hemisphere, there is about **21 million km²** of permafrost.
- **~1.5 million km² (7%)** of the total permafrost area – lie within the Hindu Kush Himalayan (HKH) region.
- Estimates of permafrost area for the HKH vary **(1.19 – 2.25) million km²**



(HI-WISE, 2023)

Permafrost research



(HI-WISE, 2023)

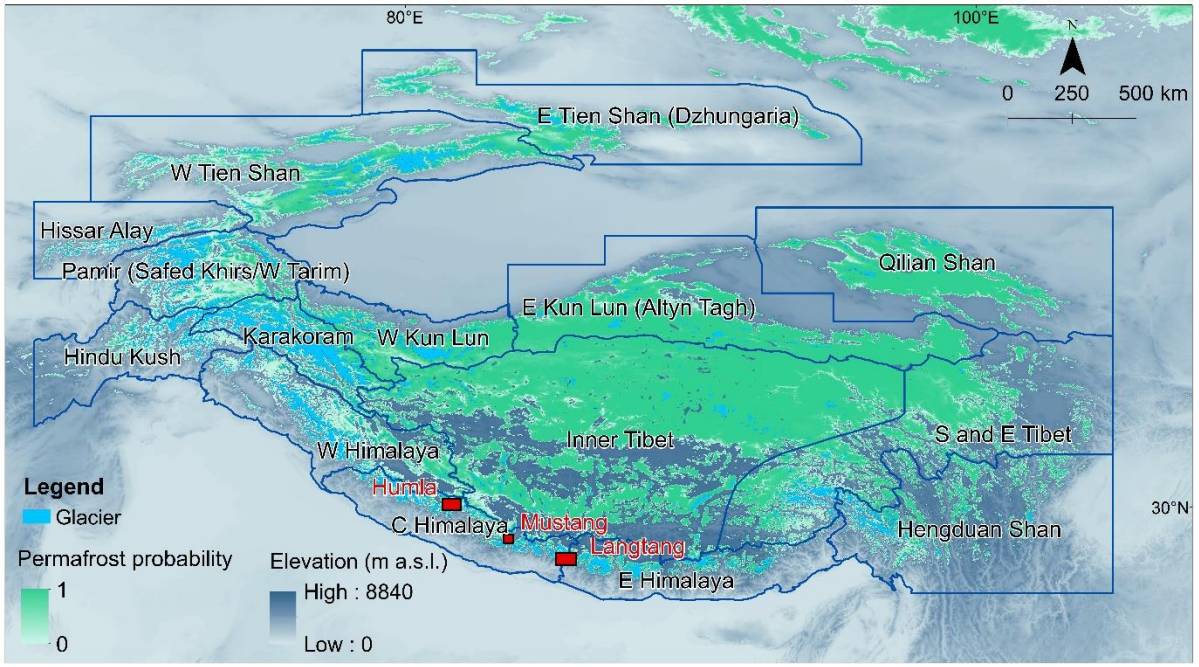
Permafrost-related activities

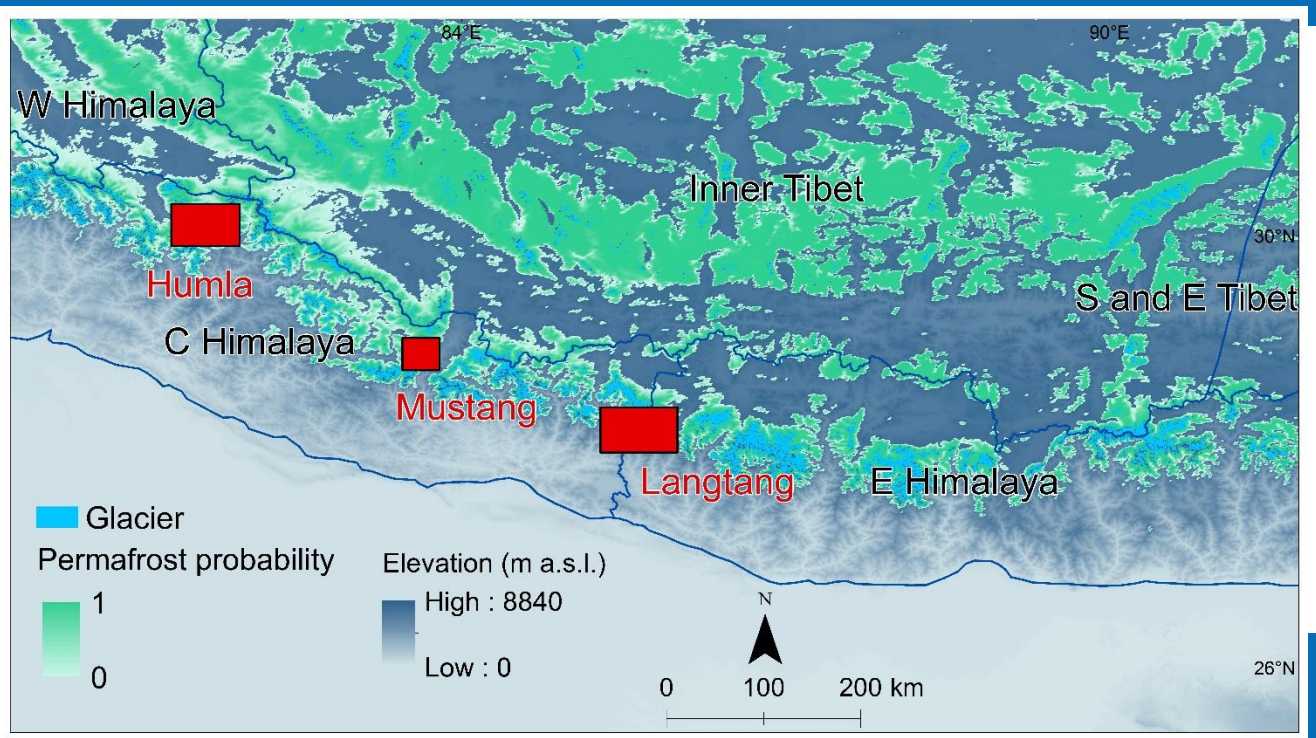
- Permafrost Monitoring & Capacity Building
- Regional Conferences & Workshops
- Regional & Global Assessments
- Basin Scale Permafrost-related Risks Assessment
- Permafrost issue brief

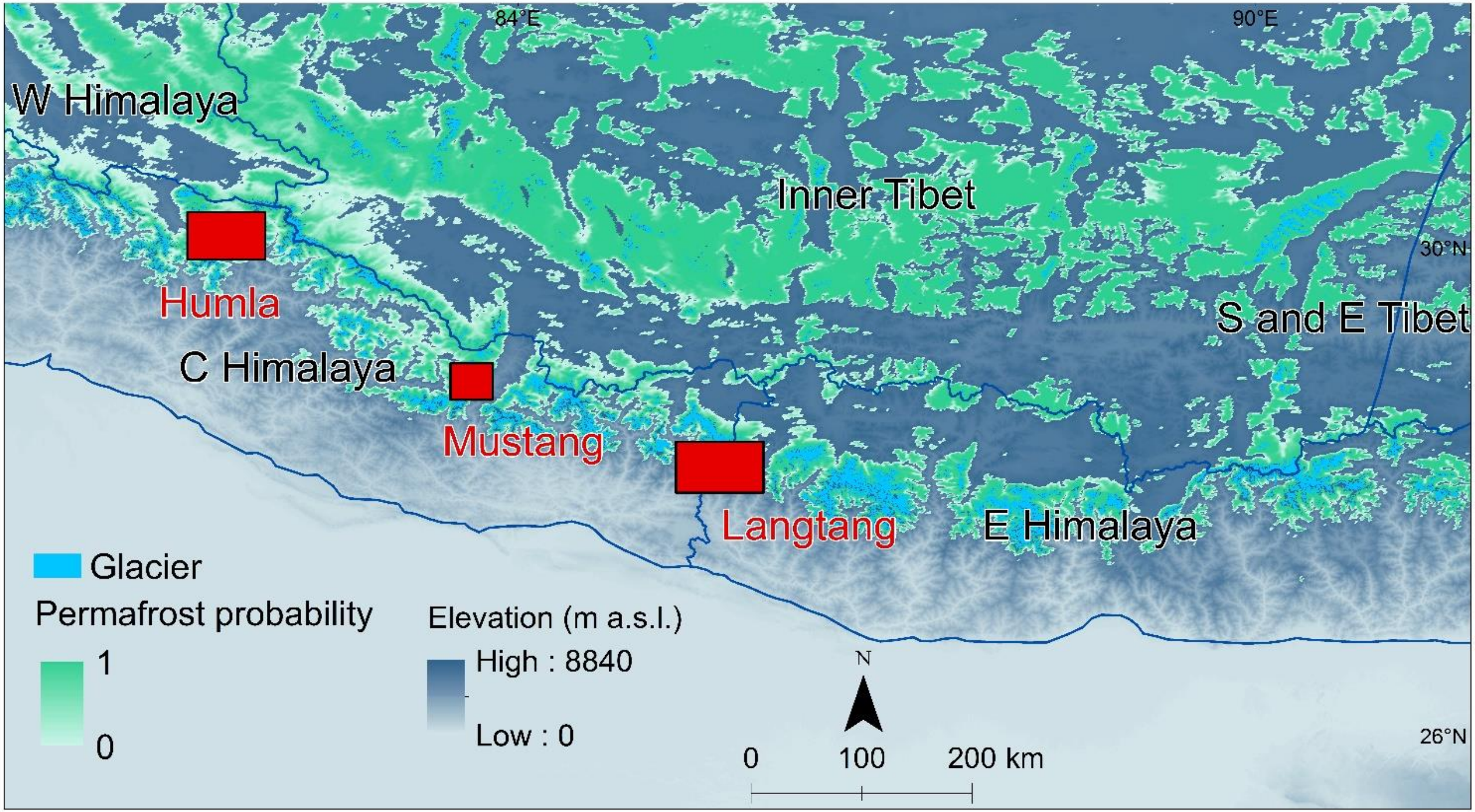
Permafrost monitoring & capacity building

Permafrost monitoring sites are established in Langtang, Mustang and Humla in Nepal.

Workshops and seminars are organized for capacity building.

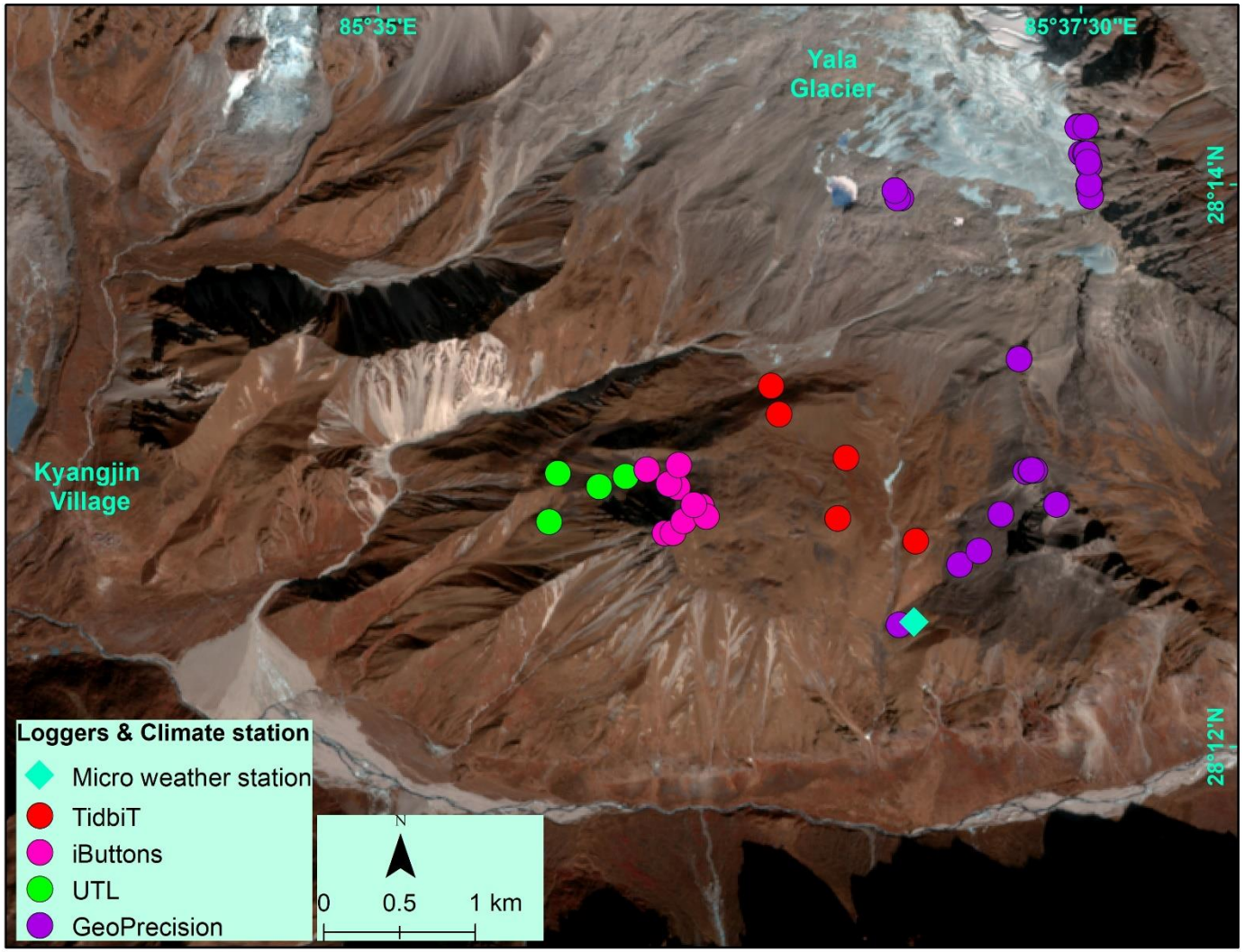





84°E
90°E
30°N
26°N
W Himalaya
Inner Tibet
S and E Tibet
Humla
C Himalaya
Mustang
Langtang
E Himalaya
Glacier
Permafrost probability
1
0
Elevation (m a.s.l.)
High : 8840
Low : 0
N
0
100
200 km

Permafrost monitoring in Langtang

Almost 10 years of measurements using iButtons, TidbiT sensors, UTL loggers, Geoprecision sensors, and a micro-weather station with soil moisture, soil temperature, air temperature and solar radiation sensors



iButton

TidbiT logger

Universal Temperature Logger

GeoPrecision Rock

GeoPrecision Simple

Micro-weather station

Permafrost monitoring – Ground surface temperature

iButton

TidbiT logger

Universal Temperature Logger

GeoPrecision Rock

GeoPrecision Simple

Micro-weather station

Permafrost monitoring – Micro weather station

Micro-weather station

Permafrost monitoring – Micro weather station

HOBO USB Micro Station
Data Logger

Permafrost monitoring – Micro weather station

HOBO External Temperature/RH Sensor Data Logger

12-Bit Temperature Smart Sensor

Soil Moisture Sensor

Solar Radiation (Silicon Pyranometer) Sensor

Light Sensor Bracket

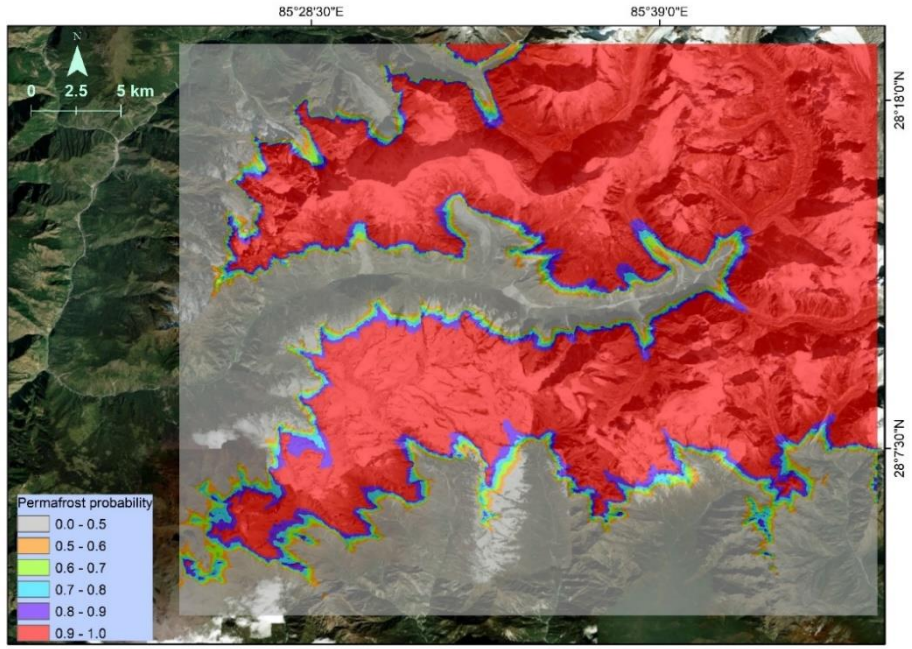
Radiation Shield

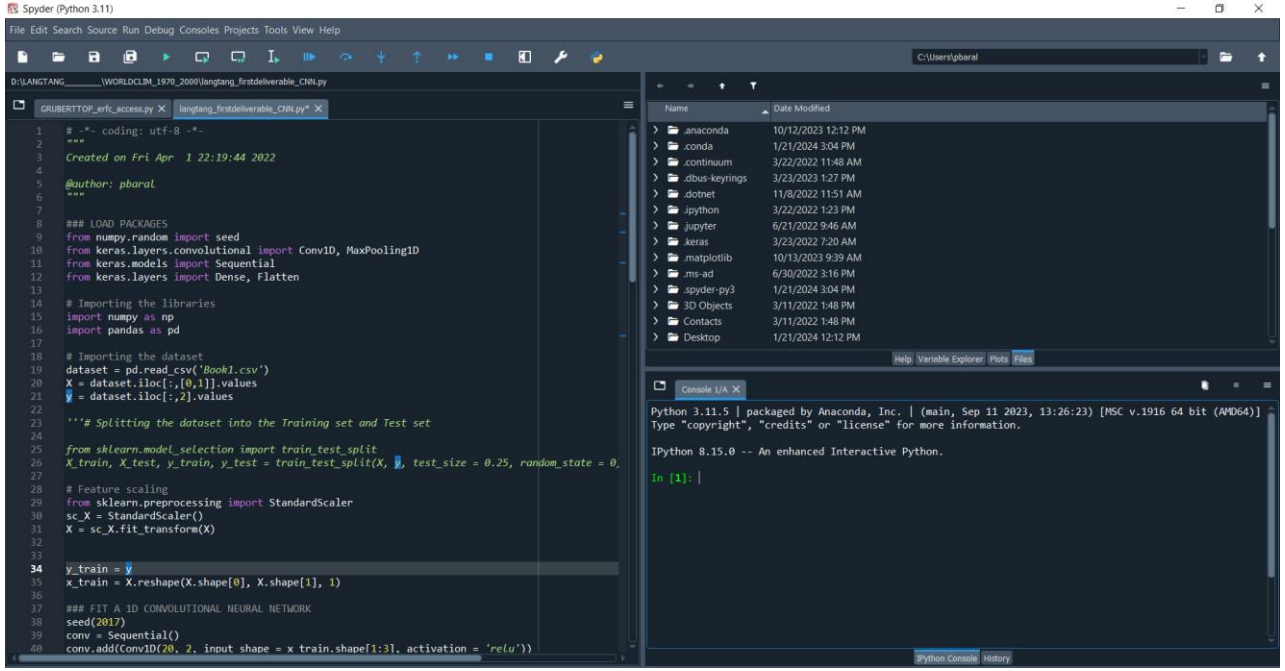
Langtang Valley, Central Himalayas

- Mapping permafrost hazards
- Permafrost hazard susceptibility maps

Langtang Valley, Central Himalayas

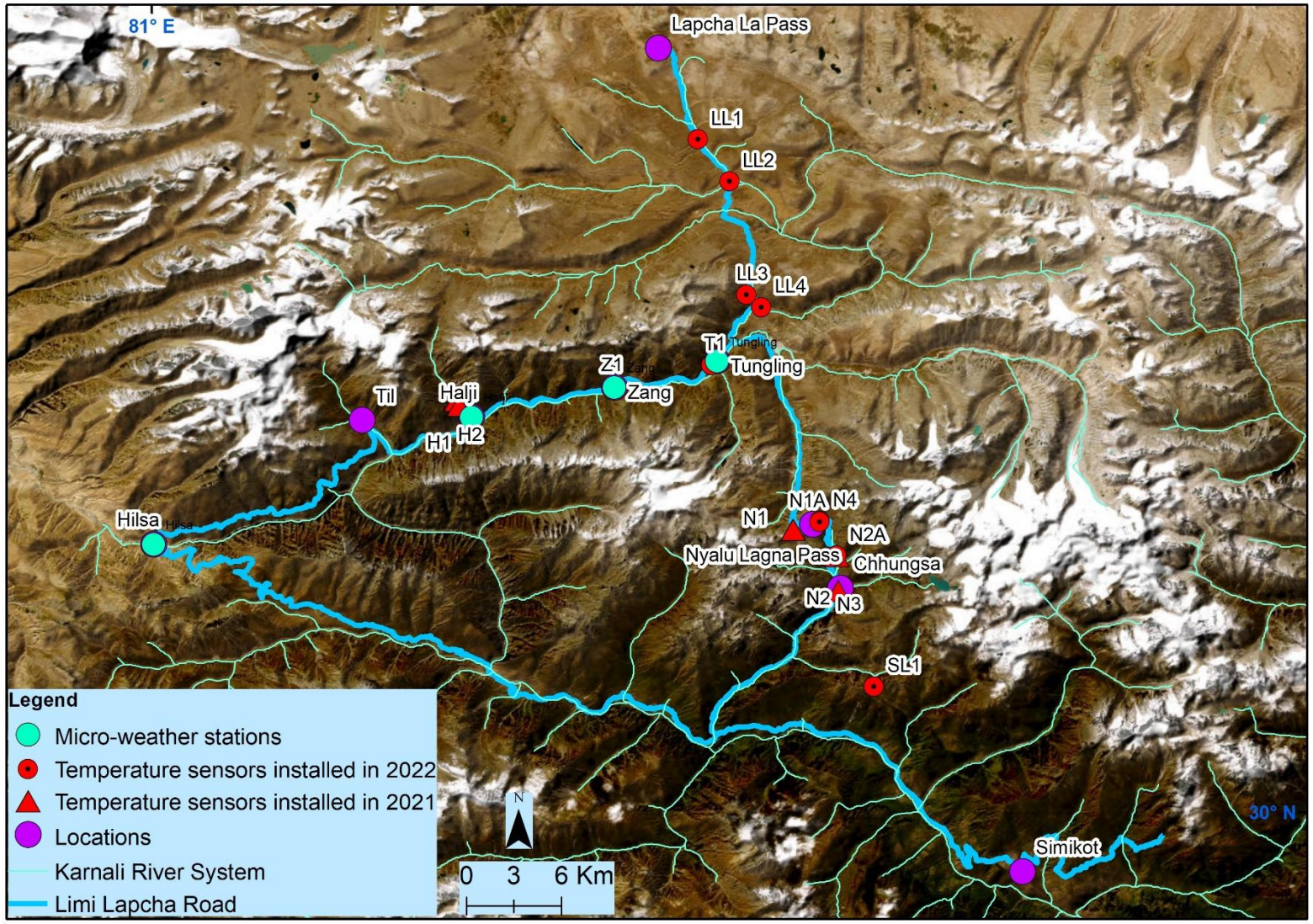
- Permafrost probability distribution maps
- Mapping rock glaciers
- Permafrost mapping using a combination of field-based measurements, remote sensing (MODIS land surface temperature data set) and machine learning algorithms





Permafrost monitoring in Humla

Two years of measurements using TidbiT sensors and micro-weather stations with soil moisture, soil temperature, air temperature and solar radiation sensors

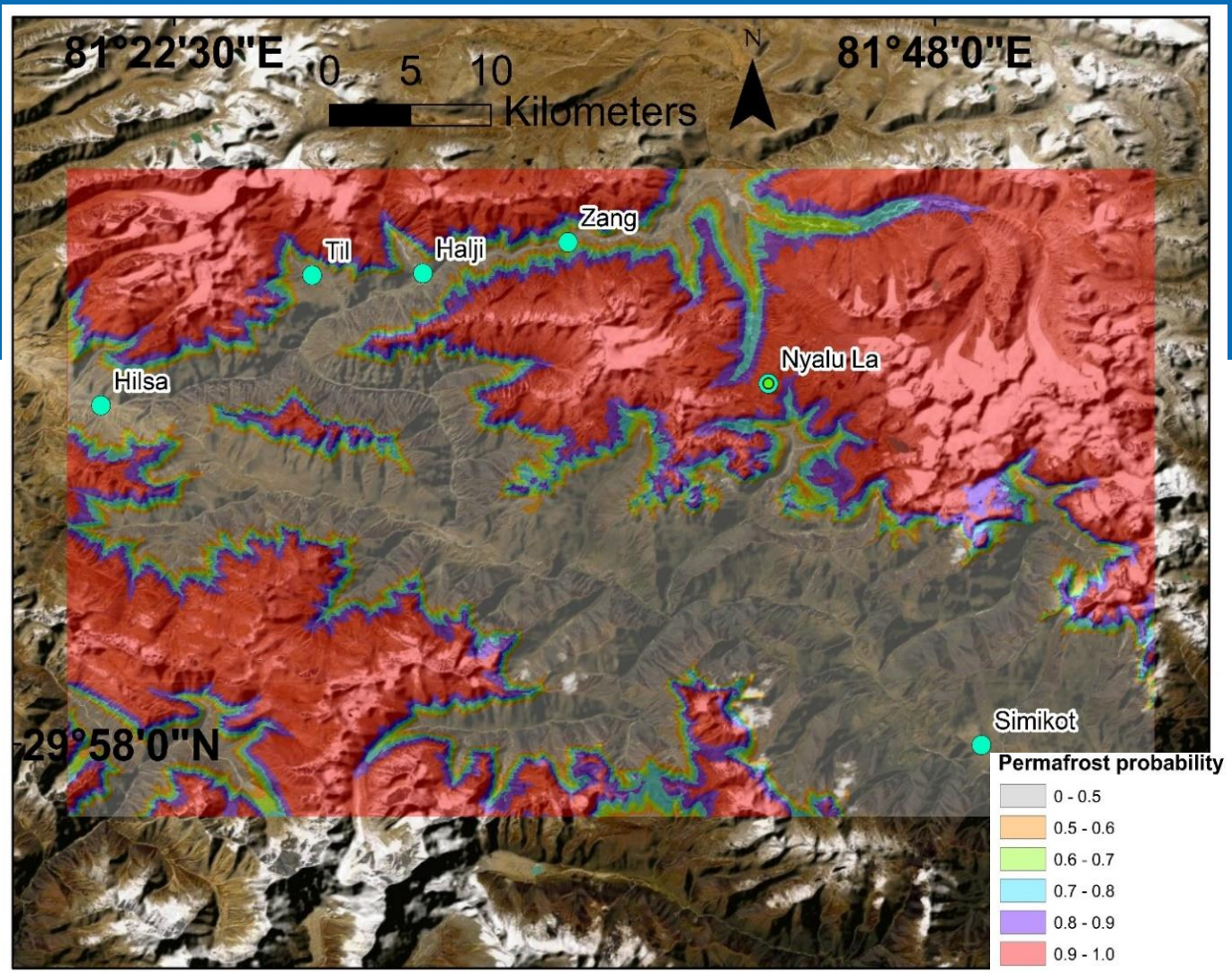


Micro-weather station at Tungling

TidbiT sensor in Halji

Humla, Western Himalayas

- Micro-weather stations, ground surface temperature and soil moisture measurements (2021)
- Permafrost maps



Humla, Western Himalayas

Permafrost related hazards

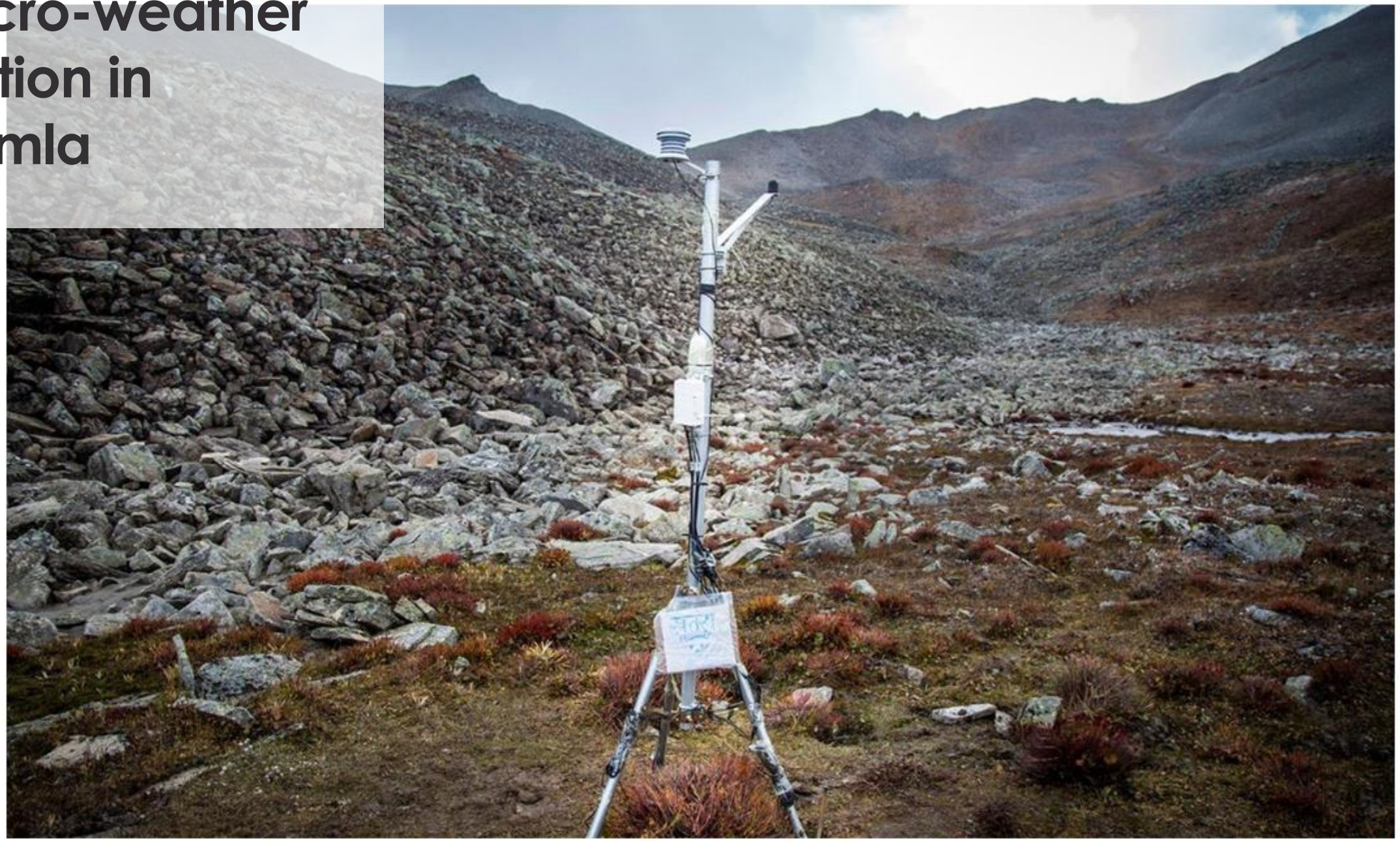
- Thaw slumps
- Destabilizing side walls (Limi Lapcha Road)
- Uneven ground surfaces
- Debris flow activities
- Active layer detachment slides

Humla, Western Himalayas

- Impacts of changing permafrost on livelihoods and ecosystem services

Interacting with the local community

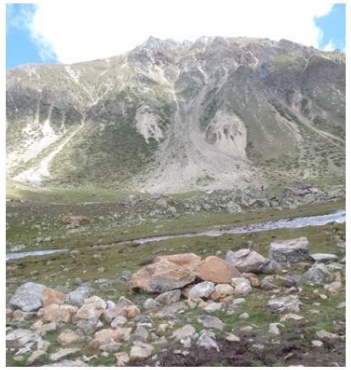
Micro-weather station in Humla



Slope destabilization







Limi Lapcha Road

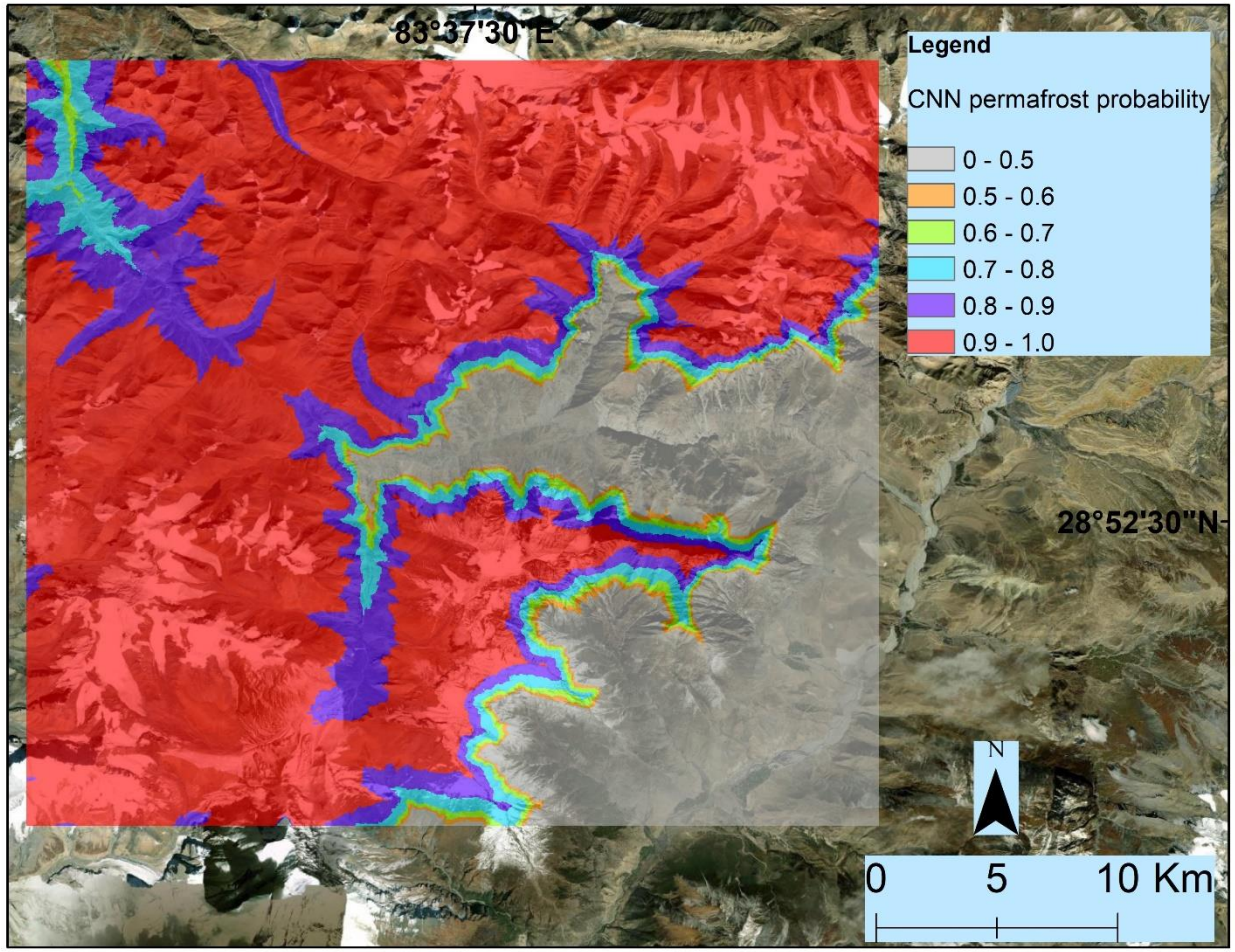



Losses of livestock

Sediment load

Mustang, Western Himalayas

- Micro-weather stations, ground surface temperature and soil moisture measurements (2021)
- Permafrost maps
- Field-based evidence of permafrost degradation



Patterned grounds

Frost cracking

Slope failures

Superficial Permafrost degradation

Regional trainings

Regional Training On Analysing Permafrost In The Hindu Kush Himalaya Using Open Access Tools

Open in Colab

ICIMOD

REGIONAL TRAINING

Analysing permafrost in the Hindu Kush Himalaya using open access tools

This notebook is prepared for the participants of the regional training on Analysing permafrost in the Hindu Kush Himalaya using open access tools by ICIMOD through its Cryosphere Initiative under the Regional Programme on River Basins and Cryosphere in collaboration with Kathmandu University and Tribhuvan University.

The Cryosphere Initiative is supported by the Government of Norway and Swiss Agency for Development and Cooperation.

Regional trainings

Open in Colab

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Regional conferences & workshops

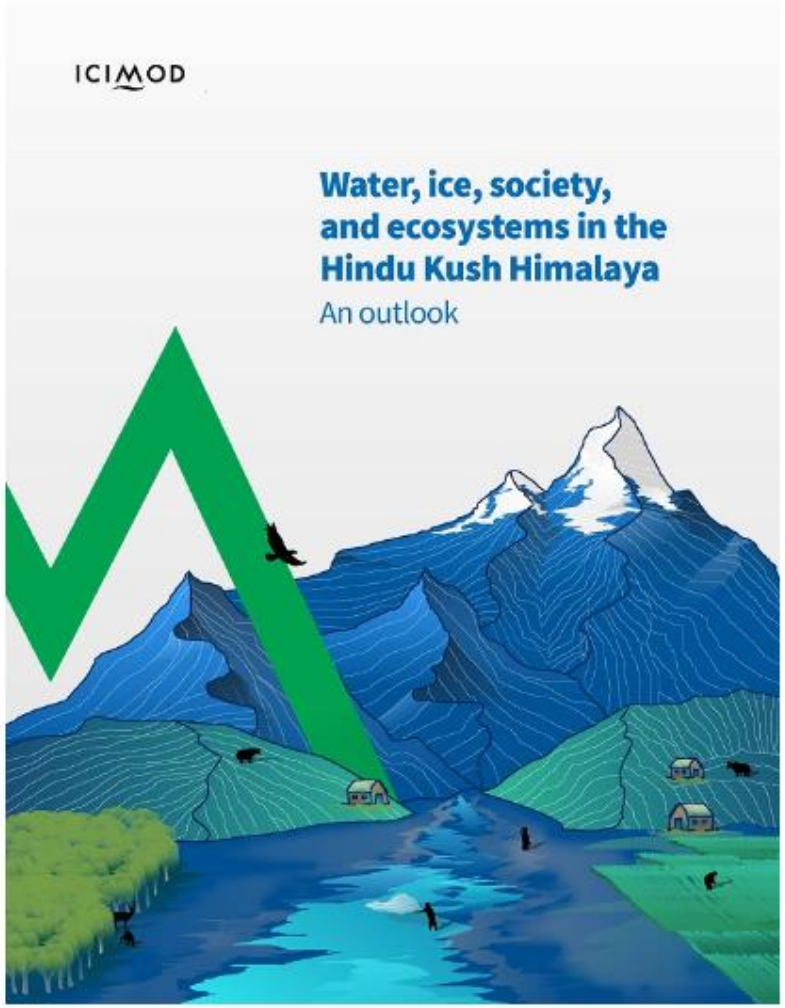
- Cryosphere Forum 2021 in September 2021

Regional conferences & workshops

- Workshop on Developing a strategy to monitor permafrost changes in the Hindu Kush Himalaya in June 2022

Regional & global assessments

- Water, ice, society, and ecosystems in the Hindu Kush Himalaya - An Outlook
- Comprehensive review paper about climate change impacts and adaptation to permafrost change in High Mountain Asia



IOP Publishing Environ. Res. Lett. 18 (2023) 093005 https://doi.org/10.1088/1748-9326/acf1b4

ENVIRONMENTAL RESEARCH
LETTERS

TOPICAL REVIEW

Climate change impacts and adaptation to permafrost change in High Mountain Asia: a comprehensive review

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Supplementary material for this article is available online

Abstract

Changing climatic conditions in High Mountain Asia (HMA), especially regional warming and changing precipitation patterns, have led to notable effects on mountain permafrost. Comprehensive knowledge of mountain permafrost in HMA is mostly limited to the mountains of the Qinghai-Tibetan Plateau, with a strong cluster of research activity related to critical infrastructure providing a basis for related climate adaptation measures. Insights related to the extent and changing characteristics of permafrost in the Hindu Kush Himalaya (HKH), are much more limited. This study provides the first comprehensive review of peer-reviewed journal articles, focused on hydrological, ecological, and geomorphic impacts associated with thawing permafrost in HMA, as well as those examining adaptations to changes in mountain permafrost. Studies reveal a clear warming trend across the region, likely resulting in increased landslide activity, effects on streamflow, soil saturation and subsequent vegetation change. Adaptation strategies have been documented only around infrastructure megaprojects as well as animal herding in China. While available research provides important insight that can inform planning in the region, we also identify a need for further research in the areas of hazards related to changing permafrost as well as its effect on ecosystems and subsequently livelihoods. We suggest that future planning of infrastructure in HMA can rely on extrapolation of already existing knowledge within the region to reduce risks associated with warming permafrost. We highlight key research gaps as well as specific areas where insights are limited. These are areas where additional support from governments and funders is urgently needed to enhance regional collaboration to sufficiently understand and effectively respond to permafrost change in the HKH region.

Regional & global assessments

- Socioecological dynamics of diverse global permafrost-agroecosystem under environmental change
- Research capability mapping

Arctic, Antarctic, and Alpine Research
An Interdisciplinary Journal

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/uaar20

Socioecological dynamics of diverse global permafrost-agroecosystems under environmental change

Melissa Ward Jones, Joachim Otto Habeck, Mathias Ulrich, Susan Crate, Glenna Gannon, Tobias Schwoerer, Benjamin Jones, Mikhail Kanevskiy, Prashant Baral, Amina Maharjan, Jakob Steiner, Andrew Spring, Mindy Jewell Price, David Bysouth, Bruce C. Forbes, Mariana Verdonen, Timo Kumpula, Jens Strauss, Torben Windirsch, Christopher Poeplau, Yuri Shur, Benjamin Gaglioti, Nicholas Parlato, Fulu Tao, Merritt Turetsky, Stephanie Grand, Adrian Unc & Nils Borchard

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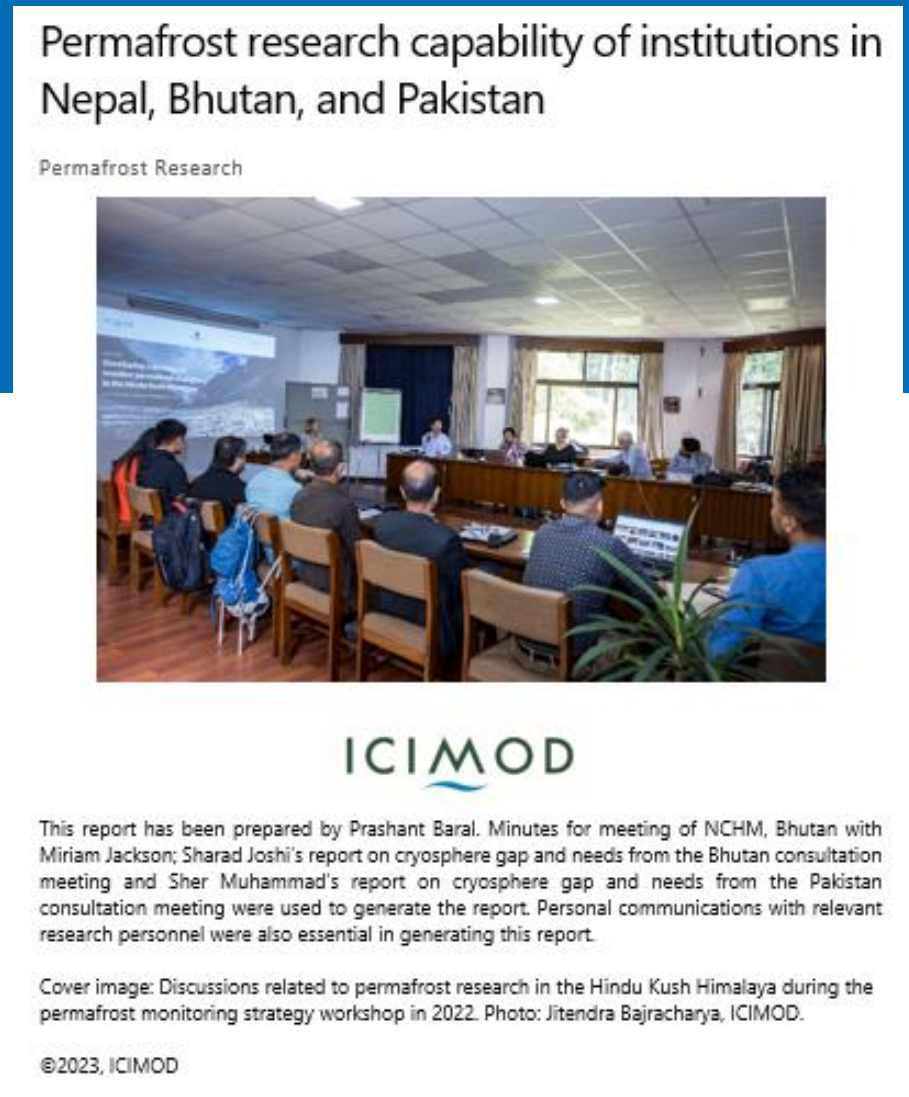


Permafrost research capability of institutions in Nepal, Bhutan, and Pakistan

Permafrost Research

ICIMOD

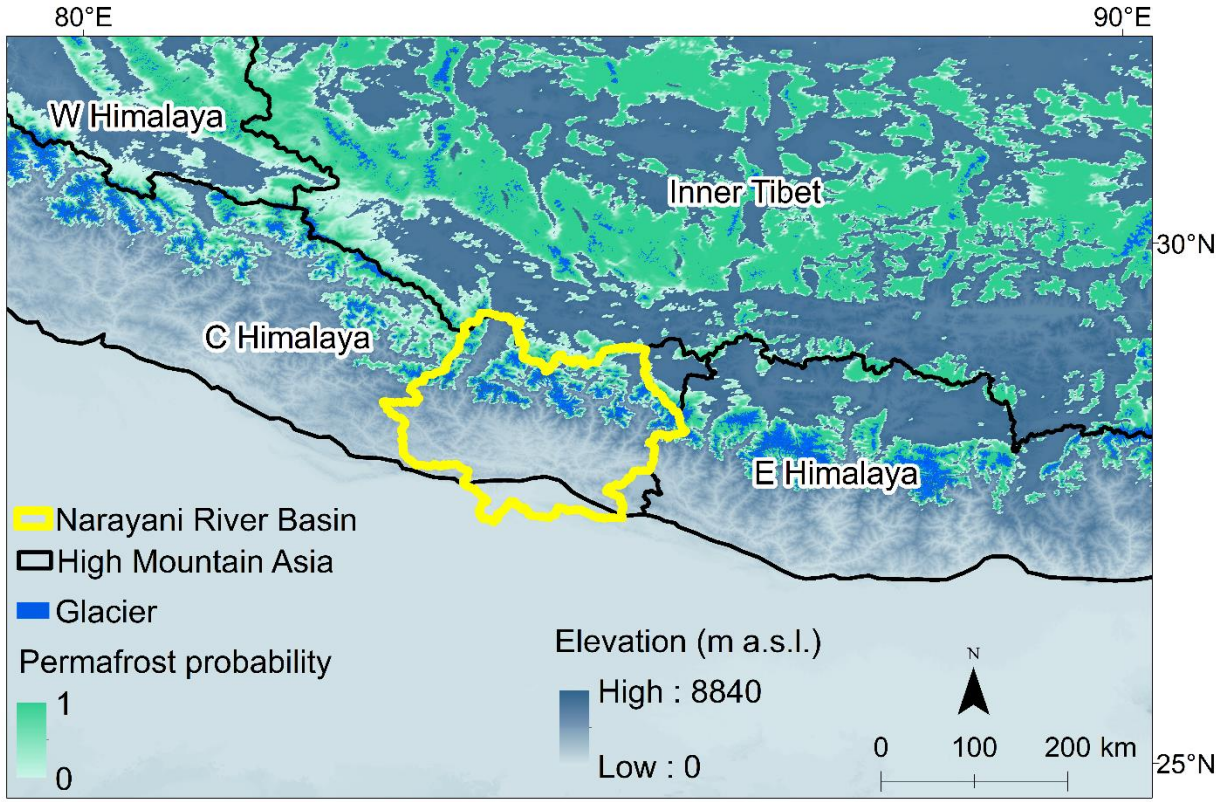
This report has been prepared by Prashant Baral. Minutes for meeting of NCHM, Bhutan with Miriam Jackson; Sharad Joshi's report on cryosphere gap and needs from the Bhutan consultation meeting and Sher Muhammad's report on cryosphere gap and needs from the Pakistan consultation meeting were used to generate the report. Personal communications with relevant research personnel were also essential in generating this report.

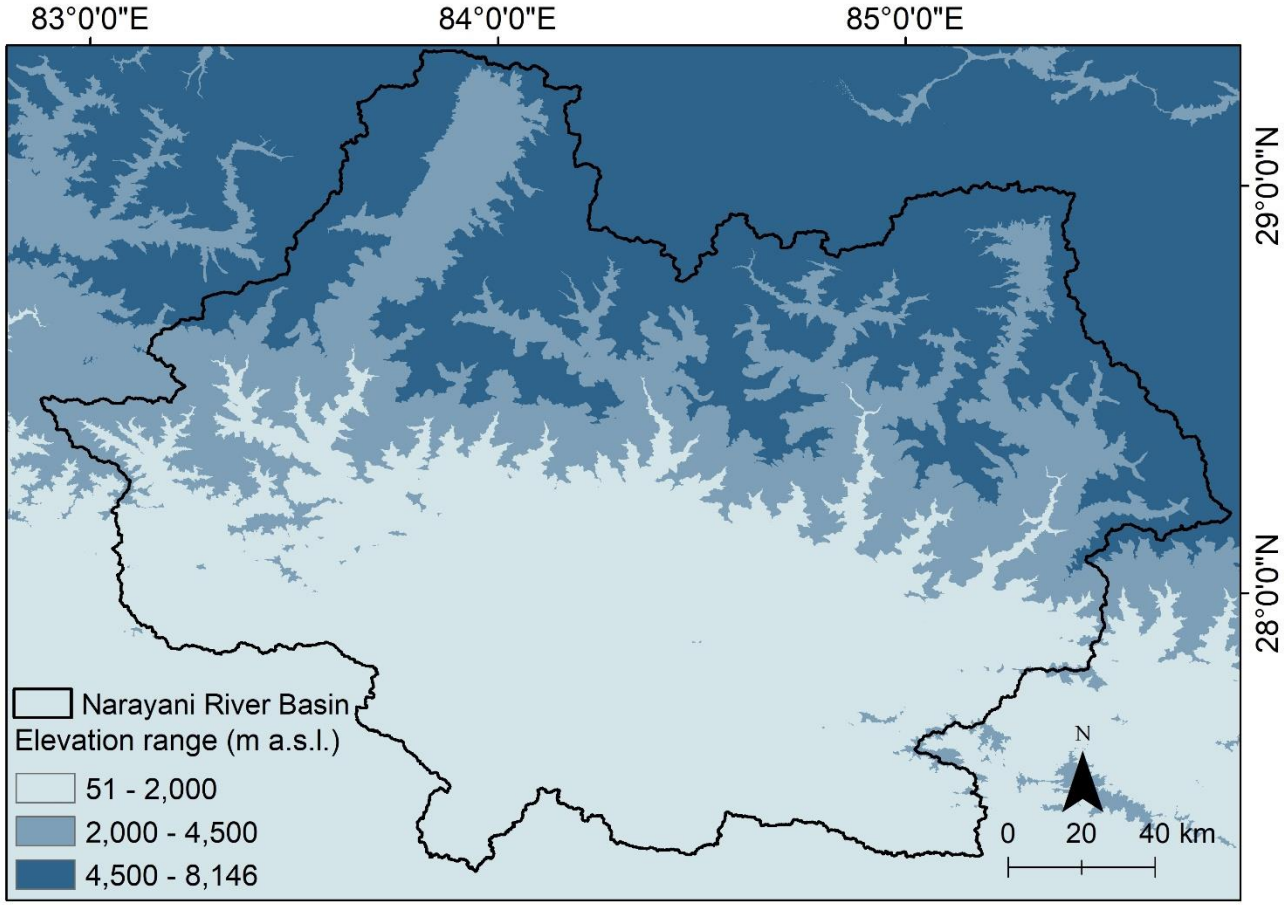
Cover image: Discussions related to permafrost research in the Hindu Kush Himalaya during the permafrost monitoring strategy workshop in 2022. Photo: Jitendra Bajracharya, ICIMOD.

Hazards, vulnerabilities and risks posed by future effects of climate change on permafrost in Narayani River Basin

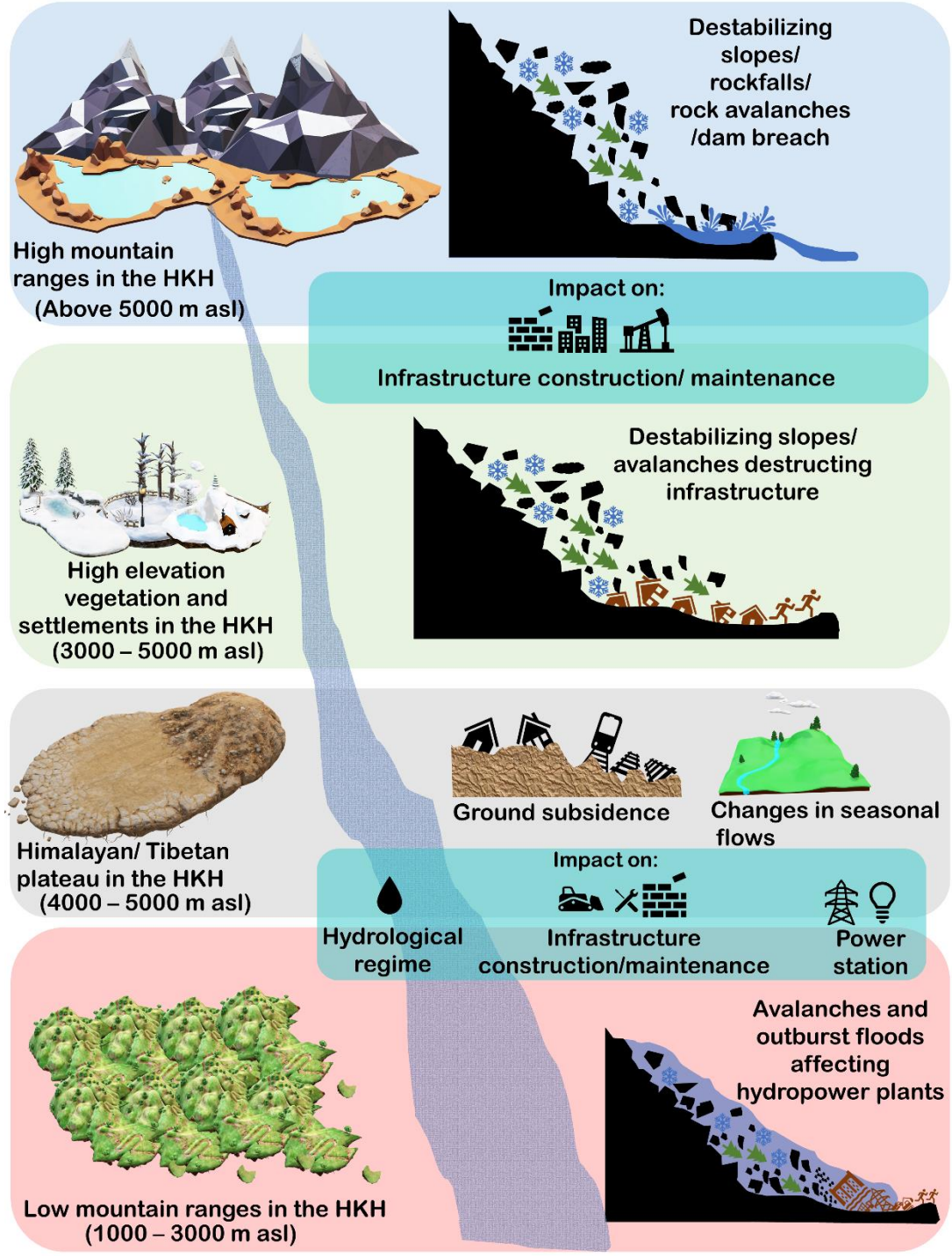
Study Area

- Narayani River Basin (25.49 – 29.28 ° N and 85.02 – 85.83 ° E) lies in the Central Himalayan region of Nepal
- Total area of Narayani River Basin: 37,440 km^2
- Elevation ranges from around 90 meters above sea level (m asl) to 8150 m asl.

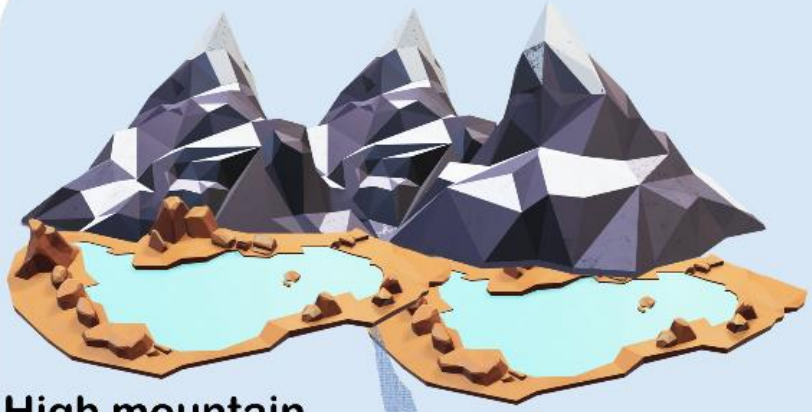




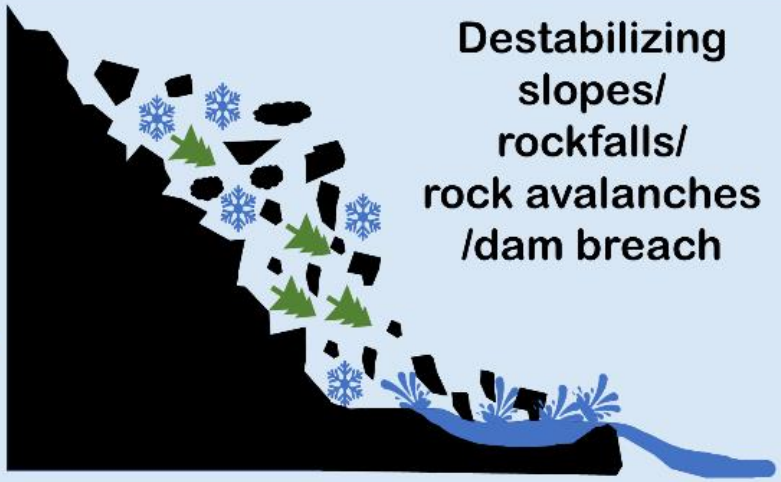
Permafrost & hydropower



Permafrost & hydropower



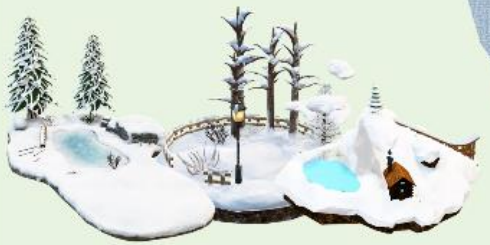
High mountain ranges in the HKH (Above 5000 m asl)



Destabilizing slopes/ rockfalls/ rock avalanches /dam breach

Impact on:

Infrastructure construction/ maintenance



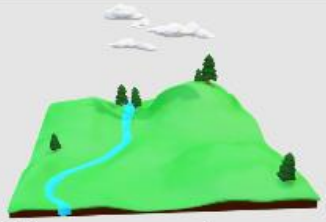
High elevation vegetation and settlements in the HKH (3000 – 5000 m asl)

Destabilizing slopes/ avalanches destructing infrastructure

Permafrost & hydropower

Himalayan/ Tibetan plateau in the HKH (4000 – 5000 m asl)

Ground subsidence



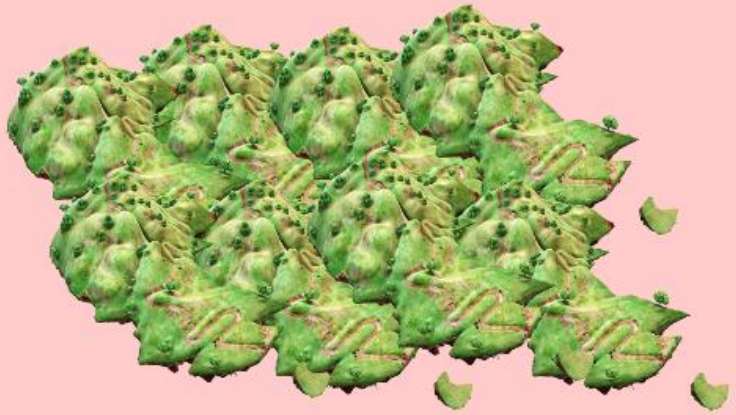
Changes in seasonal flows

Impact on:

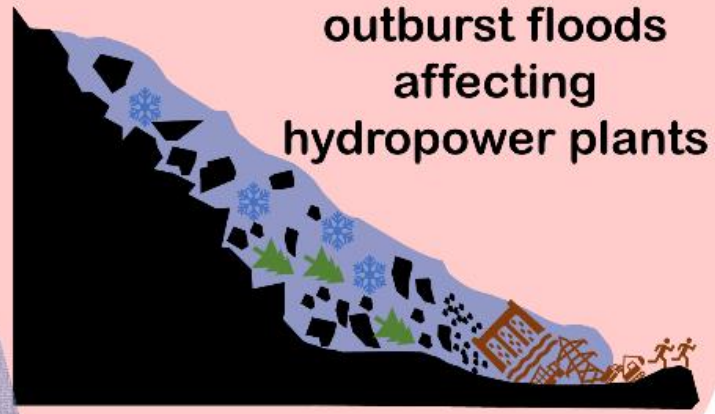
Hydrological regime

Infrastructure construction/maintenance

Power station



Low mountain ranges in the HKH (1000 – 3000 m asl)



Avalanches and outburst floods affecting hydropower plants

Methodology

1. Map permafrost probability distribution for Narayani River Basin

$$P(Y=1) = \frac{e^{\beta_0+\beta_1 x_1+\beta_2 x_2}}{1+e^{\beta_0+\beta_1 x_1+\beta_2 x_2}}$$

Model equation (Logistic Regression)
(Hosmer and Lemeshow, 2000)

P (Y = 1): Probability of Y attaining 1
β_o : Intercept; β_1, β_2 : Coefficients
χ_1, χ_2 : Independent variables

2. Model past and future permafrost extent for Narayani River Basin

Model of permafrost extent
(Gruber, 2012)

$$F_{\mathrm{MAGT}\leq 0} = \frac{1}{2}\mathrm{erfc}\left(\frac{\mathrm{MAAT}+\mu}{\sqrt{2\sigma^2}}\right)$$

$F_{\mathrm{MAGT}} \leq 0$: Probability of finding *MAGT* ≤0 ℃
MAAT : Mean Annual Air Temperature
μ : Mean temperature difference MAGT-MAAT
σ^2 : Spread of the distribution

Permafrost extent classes used in the IPA map
(Brown et al., 1997)

Methodology

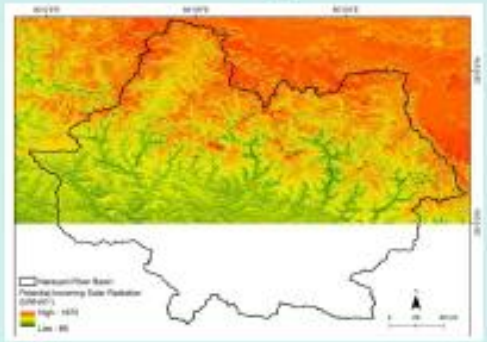
3. Map disturbance susceptibility

Model equation (Logistic Regression)
(Hosmer and Lemeshow, 2000)

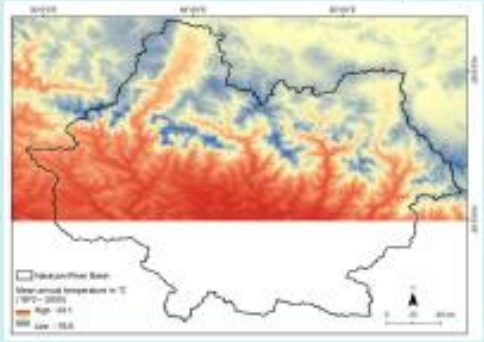
$$P(Y=1) = \frac{e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\ldots+\beta_n x_n}}{1+e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\ldots+\beta_n x_n}}$$

P (Y = 1): Probability of Y attaining 1
β_o : Intercept; $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$: Coefficients
$\chi_1, \chi_2, \chi_3, \chi_4, \chi_5$: Independent variables

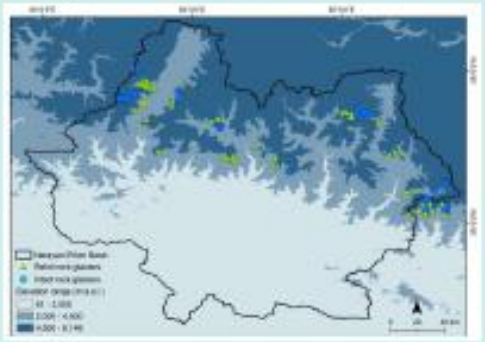
Permafrost probability distribution map for Narayani River Basin



Potential Incoming Solar Radiation

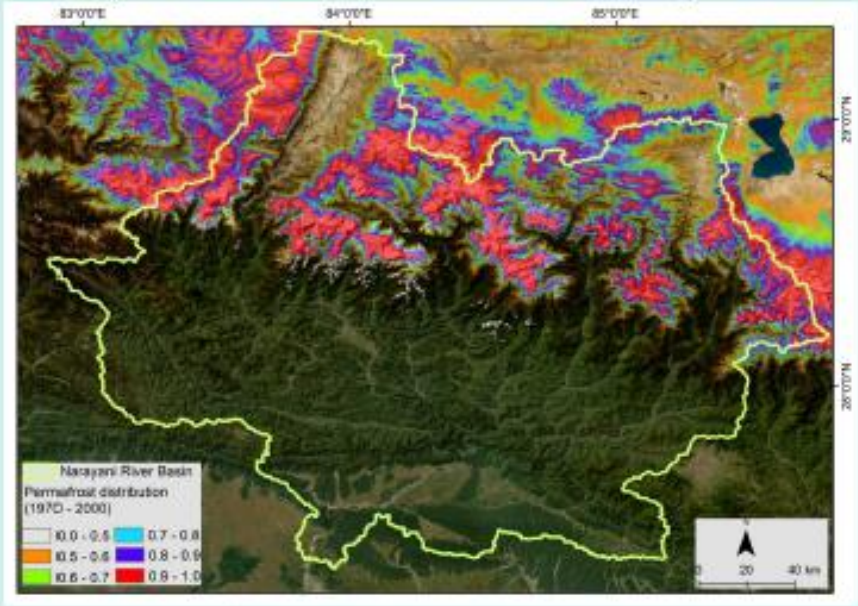


Mean Annual Air Temperature



Intact and relict rock glaciers

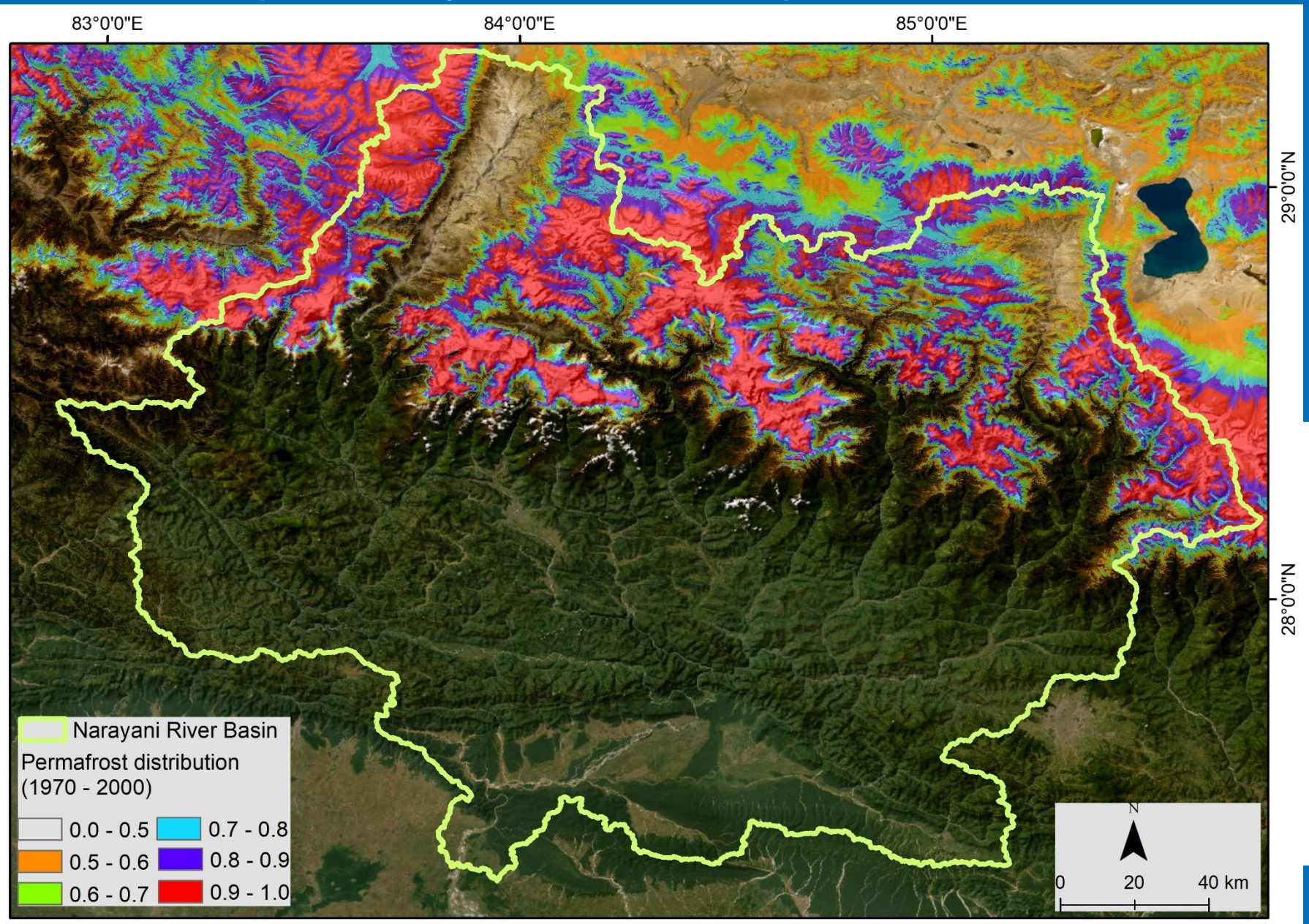
Logistic regression model generated a permafrost probability distribution map at 30 m spatial resolution, indicating that roughly 11,870 km^2 of high-elevation areas in the Narayani River Basin could be underlain by permafrost.



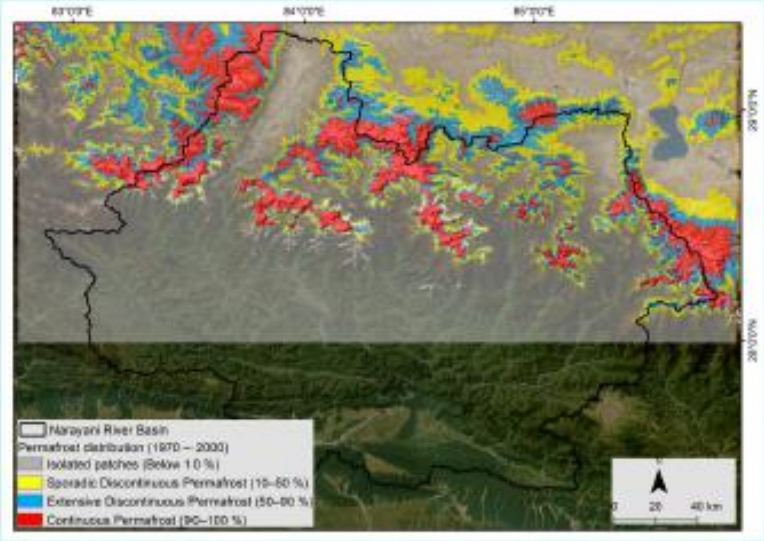
Permafrost probability distribution (1970 – 2000)

Narayani River Basin - permafrost related risks

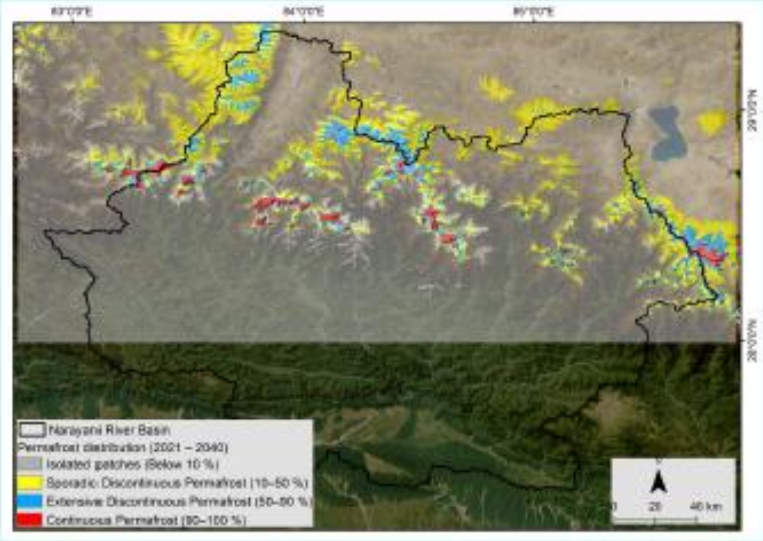
- Permafrost probability distribution map (1970 – 2000)



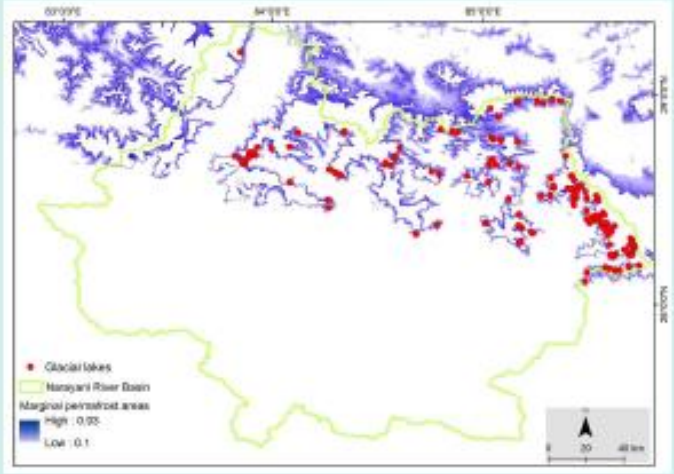
Modelling past and future permafrost extent for Narayani River Basin



Modelled permafrost distribution (1970 – 2000)



Modelled permafrost distribution (2021 – 2040)

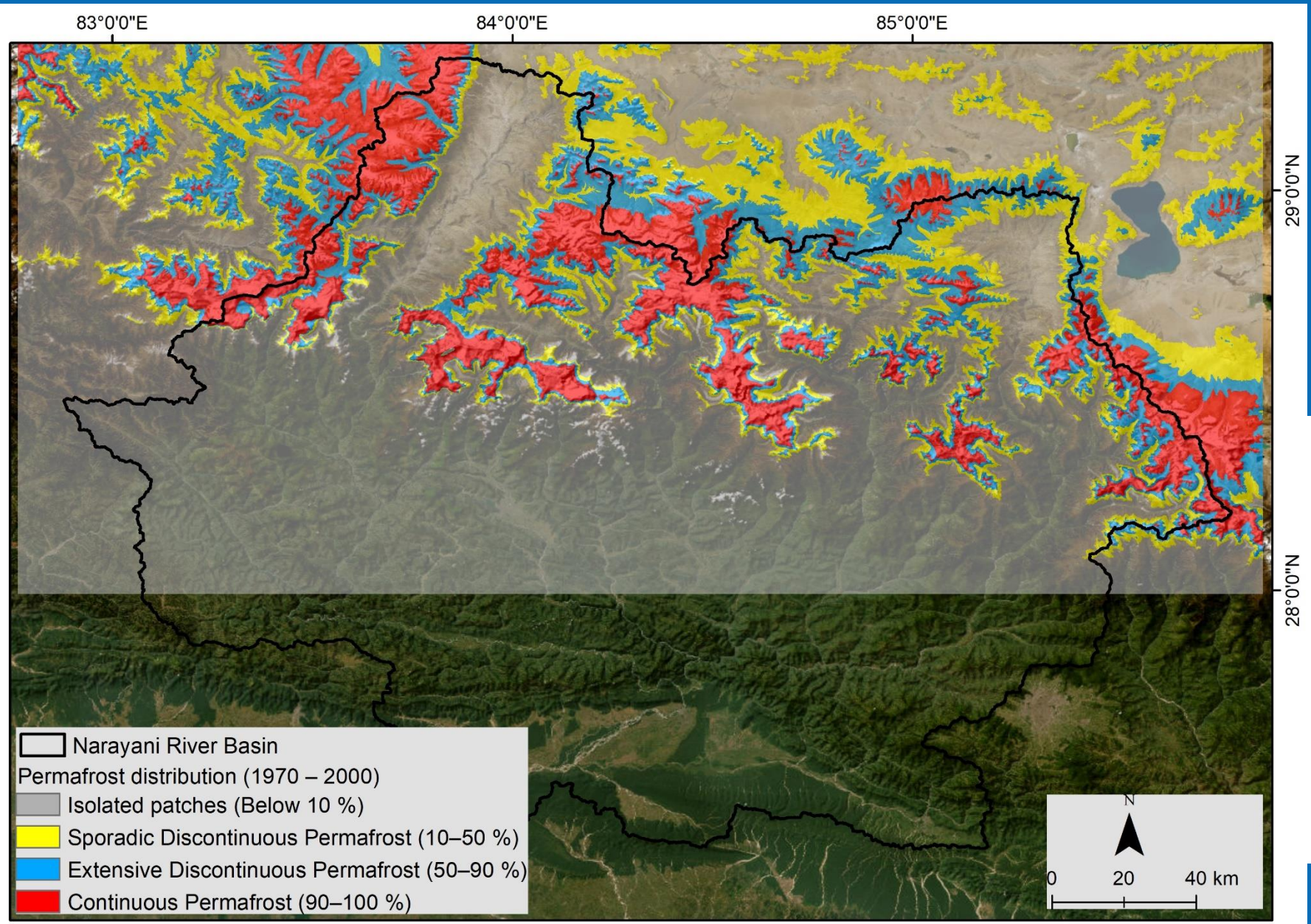


Glacial lakes on potential marginal permafrost areas by 2040

Modelled permafrost distribution for 1970 – 20000 shows about 3321 km^2 of continuous permafrost (90 – 100 %) while modelled permafrost distribution for 2021 – 2040 shows about 390 km^2 of continuous permafrost.

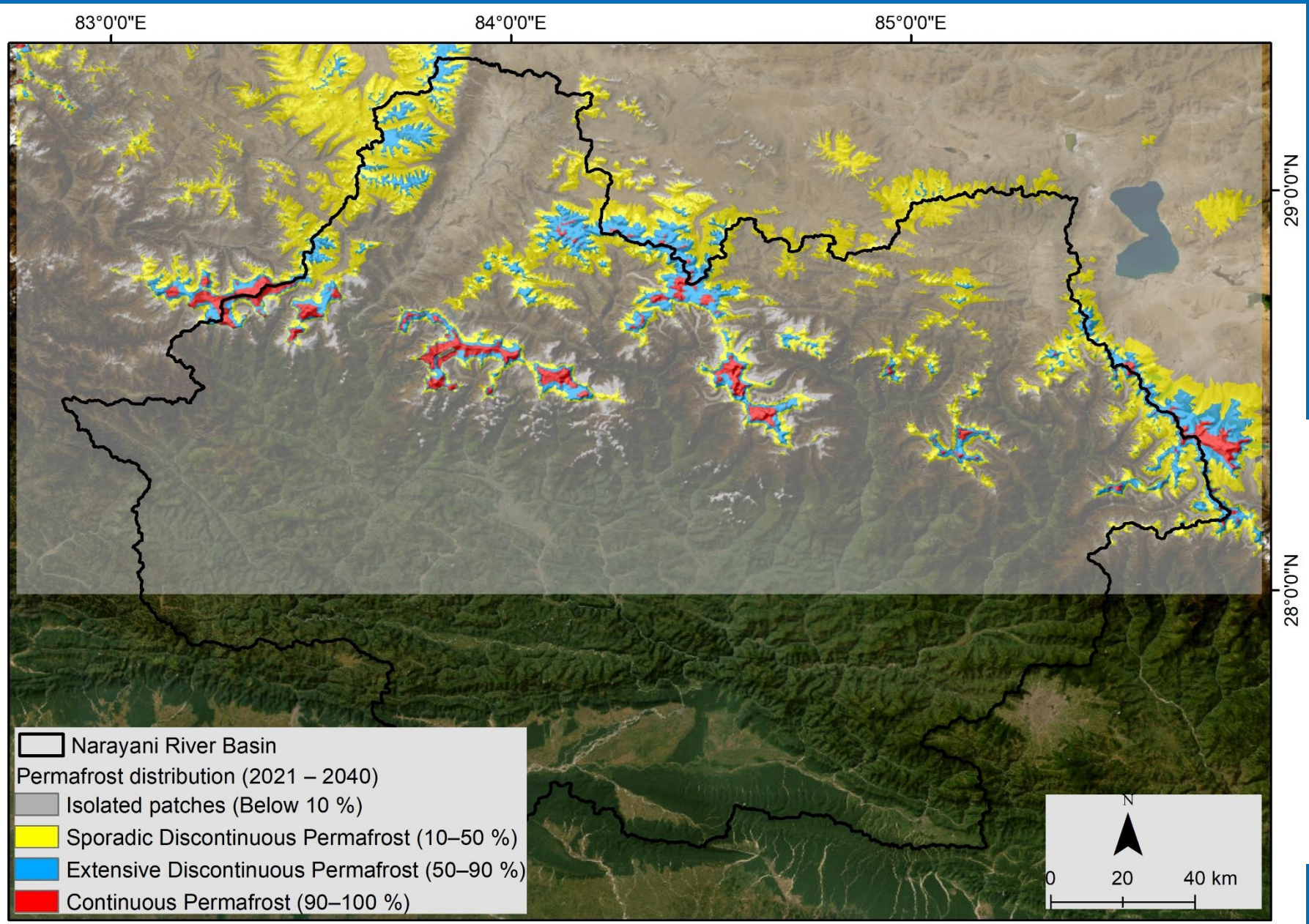
Narayani River Basin - permafrost related risks

- Permafrost extent (1970 – 2000)



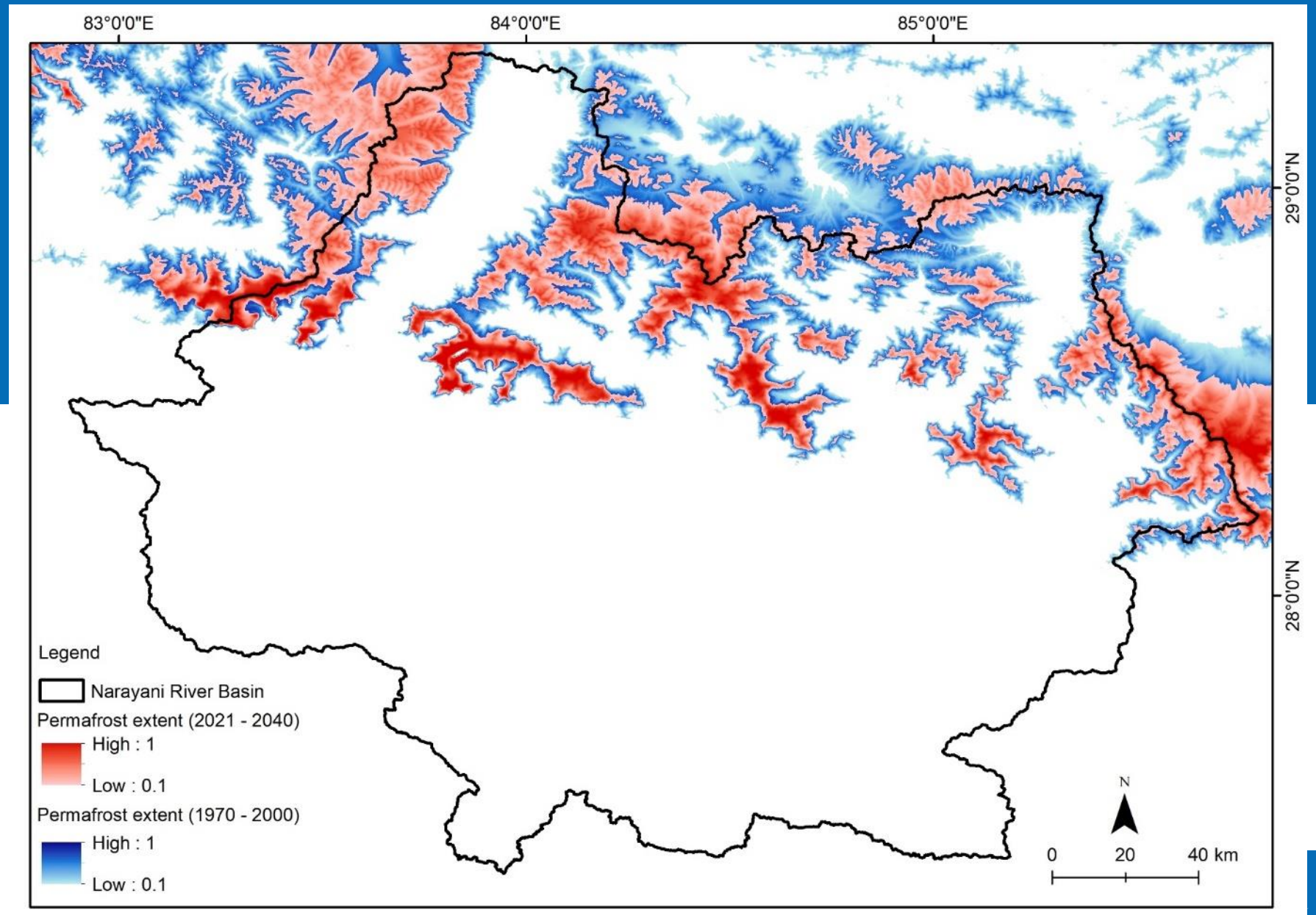
Narayani River Basin - permafrost related risks

- Permafrost extent (1970 – 2000)



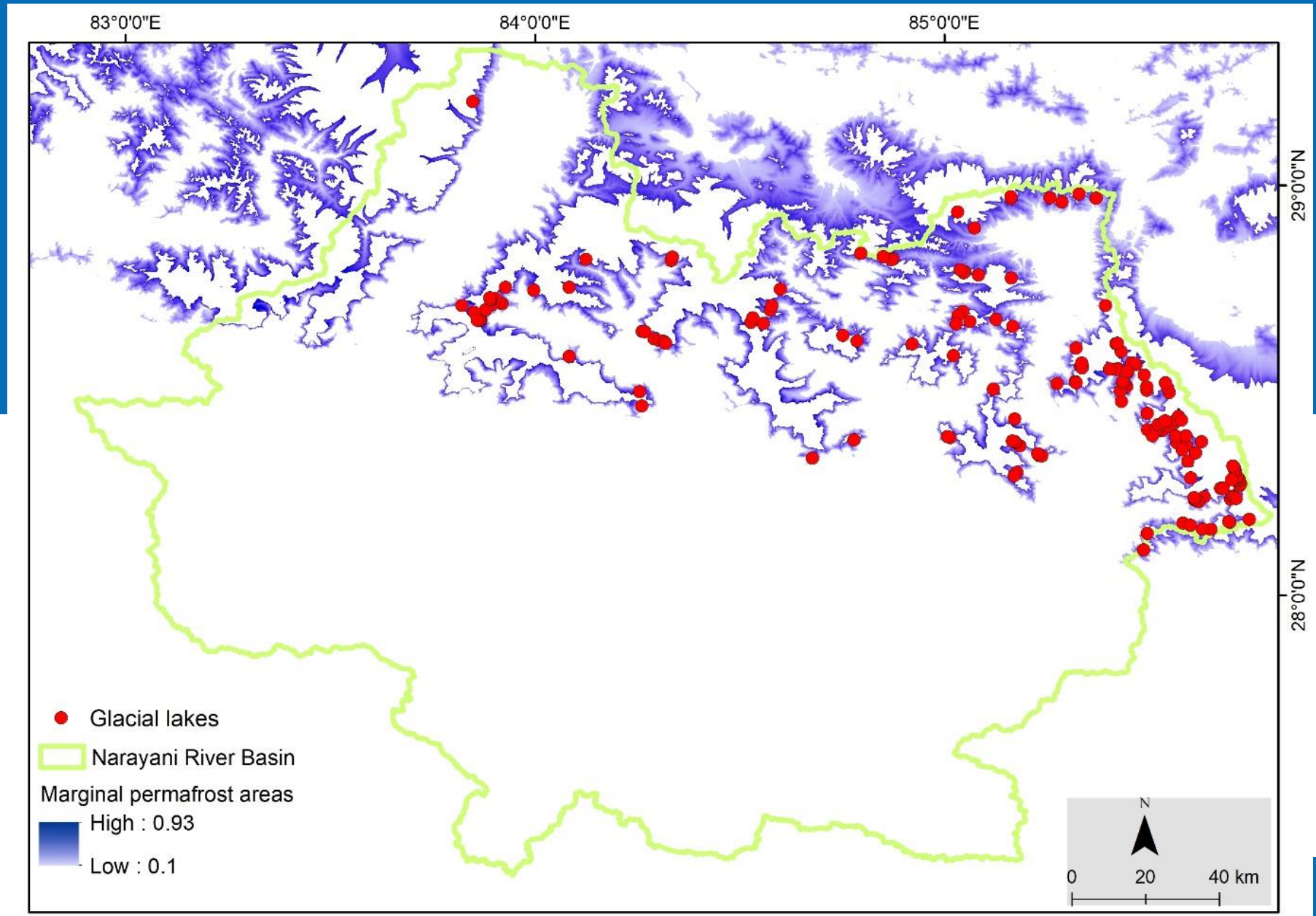
Narayani River Basin - permafrost related risks

- Permafrost extent maps for 1970 – 2000 and 2021 – 2040



Narayani River Basin - permafrost related risks

- Glacial lakes on marginal permafrost

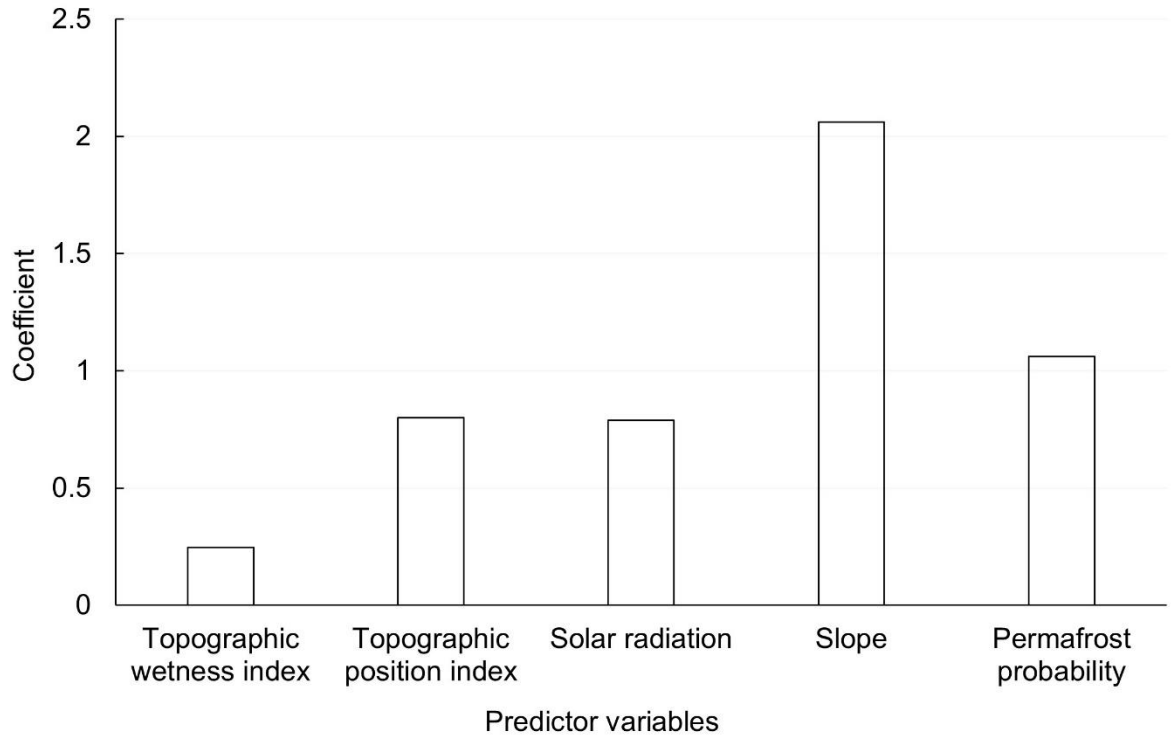


Disturbance susceptibility mapping

Predictor Variables

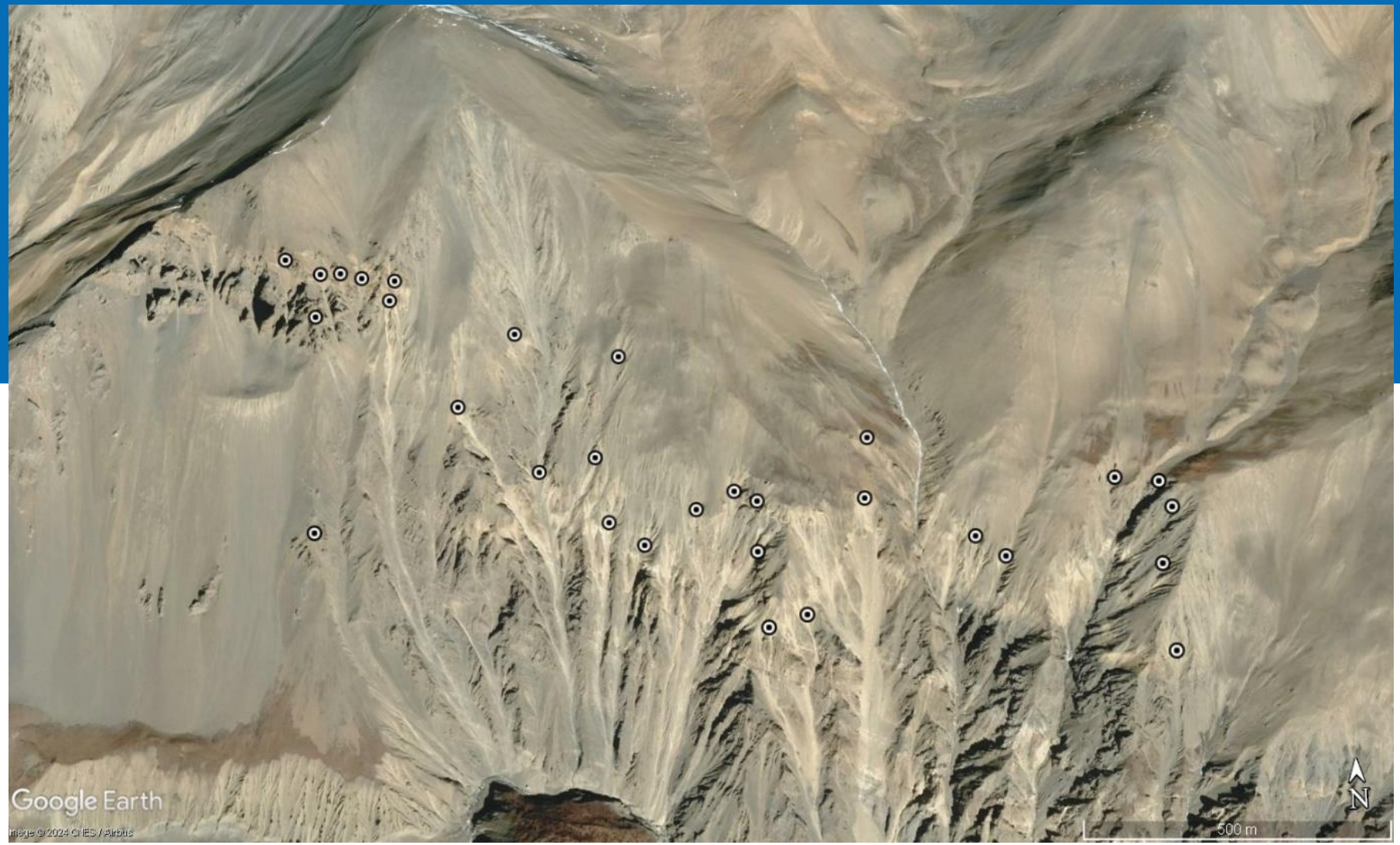
1. Topographic Wetness Index
2. Topographic Position Index
3. Permafrost Probability
4. Potential Incoming Solar Radiation
5. Slope

Steepness of slope exerts a strong control on the origin and distribution of the disturbances.



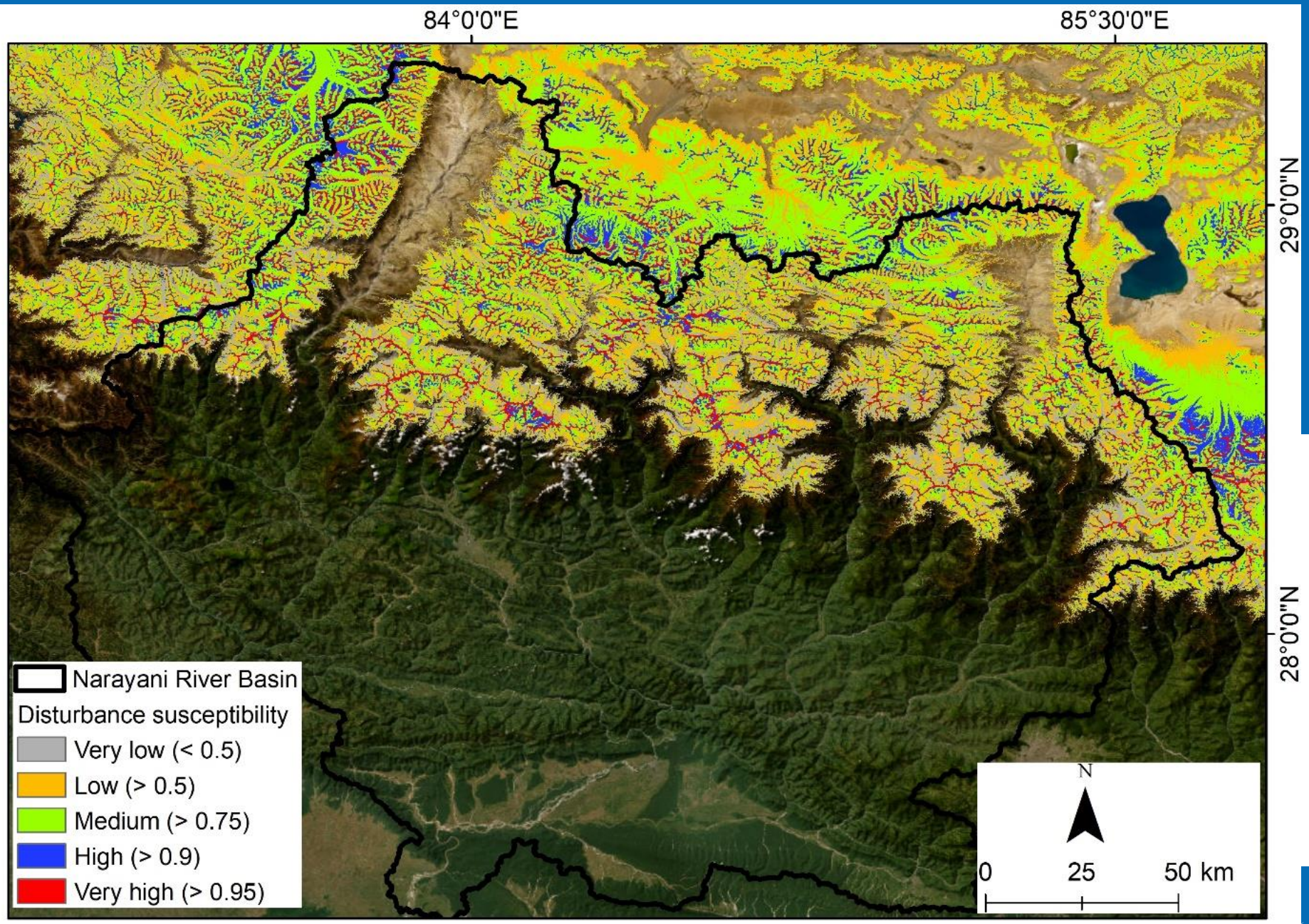
Narayani River Basin - permafrost related risks

- Permafrost slope disturbances



Narayani River Basin - permafrost related risks

- Permafrost slope disturbance susceptibility map

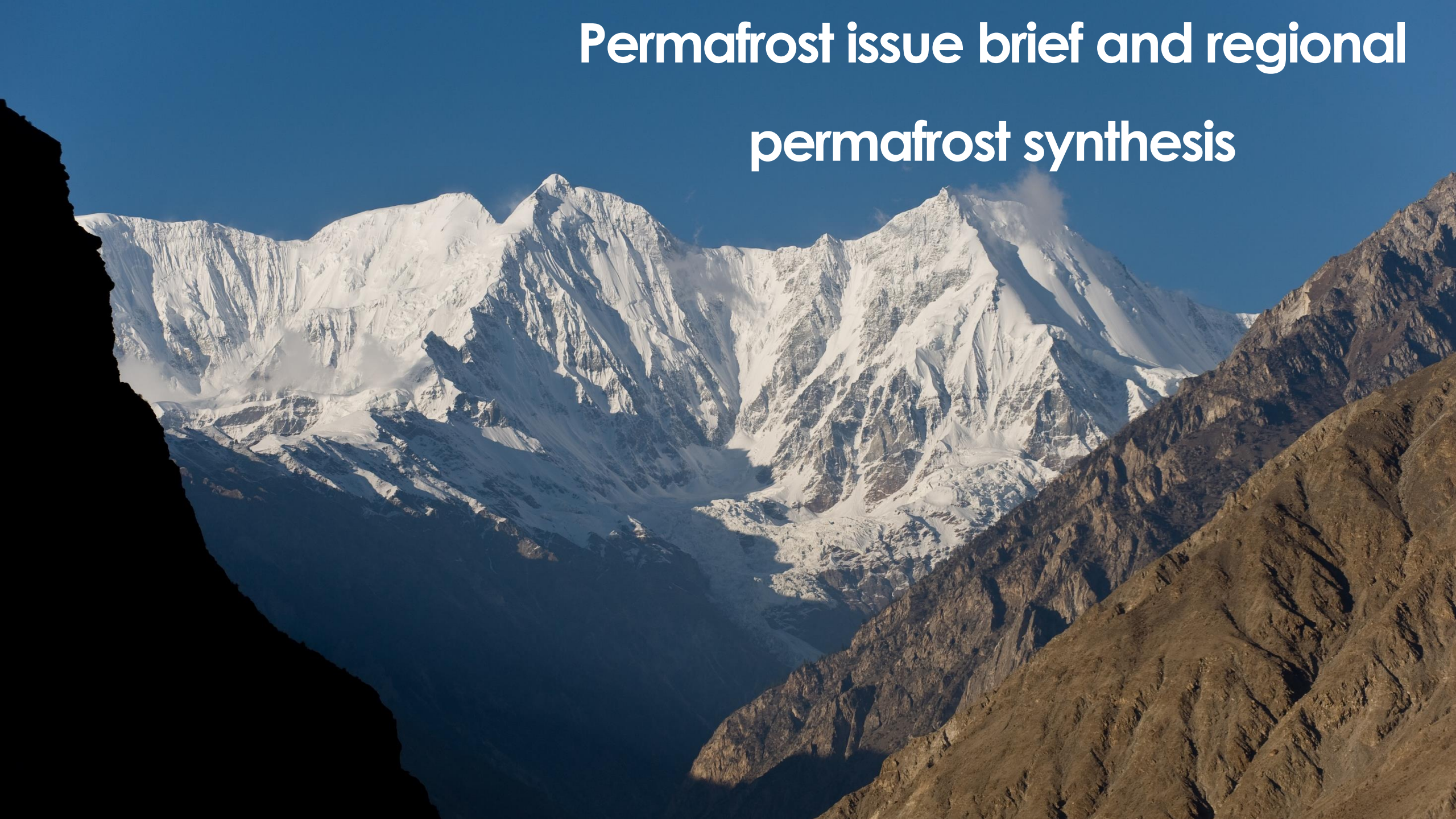


Recommendations

1. Conduct detailed permafrost mapping, monitoring, and geophysical surveys at hydropower sites to assess ground stability and integrate permafrost hazards into regional adaptation plans.

2. Prioritize smaller hydropower plants and implement comprehensive sediment management strategies throughout the project lifecycle for catchments with significant permafrost.

3. Foster regional and global knowledge exchange and collaborative research on sustainable hydropower development in permafrost landscapes.



Permafrost issue brief and regional permafrost synthesis

Permafrost issue brief

Proposed title

Climate Change and Permafrost in the Hindu Kush Himalaya (HKH): Concerns, Risks, and Resilience

Section 1

Permafrost in the HKH: distribution and characteristics

- What is permafrost?
- How can permafrost be detected and monitored?
- How large is permafrost area in the HKH?
- How well is permafrost investigated in the HKH?

Map of HKH

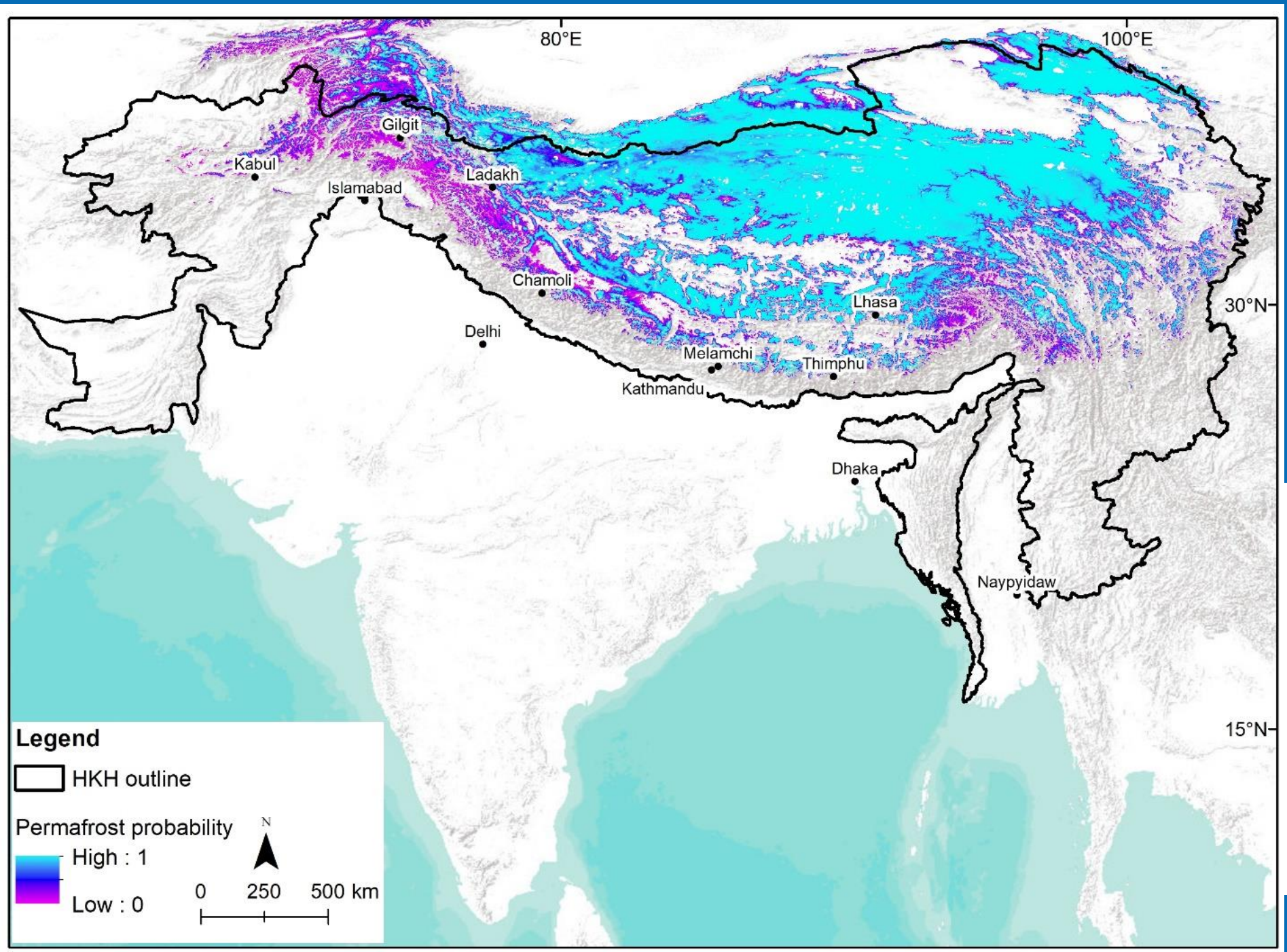


Figure 1: Map of HKH with distributed probability of occurrence of permafrost (Obu et al., 2019).

Section 2

Permafrost changes in the HKH: consequences and challenges

- Why is permafrost important ?
- What is happening to permafrost in the HKH?
- What happens when permafrost thaws and degrades?

What happens when permafrost thaws and degrades?

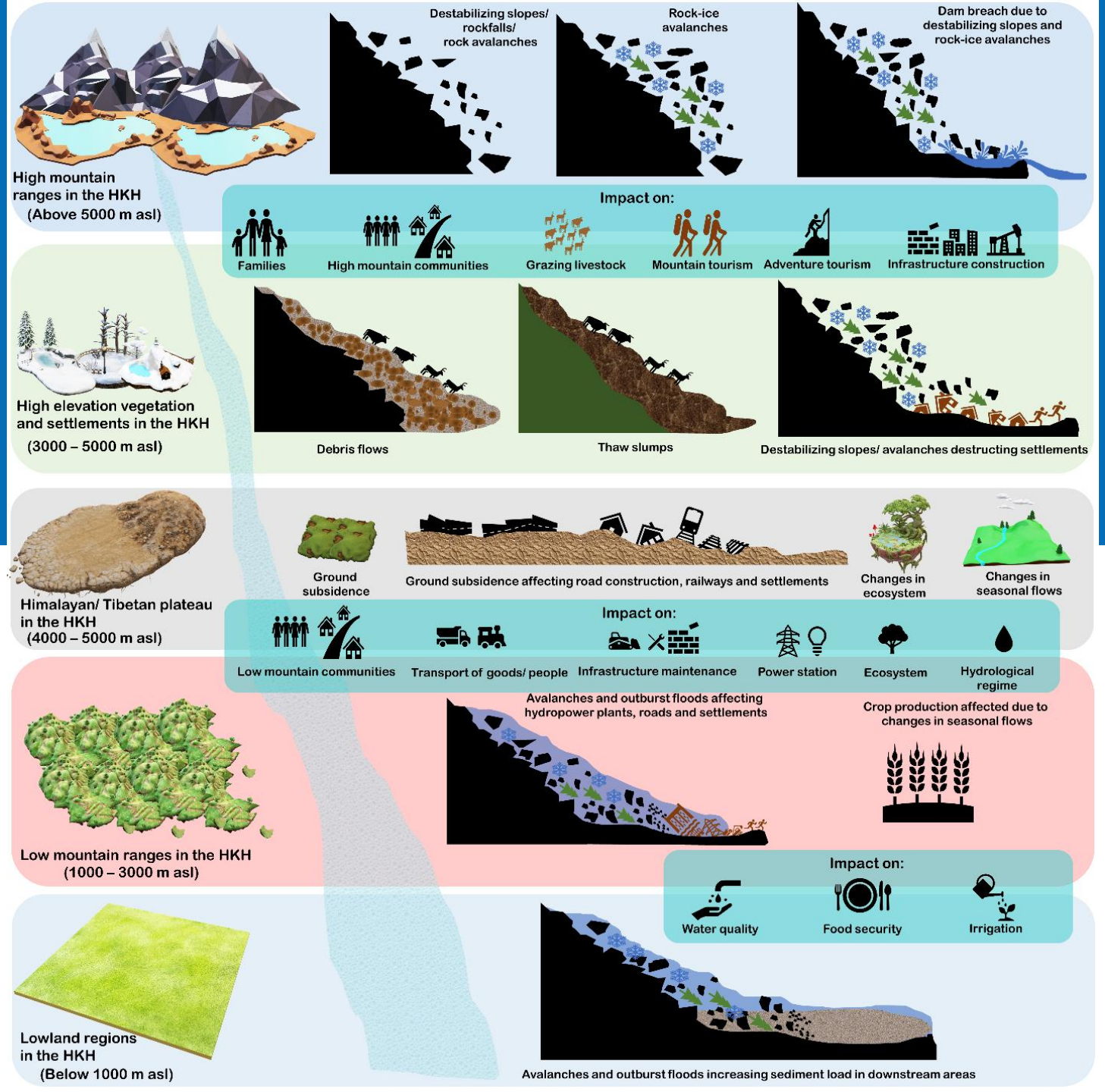
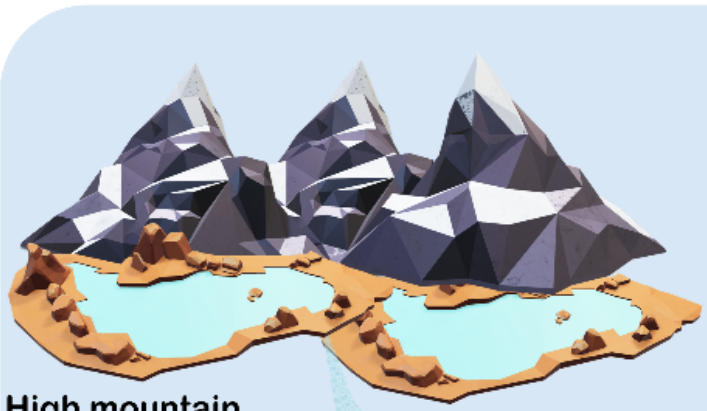
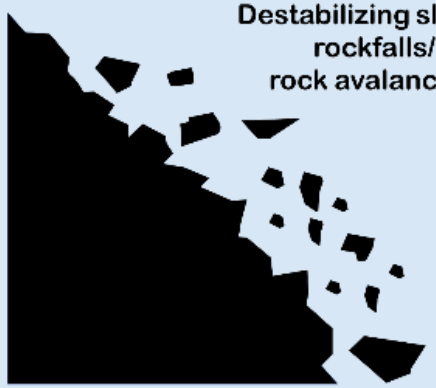


Figure 2: Examples of potential permafrost hazards and associated impacts on landforms in different elevation ranges in the HKH .

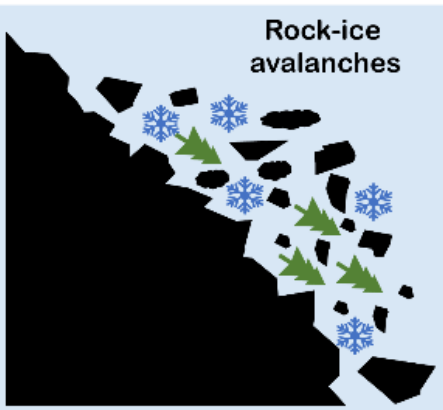
Impacts of changes in permafrost



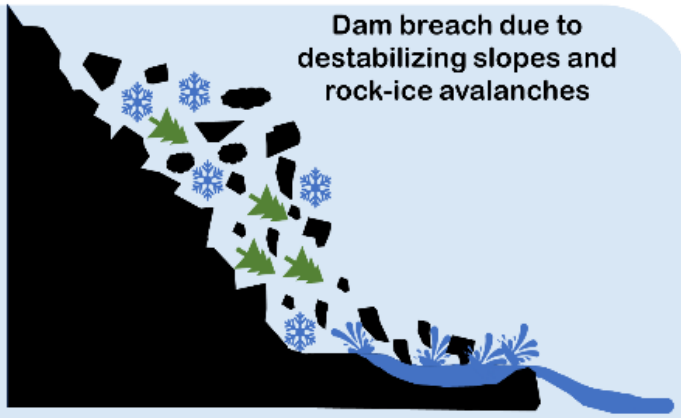
High mountain ranges in the HKH (Above 5000 m asl)



Destabilizing slopes/ rockfalls/ rock avalanches



Rock-ice avalanches



Dam breach due to destabilizing slopes and rock-ice avalanches

Impact on:

Families

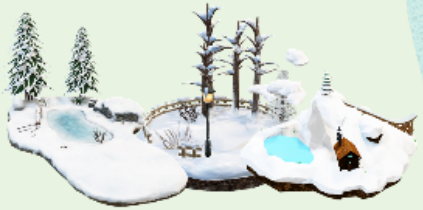
High mountain communities

Grazing livestock

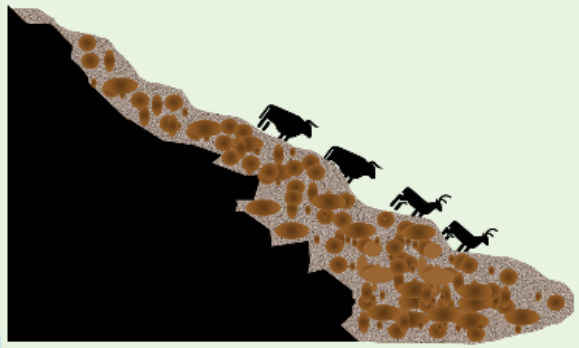
Mountain tourism

Adventure tourism

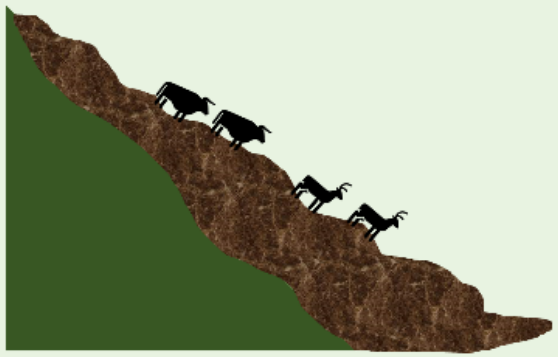
Infrastructure construction



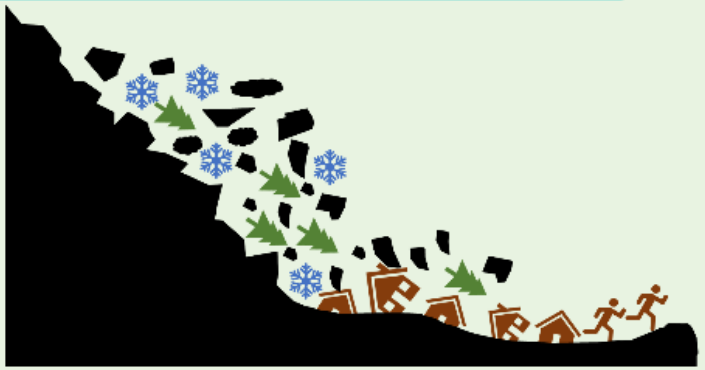
High elevation vegetation and settlements in the HKH (3000 – 5000 m asl)



Debris flows

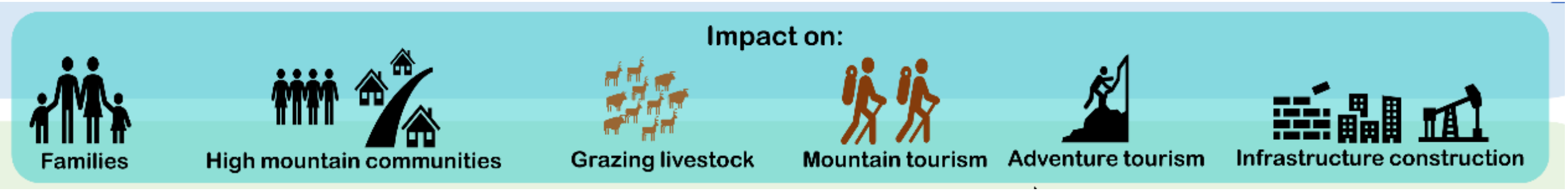


Thaw slumps



Destabilizing slopes/ avalanches destructing settlements

Impacts of changes in permafrost



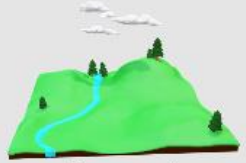
Impacts of changes in permafrost

Himalayan/ Tibetan plateau
in the HKH
(4000 – 5000 m asl)

Ground subsidence

Ground subsidence affecting road construction, railways and settlements

Changes in ecosystem



Changes in seasonal flows

Impact on:

Low mountain communities

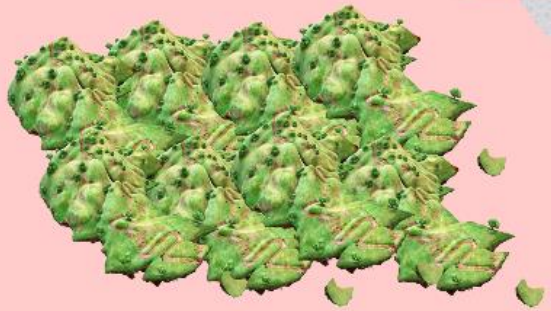
Transport of goods/ people

Infrastructure maintenance

Power station

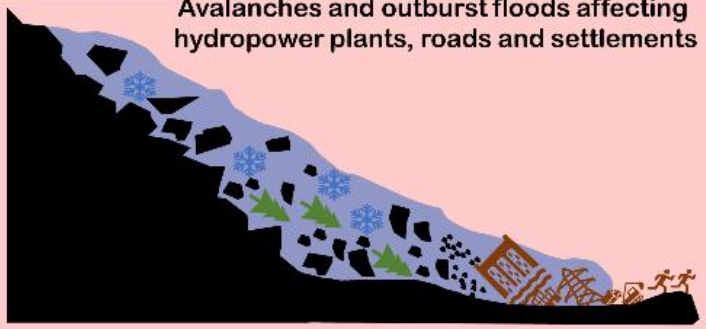
Ecosystem

Hydrological regime



Low mountain ranges in the HKH
(1000 – 3000 m asl)

Avalanches and outburst floods affecting hydropower plants, roads and settlements



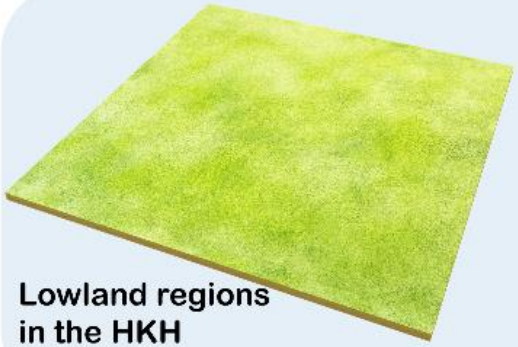
Crop production affected due to changes in seasonal flows

Impact on:

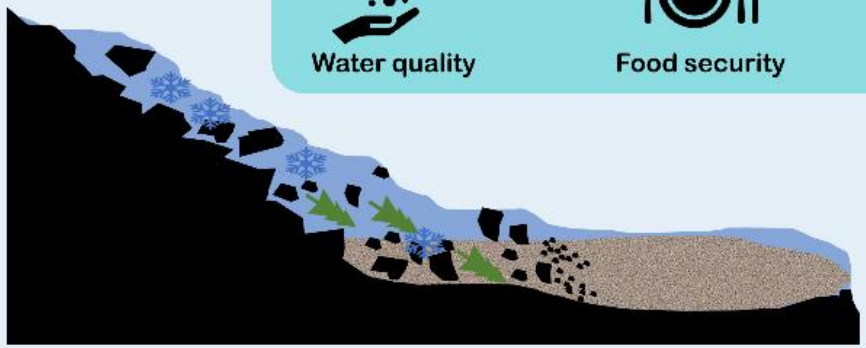
Water quality

Food security

Irrigation

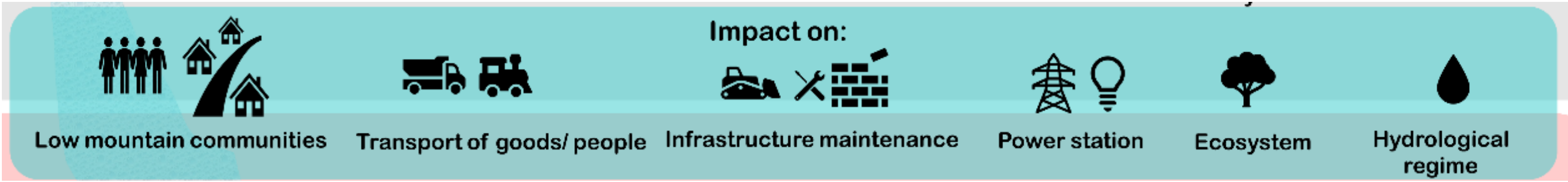


Lowland regions
in the HKH
(Below 1000 m asl)



Avalanches and outburst floods increasing sediment load in downstream areas

Impacts of changes in permafrost



Section 3

Permafrost in a changing climate: global impact, monitoring, and adaptation strategies

- Permafrost in global climate assessments
- Permafrost monitoring networks
- Permafrost projects
- Adaptation practices

Section 4

Building resilience to permafrost-related hazards in the HKH

- What are the potentials and challenges?
- SDG 13 and strategic framework for adapting to permafrost-related hazards in the HKH
- Recommendations

What are the potentials and challenges?

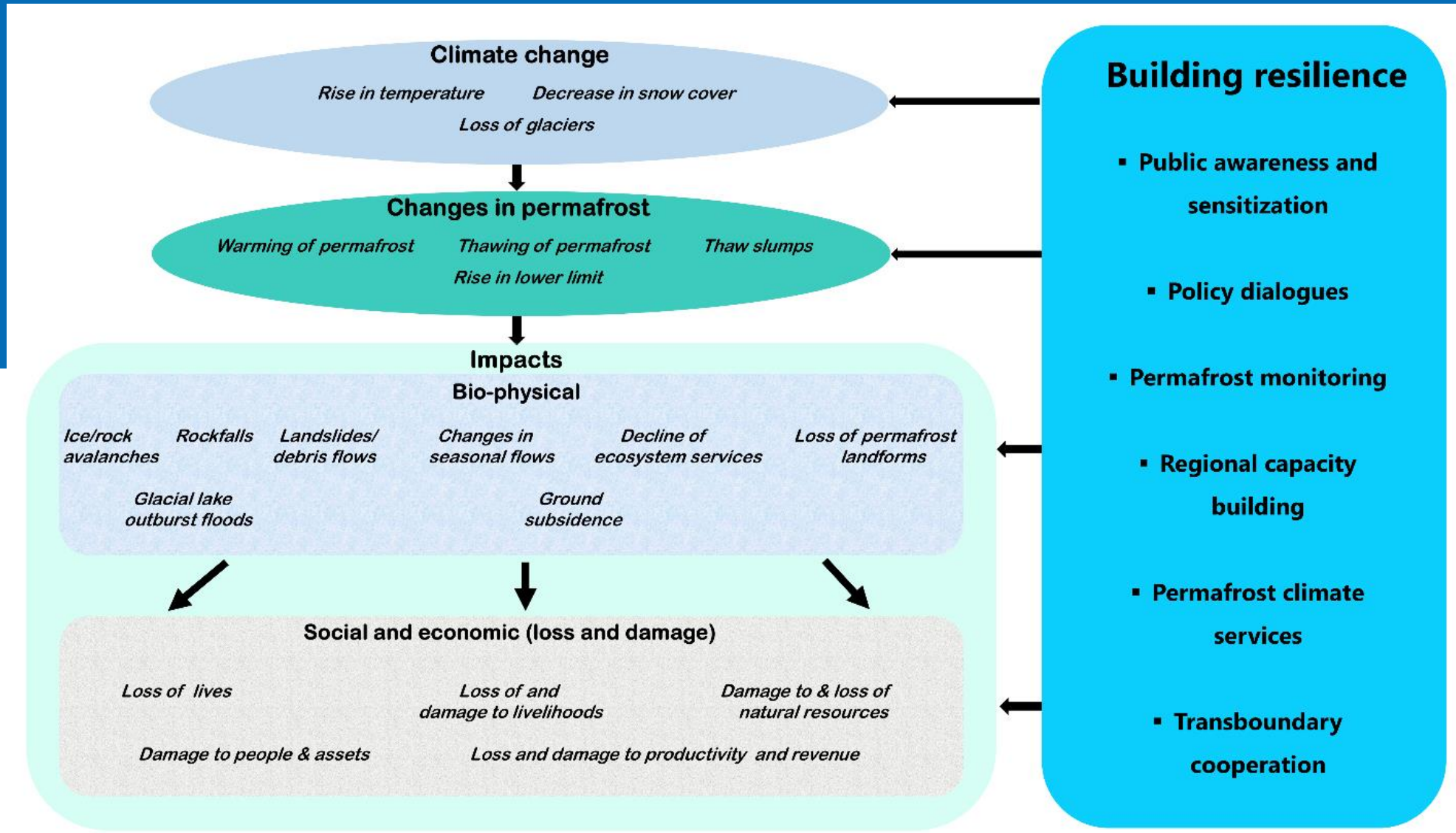
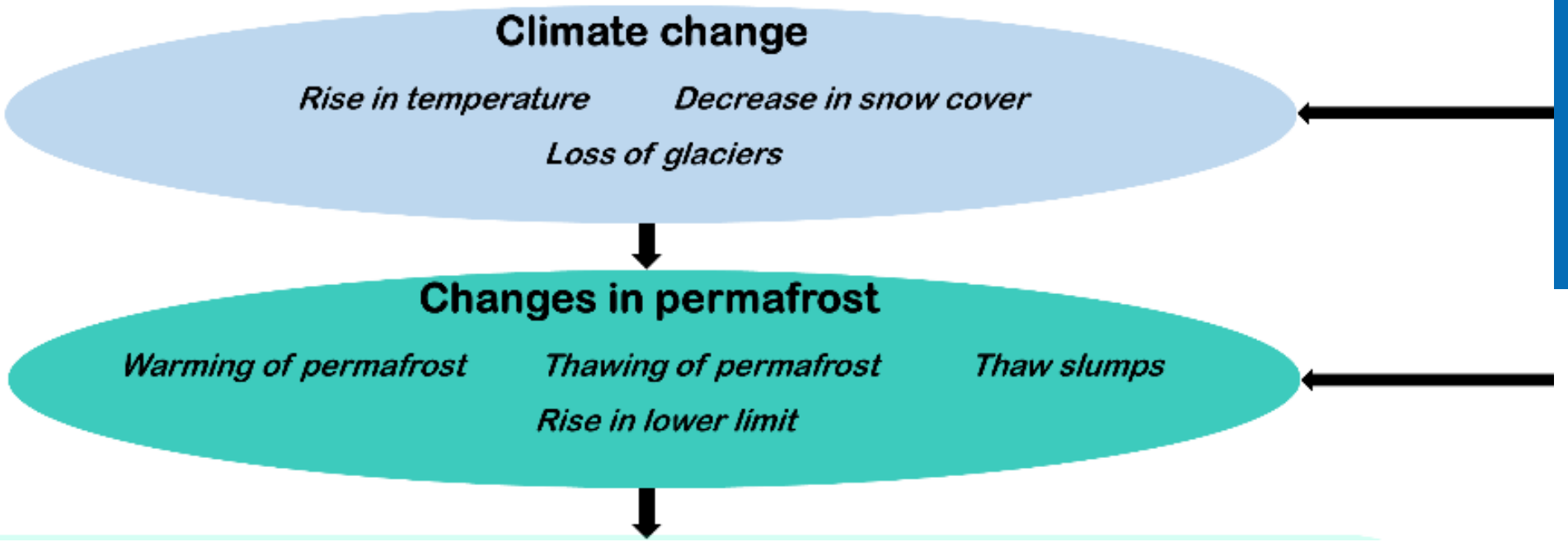
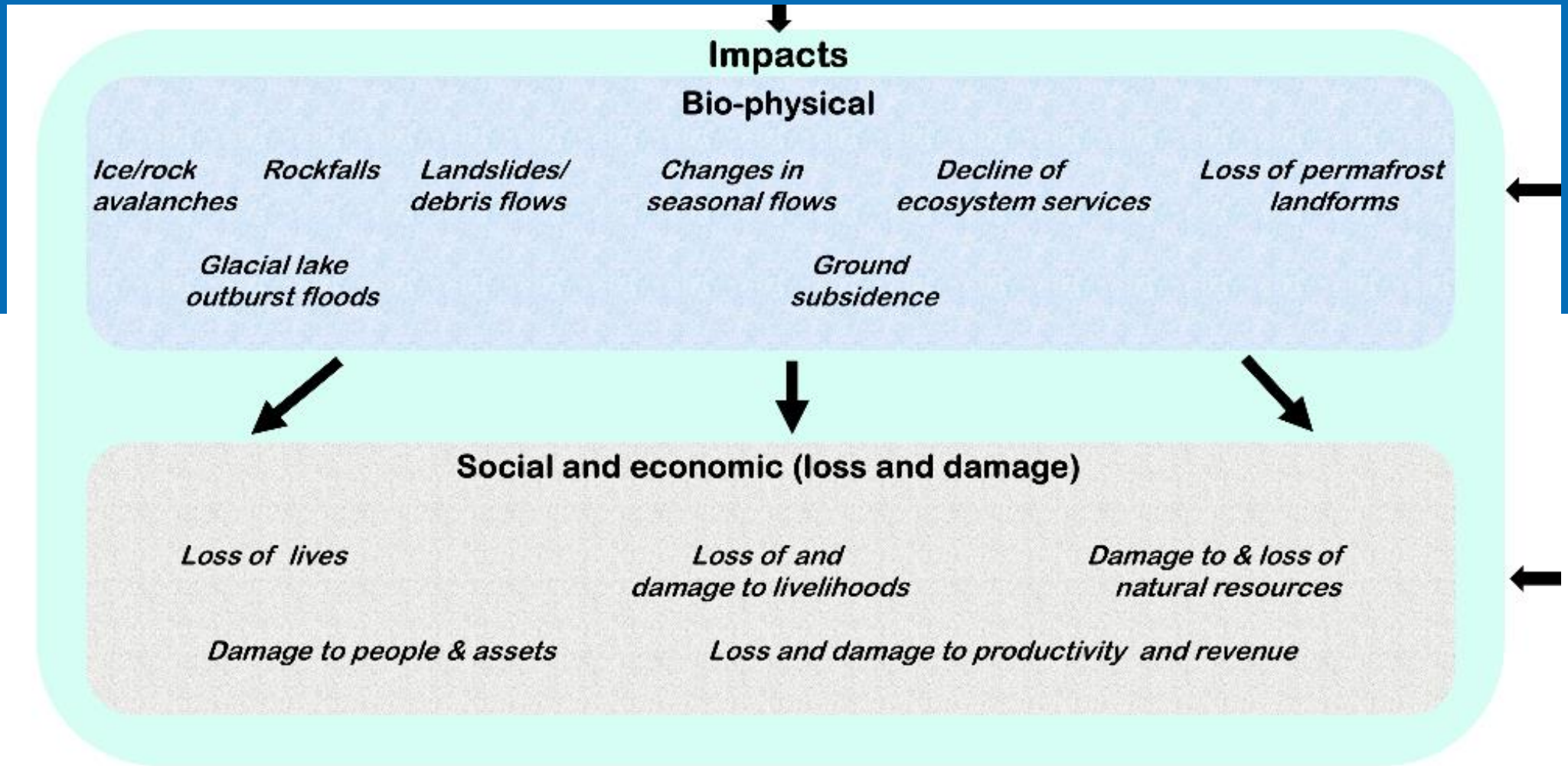


Figure 3: Climate change, changes in permafrost, resulting impacts, and proposed measures for building resilience in the HKH. (Source: Adapted from (Huggel et al., 2019)).

What are the potentials and challenges?



What are the potentials and challenges?



What are the potentials and challenges?

Building resilience

- Public awareness and sensitization
- Policy dialogues
- Permafrost monitoring
- Regional capacity building
- Permafrost climate services
- Transboundary cooperation

SDG 13 and strategic framework for adapting to permafrost-related hazards in the HKH

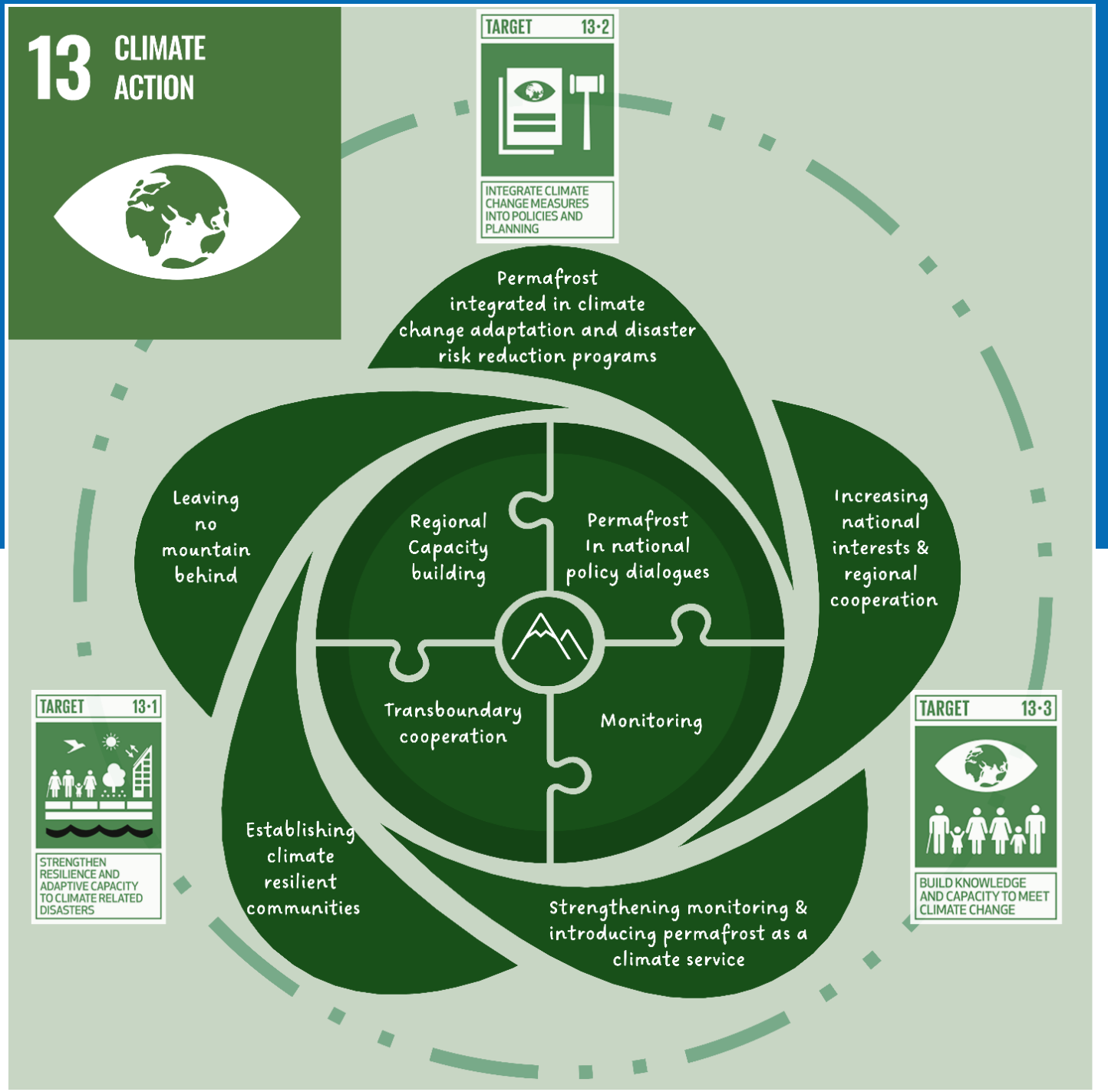
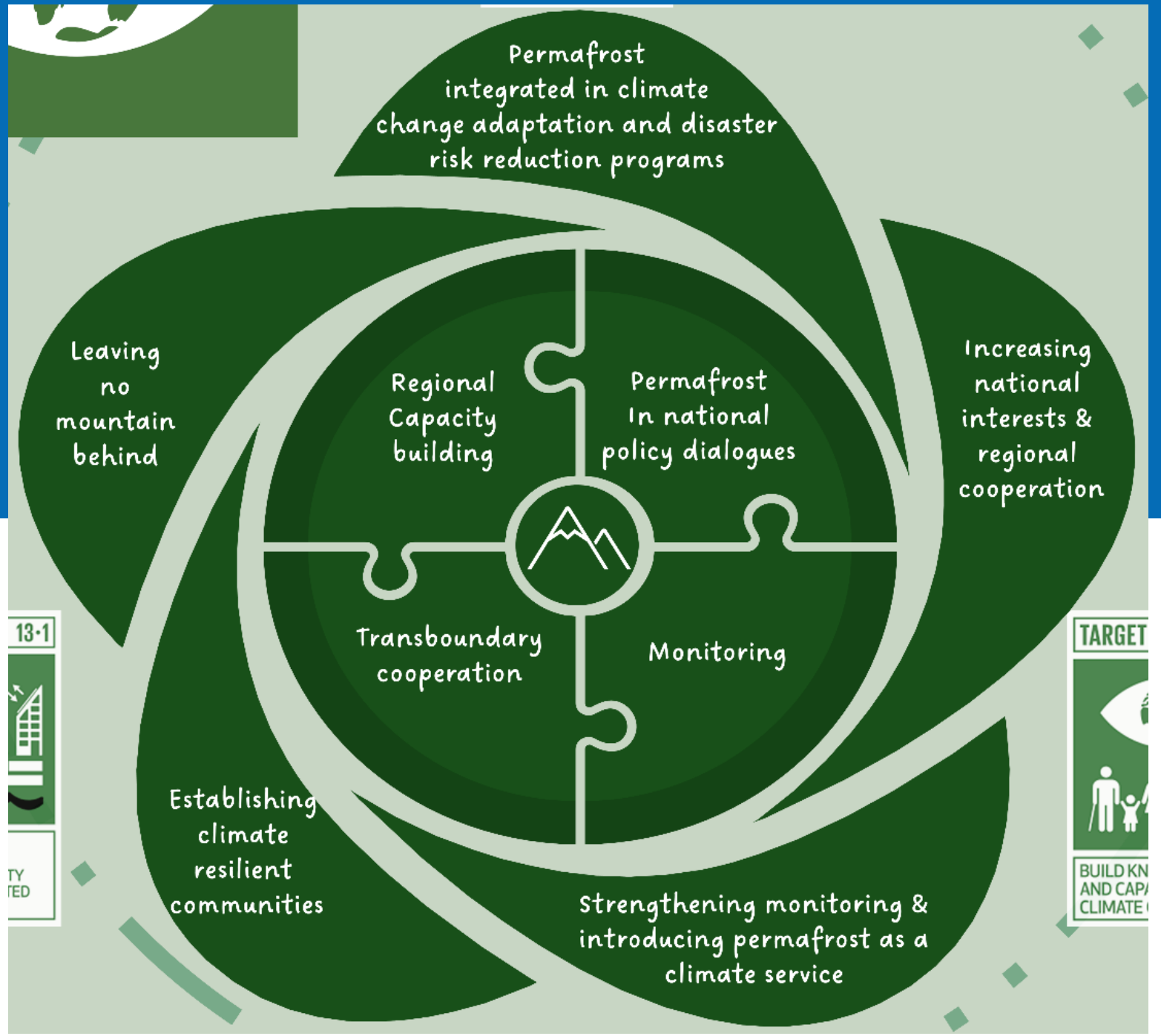


Figure 4: Strategic framework and initiatives, compliant with SDG 13 and its targets, to adapt to impacts of permafrost degradation due to climate change in the HKH.

SDG 13 and strategic framework for adapting to permafrost-related hazards in the HKH



Recommendations

1. **Promote permafrost knowledge** in the HKH and inform and **educate general public** through **easily accessible and understandable literature** published in regional languages.

2. **Develop** a **permafrost-resilient infrastructure strategy** and **implement** it during the **design and construction** of **infrastructure** in high-mountain environments .

3. **Include permafrost** in **national as well as regional policy dialogues** and **climate policies** in the HKH, such as **policy related to road construction**, **hydropower development, tourism**, and other relevant sectors.

4. **Integrate permafrost** and **permafrost-related hazards** in **national as well as regional climate change adaptation** as well as **disaster risk reduction policies**, **guideline** and **programmes**.

5. **Strengthen capacity of governments** and **academic institutions** at the **national and regional level** to **monitor permafrost** in the HKH.

Recommendations

6. **Promote collaboration** between relevant **governmental and non-governmental organizations** to **develop** a **regional permafrost monitoring network to monitor permafrost** in the HKH.

7. **Build transboundary/regional cooperation** in **permafrost research, monitoring, and policy development** in the HKH

8. **Develop Permafrost Climate Services** in the region to **support adaptation decisions** in relation to **infrastructure developments** in permafrost environments.

9. **Identify and map community vulnerability to permafrost hazards** in the HKH.

10. **Highlight mountain permafrost issues and challenges** in the HKH in **regional and international climate discourses.**

Regional permafrost synthesis

Proposed title

Rock glaciers in the Hindu Kush Himalaya: a regional synthesis

Outline of the regional synthesis

1. Introduction

- Objective and Scope of the synthesis
- Definition, characteristics and importance of rock glaciers
- Formation, evolution and types of rock glaciers

2. Regional Overview

- Geographic Setting and distribution of rock glaciers

3. Methodologies

- Monitoring Techniques and data Sources

4. Key Findings

- Geological and Geomorphological Insights
- Climatic and Environmental Implications
- Hydrological Role

Outline of the regional synthesis

5. Case Studies

- Detailed Examples of selected rock glaciers

6. Challenges and Limitations

- Data Gaps

- Methodological Limitations

7. Future Research Directions

- Research Priorities

- Technological Advances

8. Conclusion

- Summary of Findings

9. References

Planned activities for 2024 and beyond

- Regular field-based monitoring activities and capacity building workshops before the fieldworks
- Regional capacity building workshop on permafrost in September 2024
- Regional synthesis of permafrost in the HKH
- Scientific article based on data from ground temperature sensors and permafrost mapping using remote sensing methods and modeling


Thank you