9th India International Water Week 2026

"Water in Climate Related Risk "

# CRYOSPHERIC HAZARDS IN A WARMING HIMALAYA: RISKS, IMPACTS, AND PATHWAYS FOR RESILIENCE



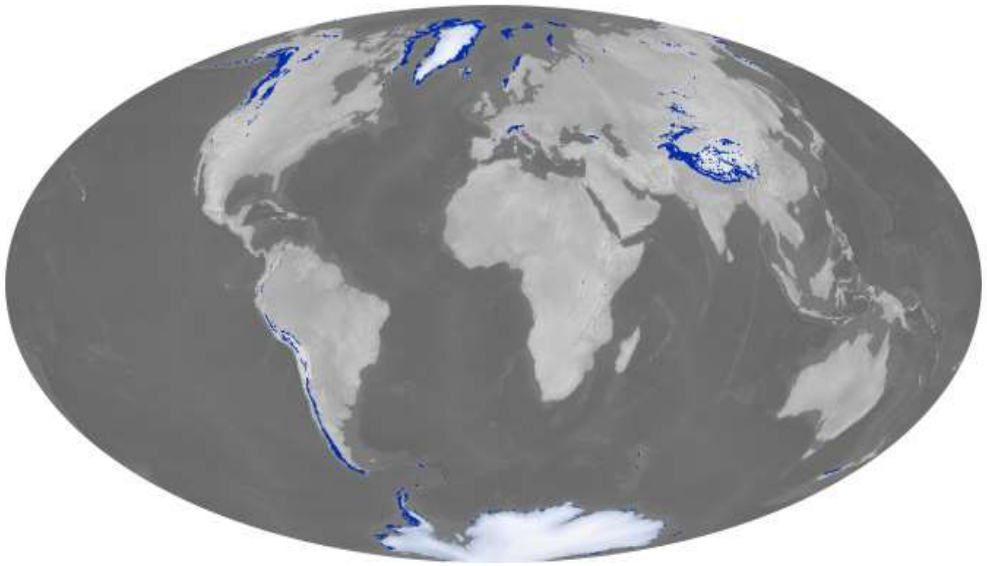

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**Centre for Cryosphere & Climate Change Studies (C4S),**
**National Institute of Hydrology, Roorkee**

# Global and IHR Distribution of Glaciers

| Region | Area ($km^2$ appox.) | % |
|---|---|---|
| South Polar Region | 12,612,000 | 84.42 |
| North Polar Region | 1,995,027 | 13.35 |
| Asia | 174,400 | 1.16 |
| North America | 124,000 | 0.83 |
| South America | 25,500 | 0.17 |
| Europe, Africa & Pacific Region | 8,334 | 0.05 |
| Grand total | 14,939,261 $km^2$ | 100 |

(Global Glacier Changes: Facts and Figures, WGMS, UNEP)



| Basin | Sub-basin | No. of glaciers | Total no. of glaciers |
|---|---|---|---|
| Indus | Ravi | 172 | 7997 (83.52%) |
| | Chenab | 1278 | |
| | Jhelum | 133 | |
| | Beas | 277 | |
| | Satluj | 926 | |
| | Indus | 1796 | |
| | Shyok | 2658 | |
| | Kishanganga | 222 | |
| | Gilgit | 535 | |
| Ganga | Yamuna | 52 | 1578 (16.48%) |
| | Bhagirathi | 238 | |
| | Alaknanda | 407 | |
| | Ghaghra | 271 | |
| | Tista | 449 | |
| | Brahmaputra | 161 | |
| Geological Survey of India (2008) | | | |
| Grand Total | | | 9575 |

Randolph Glacier Inventory (Arendt *et al.*, 2013)

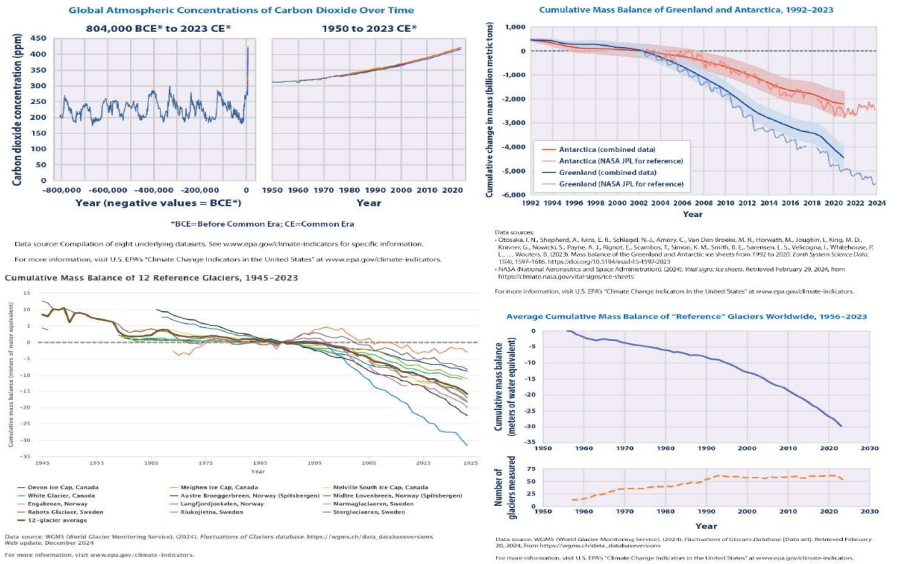
# A warming Himalaya is transforming hazard conditions

Rising temperatures and changing precipitation regimes accelerate glacier recession and reduce snow persistence.

Rain–snow phase shifts and light-absorbing aerosols can lengthen the ablation season.

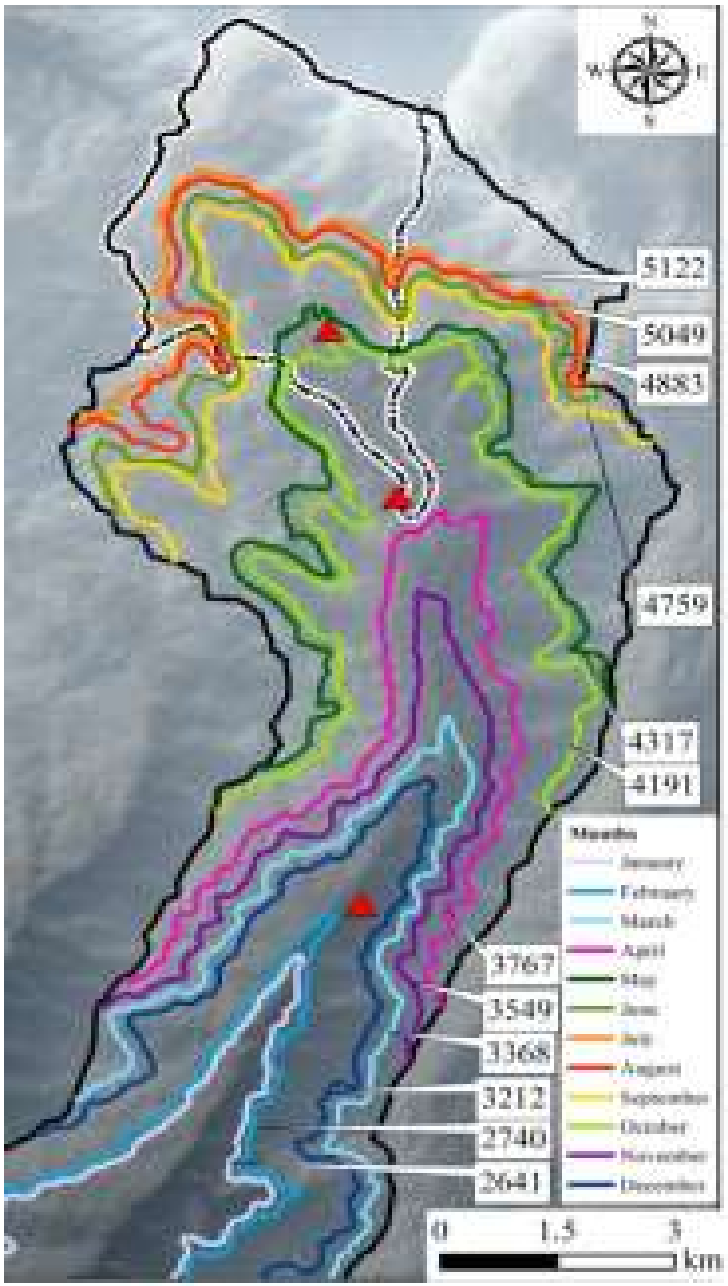
Retreat exposes over-deepened basins, unstable moraines and unconsolidated sediment stores.

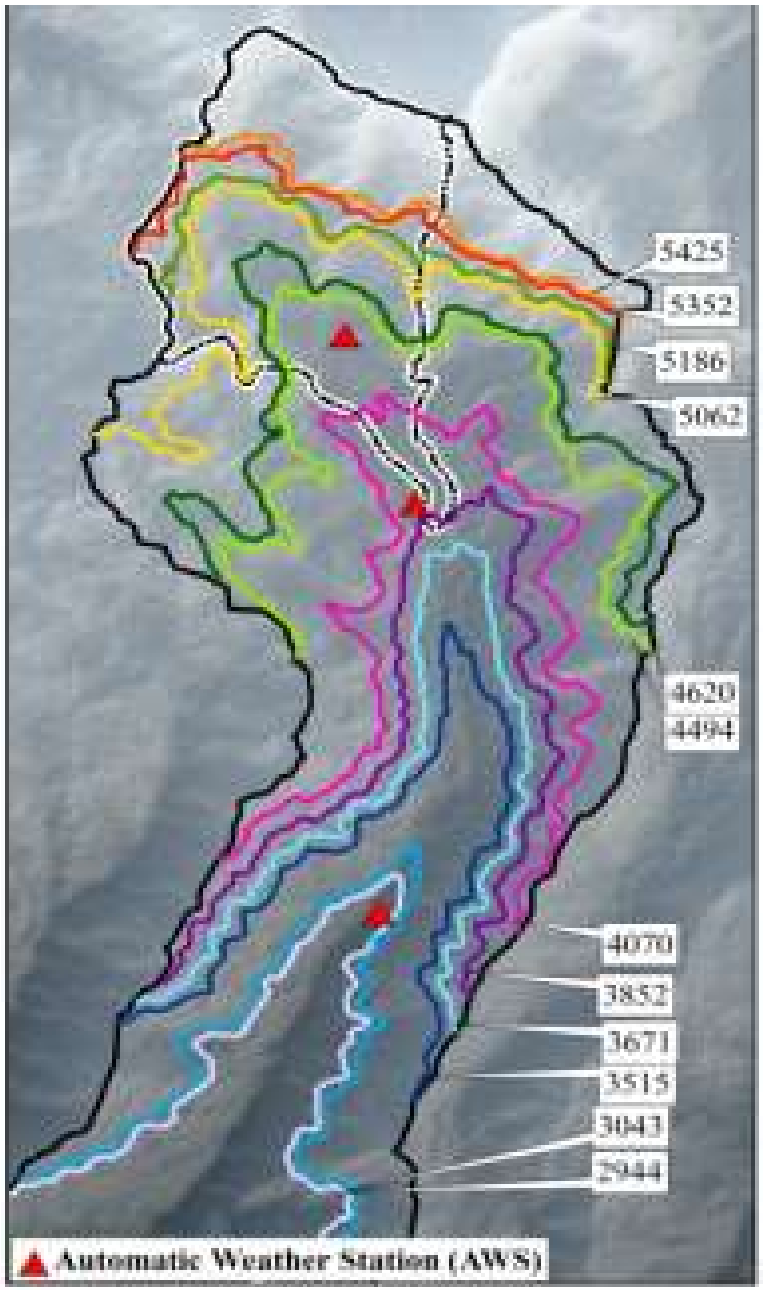
Climate projections indicate continued glacier retreat, with implications for long-term dry-season water availability.




**Short term: potentially higher meltwater**
**Long term: declining ice storage and dry-season buffering**

# Temperature Isotherms and Snowline (0°C & 2°C)



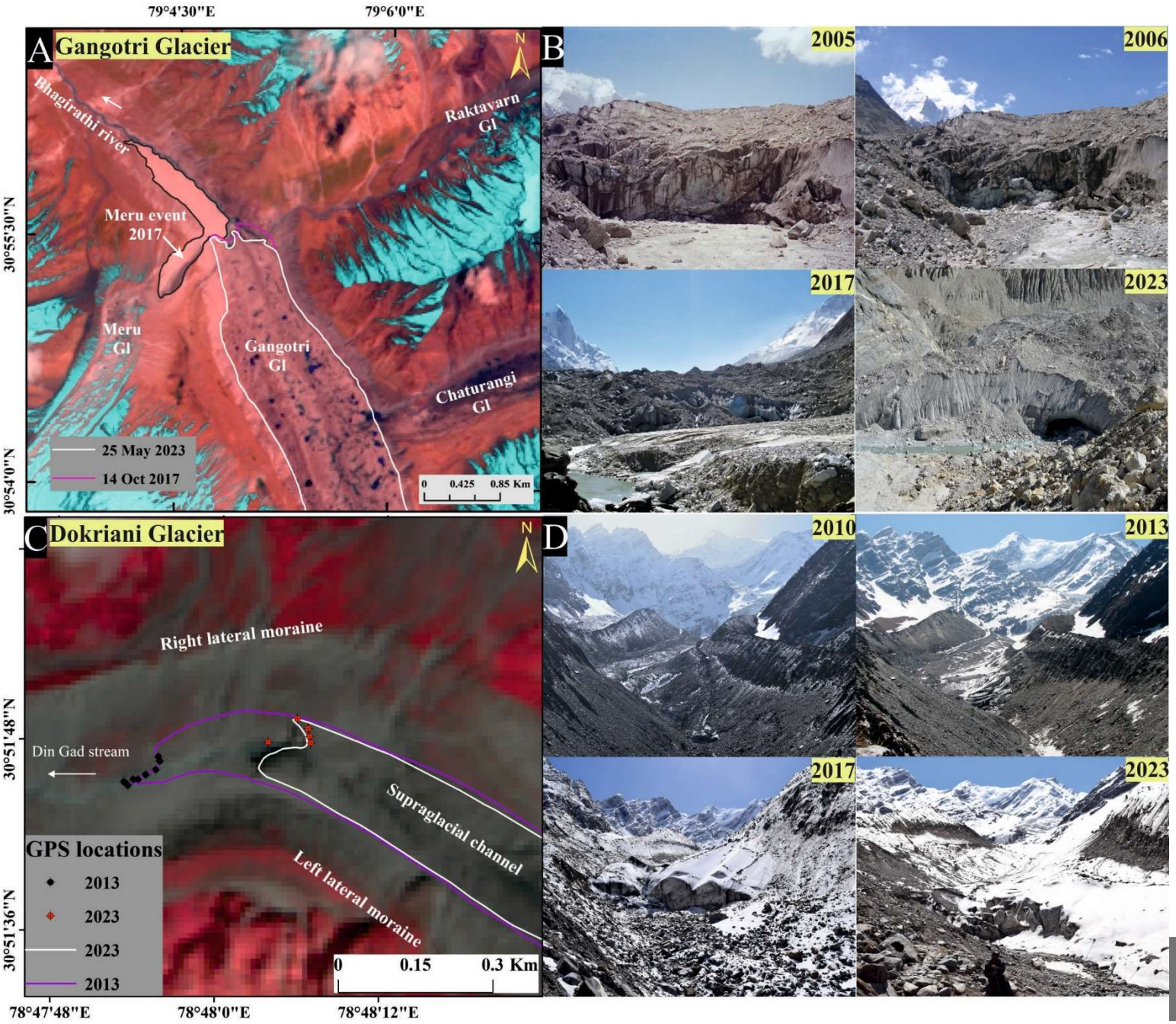




• **Isotherm** is the elevation that has the same temperature

•The maximum 0°C & 2°C isotherms are at **5122 m** & **5425** m asl respectively in the month of July.

**Misra et al., (2020) Journal of Hydrology**

# Recession and morphological changes

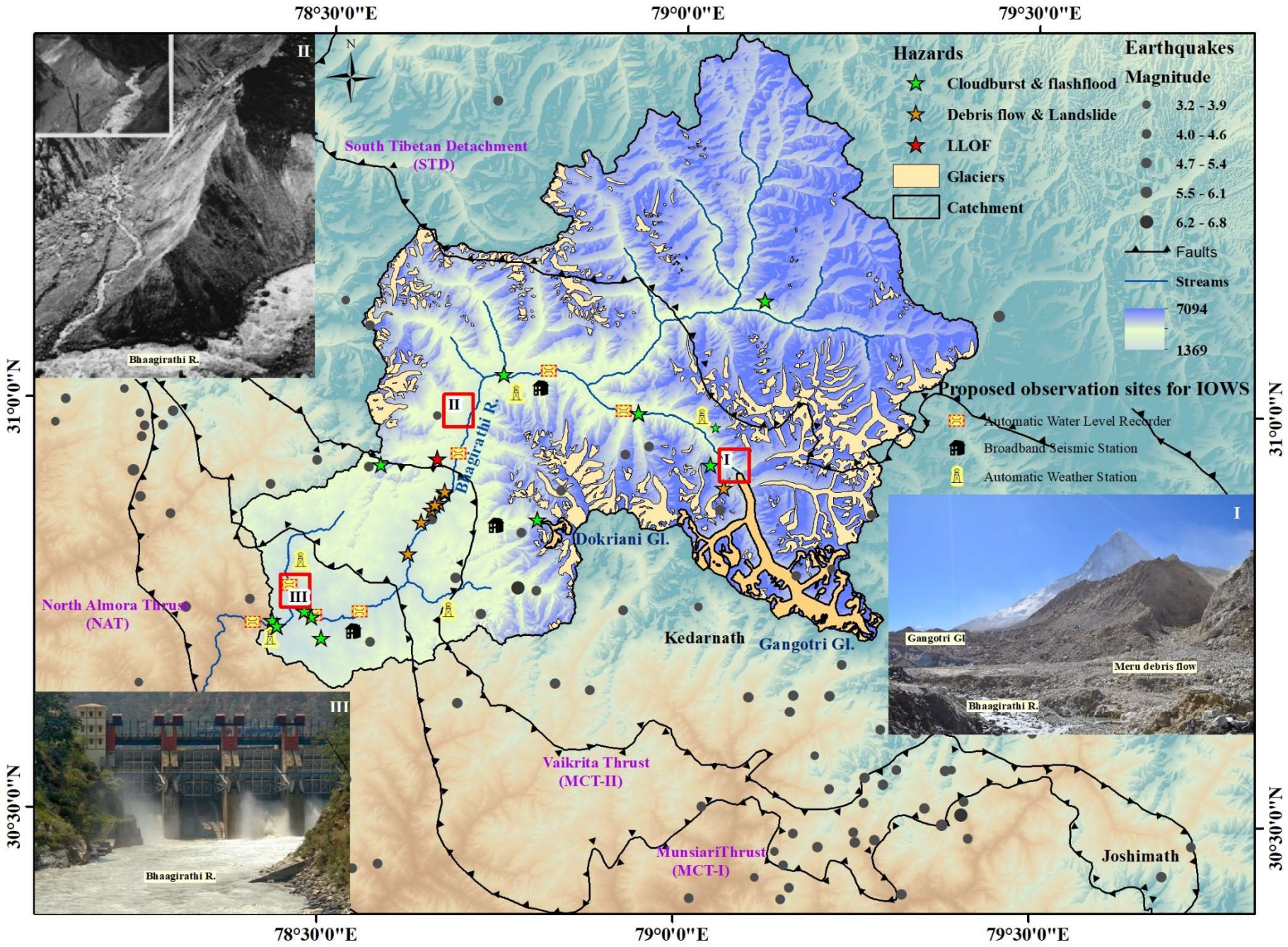



- **Gangotri Glacier** retreated at a rate of **21.1 m/yr** during 2017-2023

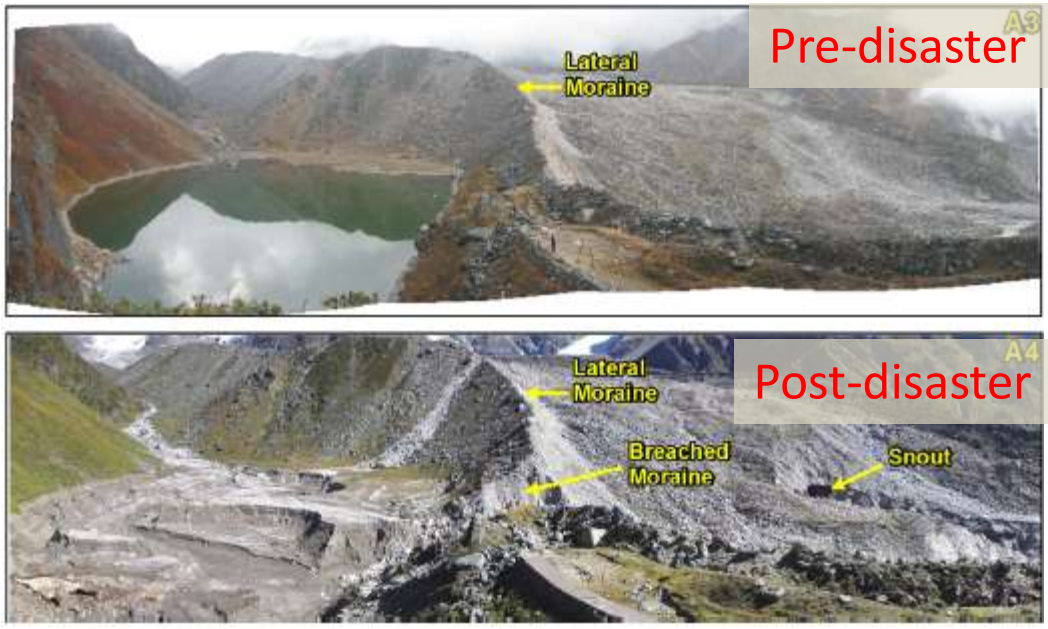
- **Dokriani Glacier** retreated at a rate of **38.7 m/yr** during 2013-2023.

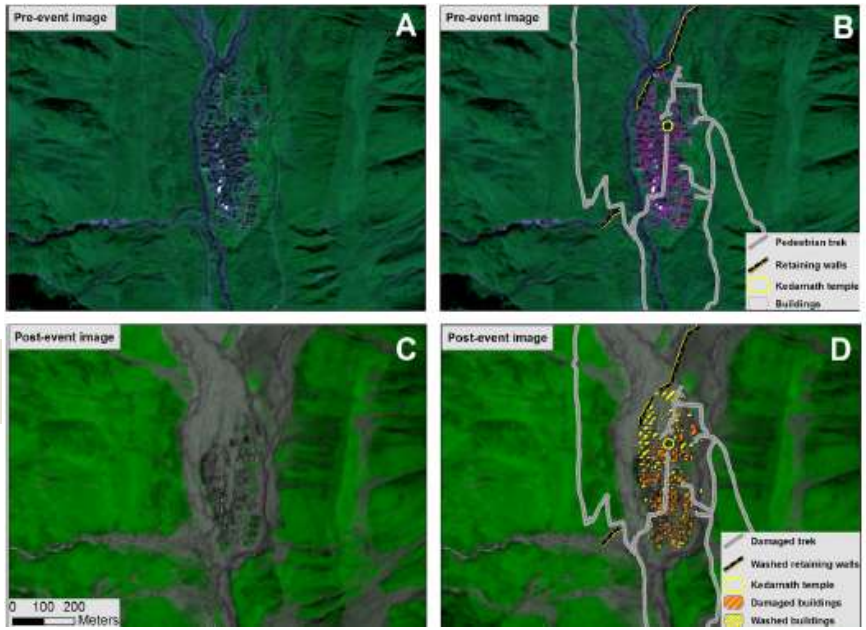
**Kumar et. al. 2024 (SETA)**

# Major hazards in Upper Ganga Basin



# Assessment of Devastation (GLOF) in Kedarnath Valley




**Pre-&-Post disaster scenario in Chorabari Lake**

**Devastation assessment in Kedarnath**



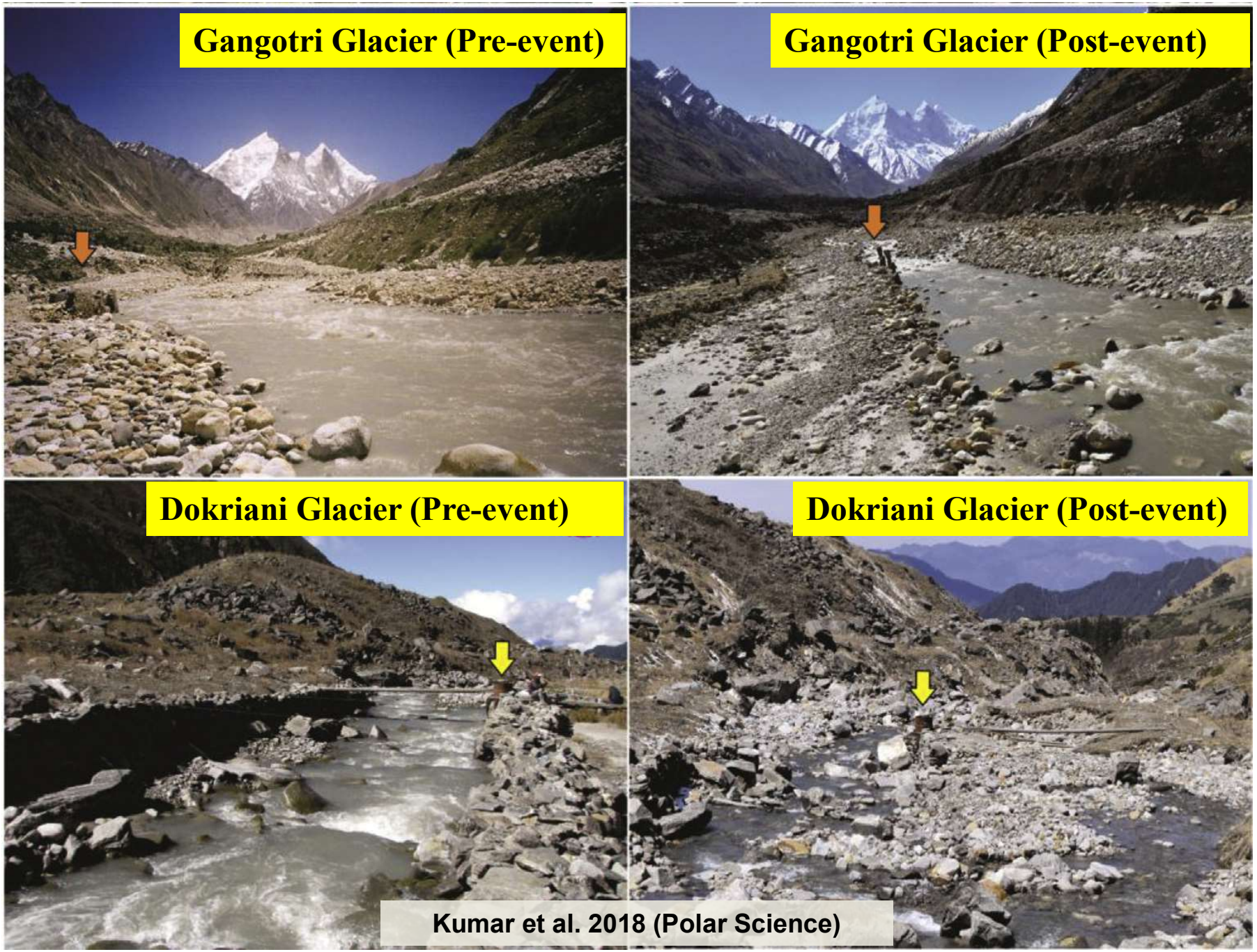




**Landscape changes at Gaurikund (left panel) and Rambara (right panel)**

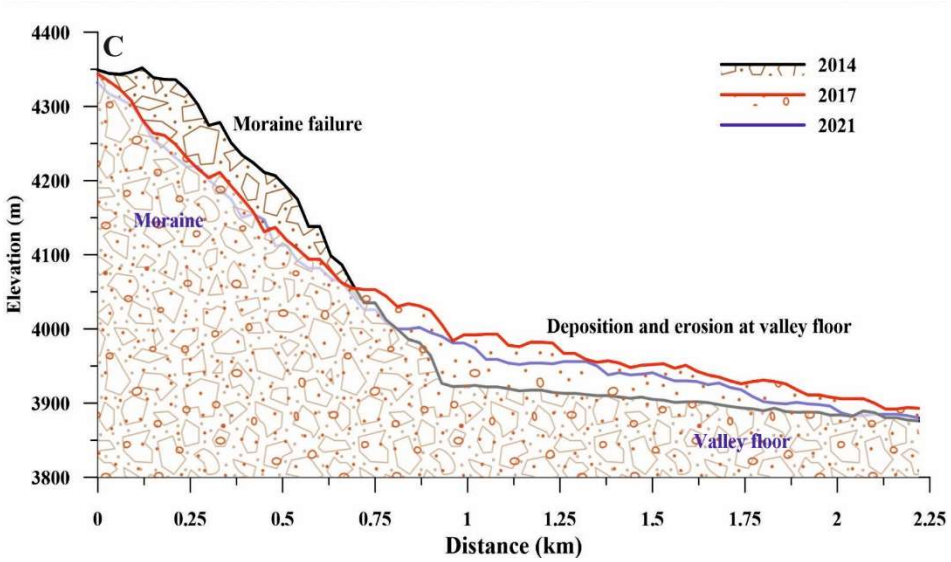
**Bhambri et al., (2016) Natural Hazards**

# Extreme Flood Events near the Glacier Terminus



# Post disaster recovery near the Glacier Terminus

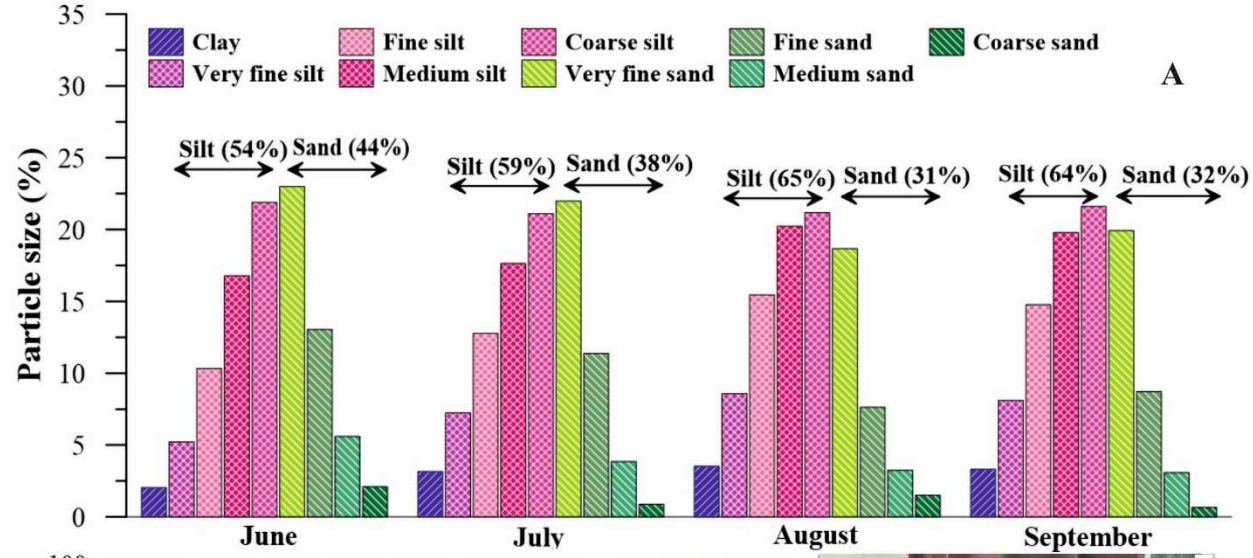


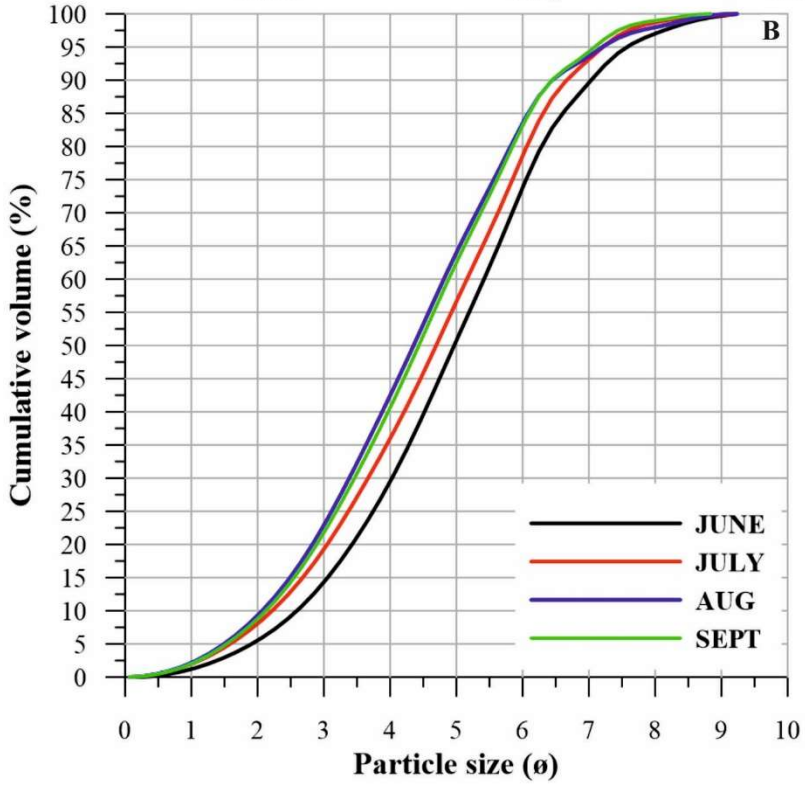




- ~6.5 million $m^3$ of sediments deposited in the pro-glacial region
- ~1.54 ± 0.2 million m3 of sediments evacuated over this period i.e. ~24% of the total deposit with a maximum surface lowering of ~35 m and average thinning of 17.5 m

**Kumar et al. 2024 (SETA)**

# Extreme Flood Events near the Glacier Terminus

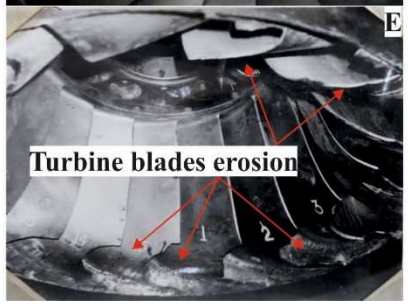









Kumar et al. 2024 (SETA)

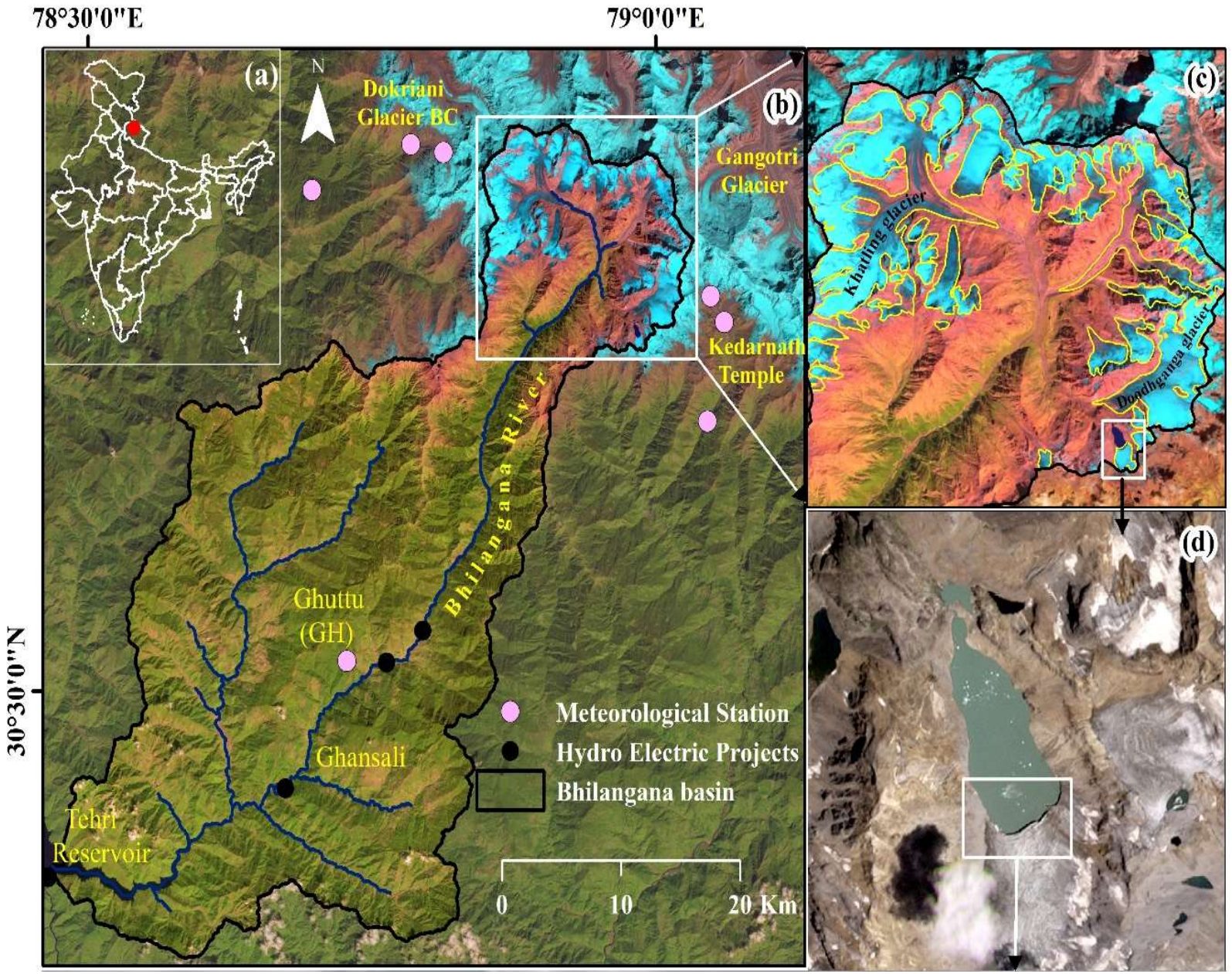
# Ice-rock avalanche in Rishiganga – Dhauliganga basins



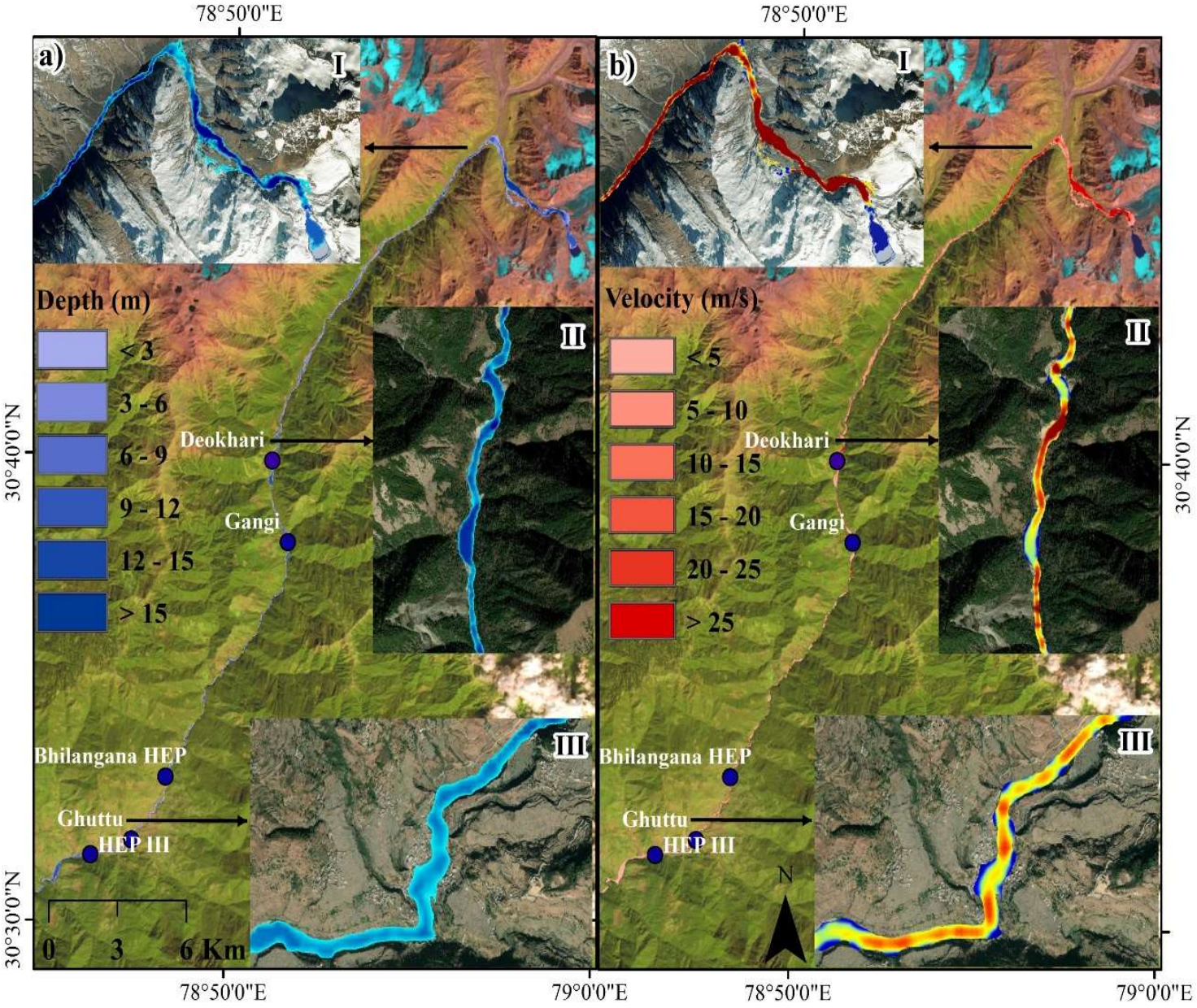

Sain et al., (2021) JGSI

- A ground-based and heliborne survey was conducted immediately after the disaster that took place on 7th February, 2021 in the Chamoli district of Uttarakhand.
- The entire event of disaster is summarized below:
- Breaking of rock mass and overlying hanging glacier from Raunthi peak (5600 m asl) to Raunthi stream (3600 m asl).
- This created slurry materials that dammed the Rishiganga River at ~2300 m asl.
- The slurry further entrained a large quantity of sediment, wood debris, ice block and water, and caused devastation to Rishiganga and Tapovan HEP along with roads and bridges in downstream.

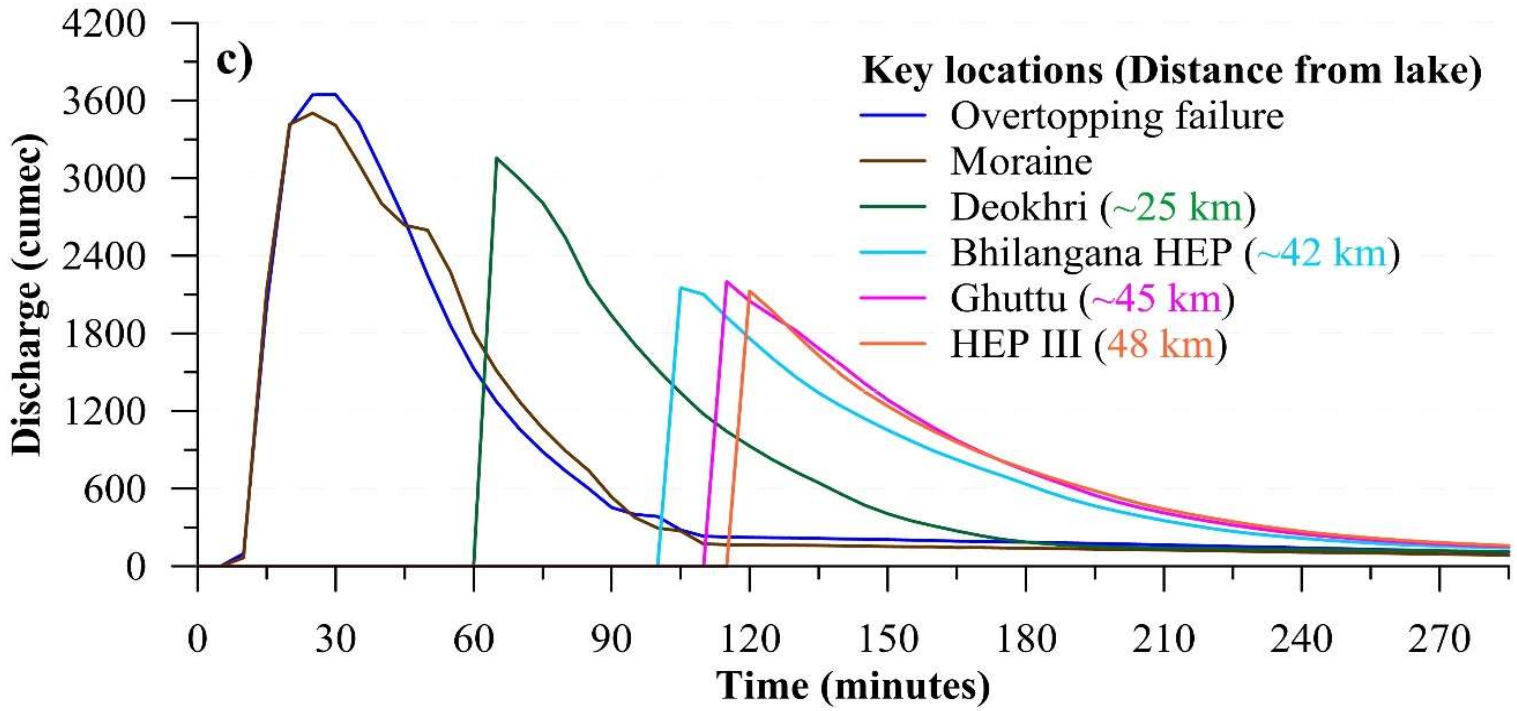
# Integrated monitoring of glaciers in Bhilangana Basin Uttarakhand



# GLOF simulation depicting water depth & velocity during flood for Bhilangana Basin



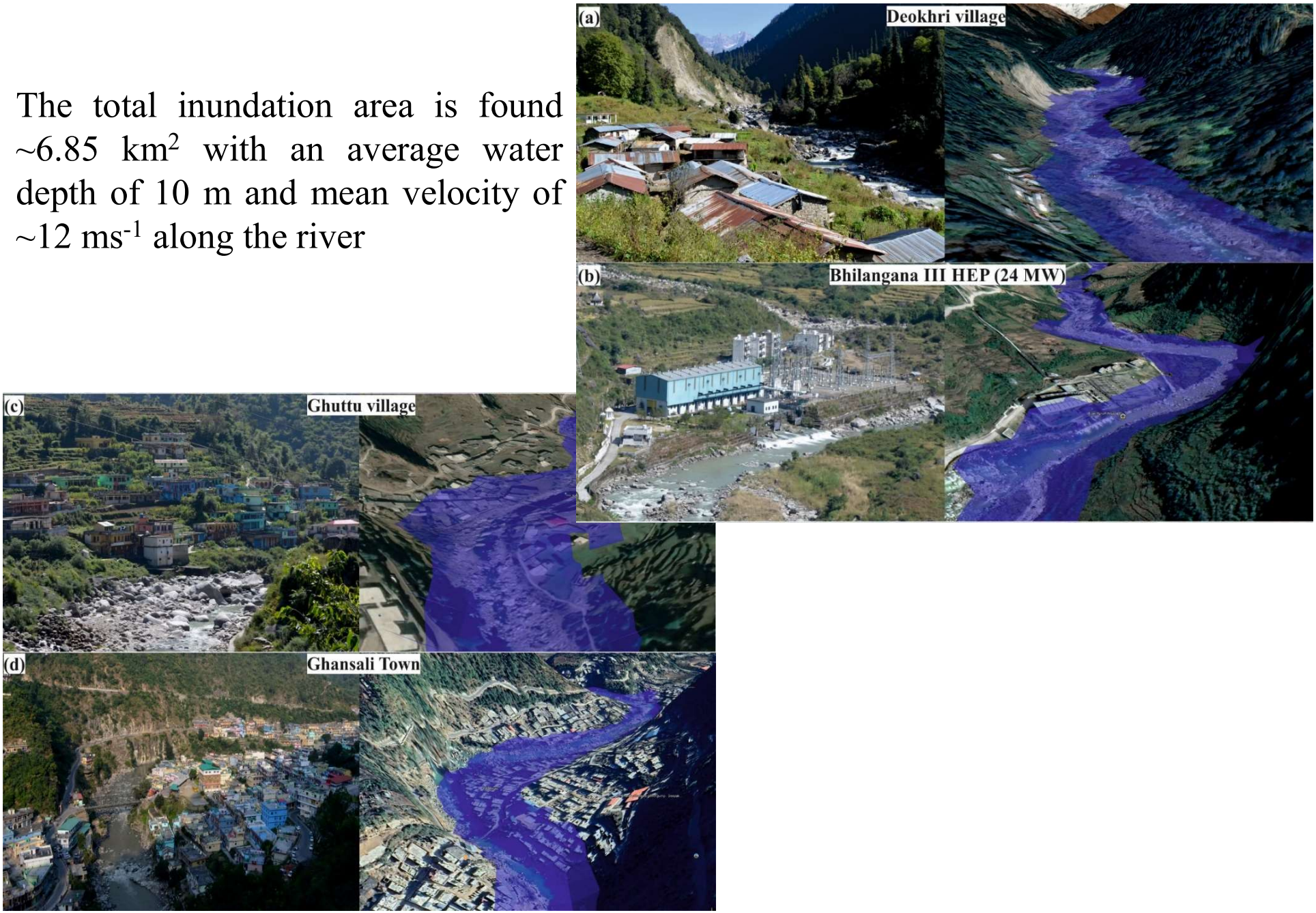
# GLOF simulation breach hydrograph for various locations



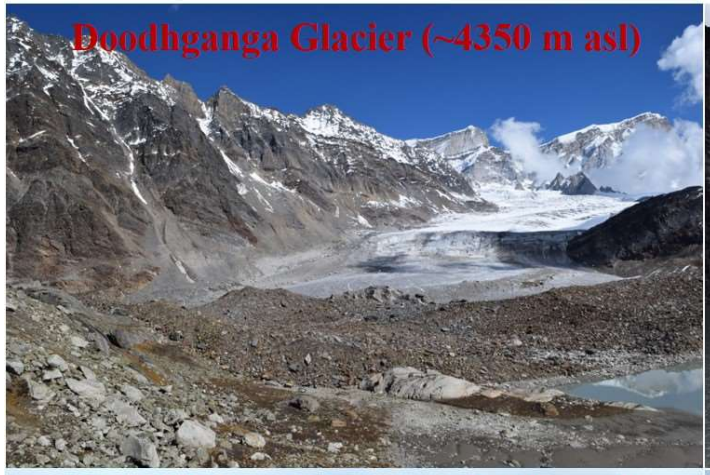

| S No | Critical location | Distance (km) | Max Depth (m) | Peak Discharge ($m^3/s$) | Arrival Time (hrs) |
|---|---|---|---|---|---|
| 1. | **Deokhri** | 24 | 11.15 | 3156 | 1.25 |
| 2. | **Bhilangana HEP** | 42 | 8.42 | 2153 | 2.01 |
| 3. | **Ghuttu** | 45 | 7.25 | 2204 | 2.08 |
| 4. | **HEP III** | 48 | 8 | 2126 | 2.25 |
| 5. | **HEP Reservoir** | 59 | 6.67 | | 3.42 |
| 6. | **Ghansali** | 65 | 9.35 | | 4.76 |

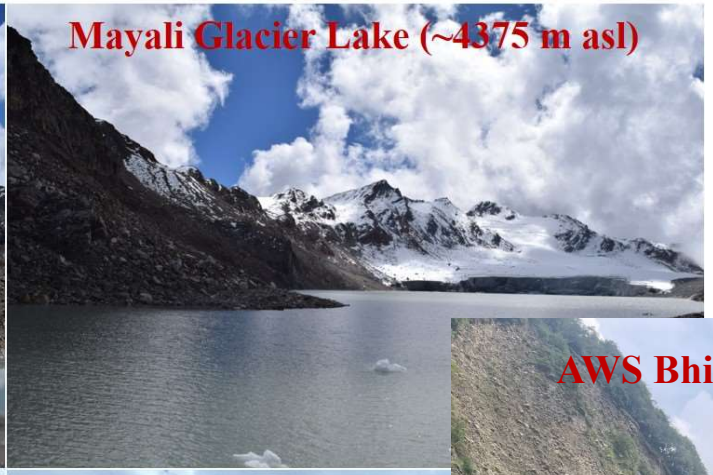
# Field photographs and inundation area over Google Earth Images

The total inundation area is found ~6.85 $km^2$ with an average water depth of 10 m and mean velocity of ~12 $ms^{-1}$ along the river



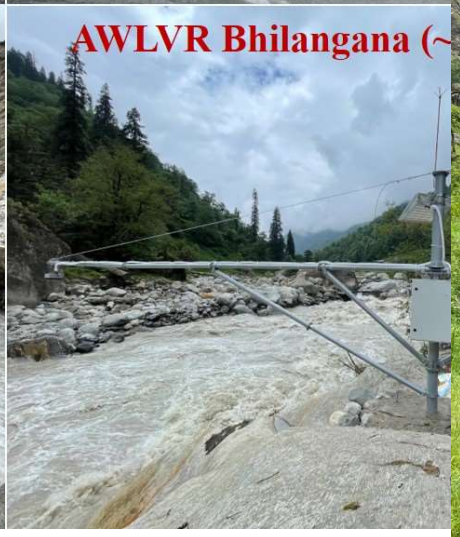
# Field Pictures & Observatories












# Integrated Multi-Hazard Early Warning System (MHEWS) for Glacierized River Basins in the Indian Himalaya

## 1. OBSERVATION NETWORKS



**Automatic Weather Stations (AWS)**
- Temperature, rainfall,
- snow, wind, humidity,
- solar radiation



**Hydrological Monitoring**
- River discharge, water level, sediment concentration



**Glacier & Lake Monitoring**
- Glacier mass balance, lake level, bathymetry, expansion



**Geohazard Monitoring**
- Seismometers, ground motion, slope movement sensors

## 2. REMOTE SENSING DATA



**Optical Satellite Data (Landsat, Sentinel-2)**
- Glacier mapping,
- lake inventory,
- land use/land cover



**SAR Data (Sentinel-1, ALOS-PALSAR)**
- Surface deformation, landslides, flood extent



**High-Resolution DEMs (ICESat-2, TanDEM-X, CartoDEM)**
- Terrain analysis, slope, drainage



**UAV & Aerial Surveys**
- High-resolution mapping of glaciers, lakes, sediment & damage

## 3. DATA TRANSMISSION & INTEGRATION



Telecommunication (GPRS/4G/5G/Satellite)



**Central Data Platform (Cloud-Based)**

Data Quality Control • Standardization
Archiving • Interoperability

## 4. MODELLING & FORECASTING



**Weather Forecasting (NWP Models)**
- Rainfall, temperature,
- snowfall forecasts



**Hydrological Modelling**
- Runoff, flood forecasting,
- water level prediction



**GLOF Modelling**
- Lake breach, peak discharge,
- inundation mapping



**Debris Flow & Landslide Modelling**
- Susceptibility, runout,
- impact assessment



**Rock–Ice Avalanche Modelling**
- Runout & flood generation

## 5. DECISION SUPPORT SYSTEM (DSS)



**Real-Time Dashboard**
- Visualization of observations, forecasts & alerts



**Risk Assessment**
- Hazard maps, exposure & vulnerability analysis



**Alert Generation**
- Threshold-based alerts for multiple hazards



**Scenario Analysis**
- What-if scenarios for planning & preparedness

## 6. WARNING DISSEMINATION



Siren / Alarm Systems | SMS / Cell Broadcast | Mobile Apps & Web Portals | E-mail Alerts | FM Radio / Community Radio | Social Media & Others

## 7. END USERS



Government Agencies & Disaster Management Authorities



Local Administration & Field Officers



Communities & Local People



Infrastructure Operators & Hydropower Projects

## 8. FEEDBACK & SYSTEM IMPROVEMENT (CONTINUOUS LOOP)



Post-Event Evaluation → Data Validation & Updating → Model Calibration & Improvement → Capacity Building & Training → Awareness & Community Engagement → Stronger Resilience & Risk Reduction

- Data Flow
- Information Flow
- Model/Forecast Flow
- Alert/Warning Flow
- Feedback Loop



MHEWS integrates multi-source observations, advanced modelling and decision support tools to provide timely, accurate and location-specific early warnings for multiple cryosphere-related hazards in the Indian Himalaya.

# Adaptation strategies for the Cryosphere

## Monitoring and Data Collection:

- Integrated long-term monitoring of glaciers and glacial lakes (cryosphere) including snow and glacier dynamics, hydrometeorology, permafrost, glacier hazards, aerosols, GHG's, etc. to fill the data gaps and improve models and future projections

## Climate Impact Assessment:

- Projection of future snow and glacier melt scenarios (water availability) based on high-resolution dynamically downscaled climate projections from regional climate models for Himalaya

## Water Resource Management:

- Developing integrated water management strategies to cope with changing water availability including both short-term strategies (e.g., optimizing current water usage, spring rejuvenation, rainwater harvesting) and long-term solutions (e.g., creating new water storage infrastructure or alternative water sources).
- Augmentation of water storage capacity in the IHR

## Disaster Risk Reduction:

- Identification of vulnerable glacial lakes and their real-time monitoring
- Strategies to neutralize the threat of GLOF by proactive measures like controlled breach or siphoning
- Development of a multi-hazard early warning system
- Standard operating procedures (SOP's) and evacuation plans for glacier-related hazards
- Resilient infrastructure to extremes and hazards like embankments, check dams, etc. to control the erosion, further destabilization of slopes in the region

## Ecosystem Protection and Restoration

- Promoting the protection and restoration of ecosystems that depend on glacier-fed rivers and streams
- Enhancing protected areas like Gangotri National Park, Nandadevi Biosphere Reserve, etc.

## Community Engagement and Capacity Building

- Awareness and capacity building for different stakeholders including local communities, government officials, hydropower officials, local NGOs, schools, etc. about conservation and optimum utilization of water resources
- Promoting sustainable livelihood alternatives to reduce pressure on fragile ecosystems and creating disaster preparedness programs


THANK YOU