



CLIMATE-RESILIENT DAMS AND  
**HYDROPOWER INFRASTRUCTURE**  
INTEGRATING  
**ENVIRONMENTAL SUSTAINABILITY**  
IN PLANNING AND DEVELOPMENT

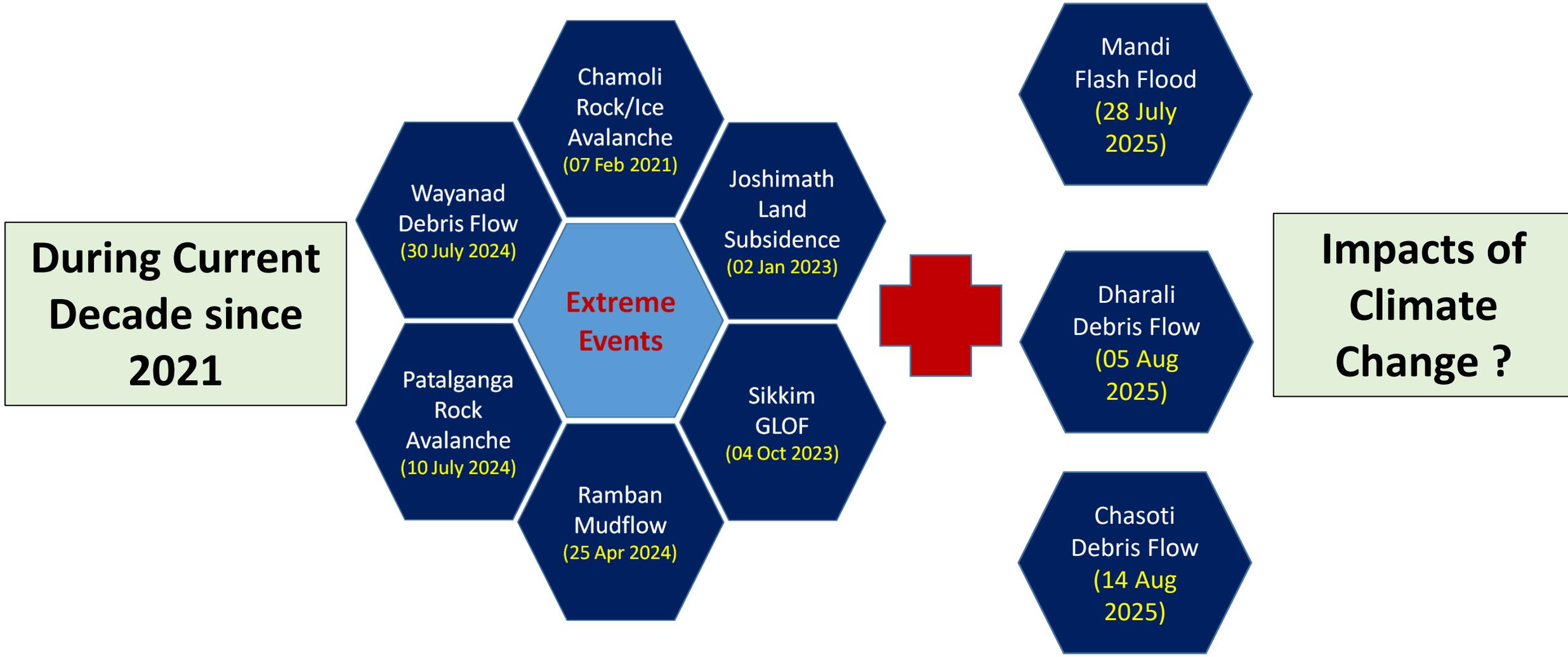


Climate Change Impacts on the Himalayan  
Cryosphere – A Special Focus on  
Avalanches, GLOFs and Debris Flows



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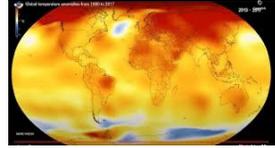




# MOTIVATION

Events that demands the adaptation of robust strategy and to explore new dimension of research





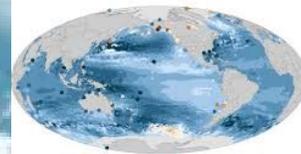
Rising Global Temperatures



Melting Glaciers & Ice Sheets



SEA LEVEL CHANGE (1993-2023)

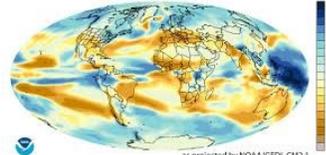


Change in sea level (cm)



NOAA Climate.gov  
Satellite altimetry

CHANGE IN PRECIPITATION BY END OF 21st CENTURY  
inches of liquid water per year



as projected by NOAA/GFDL, CM2.1

Rising Sea Levels

Changing Precipitation Pattern

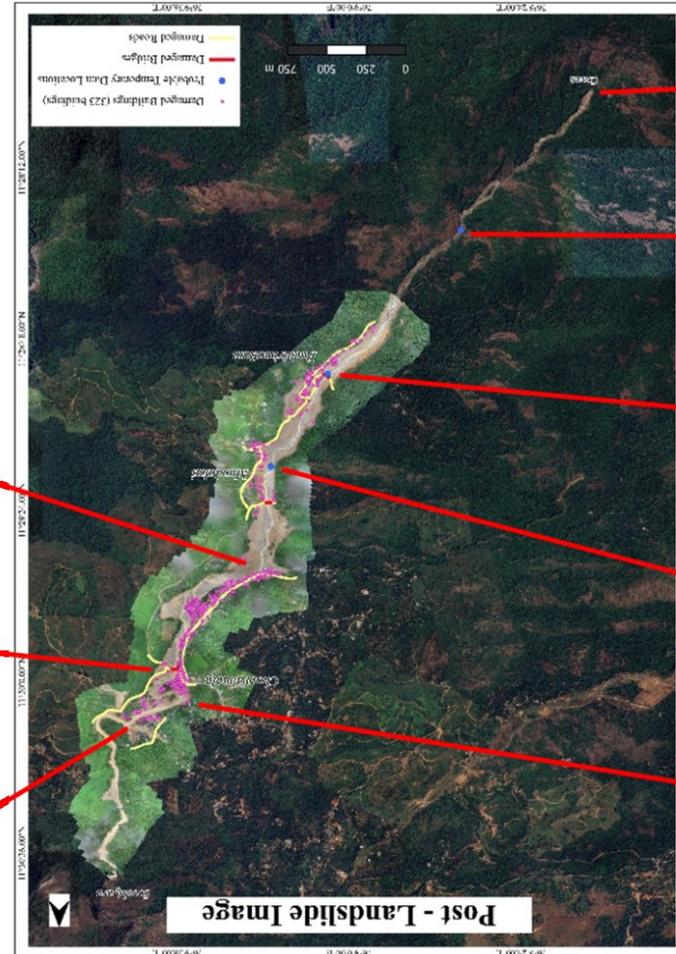


Intense Extreme Weather Events

# WAYANAD DEBRIS FLOW (2024)



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**Landslide in the release area at ~11:45PM on 29 July 2024 to 00:15AM on 30 July 2024**

**Landslide Dam 1 at ~00:30AM on 30 July 2024**

**Landslide Dam 2 at ~01:30AM on 30 July 2024**

**Landslide Dam 3 at ~03:30AM on 30 July 2024**

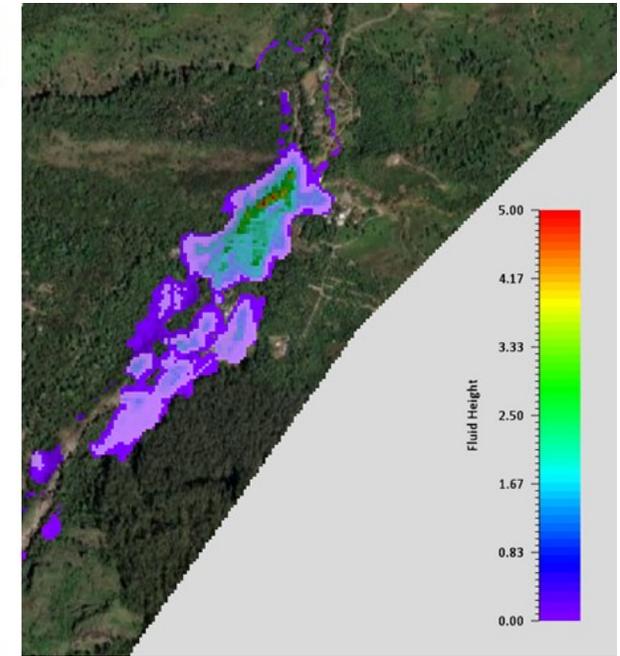
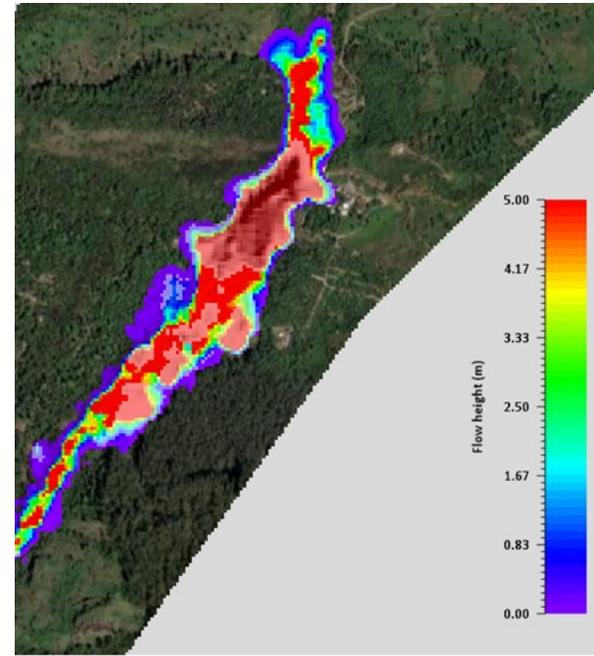
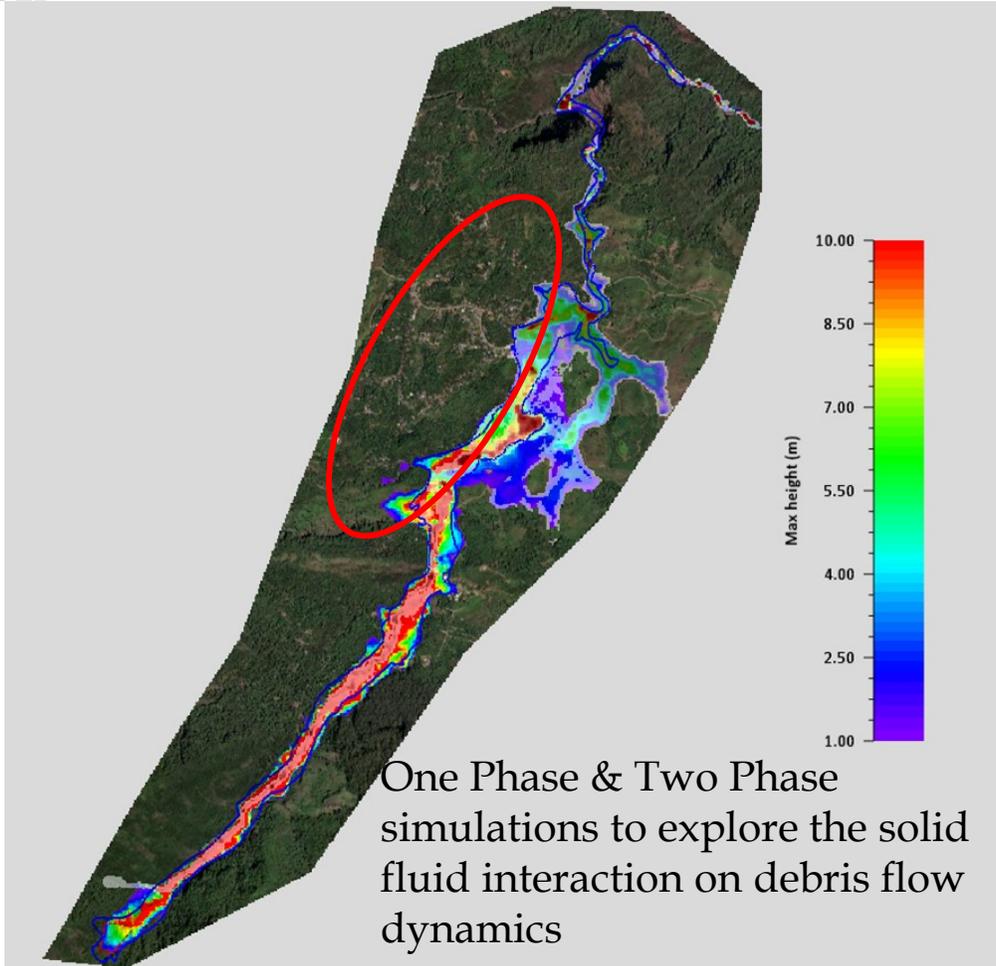
**Energy got dissipated at Chooralmala due to flatter topography & wide open are**

**90° turn of the channel affecting right bank (Erosion & Deposition)**

**Blockage of Chooralmala Bridge with tree logs & big boulders**

**Beyond this point only flood without Deposition with minor erosion of banks**





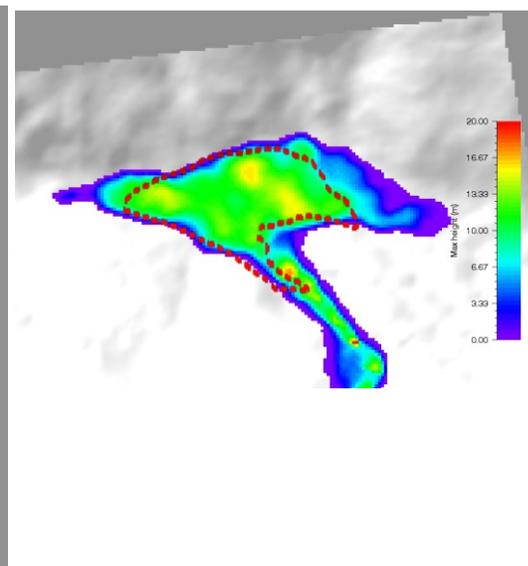
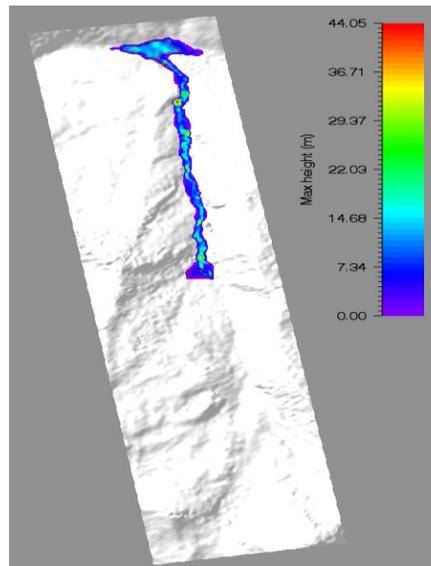
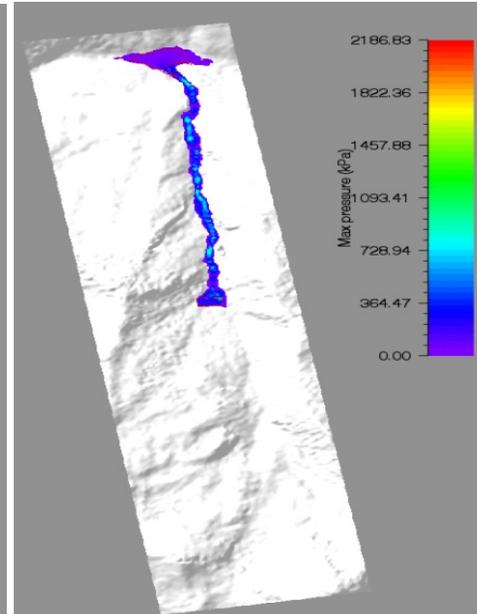
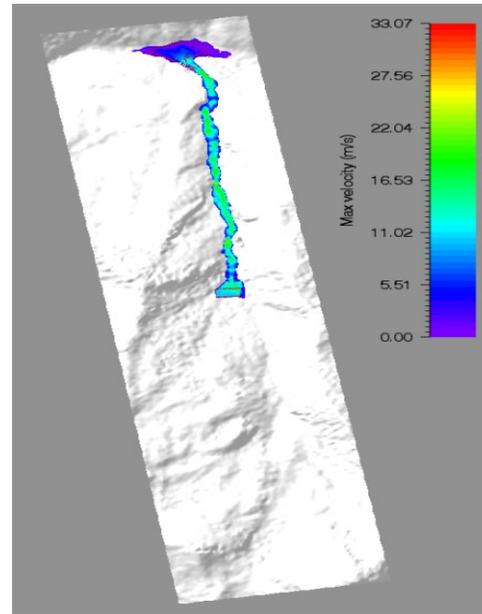
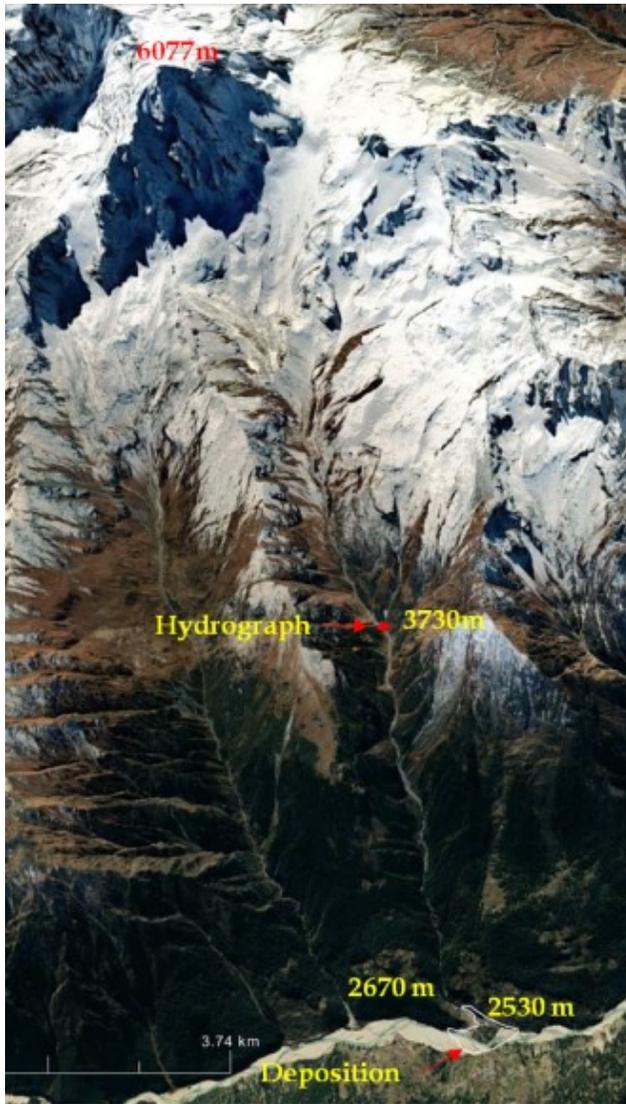
- ✓ Debris Flow Susceptibility-Hazard-Vulnerability- Risk Zonation in the potential regions
- ✓ Identification & Assessment of Future Possible Release Areas for Debris Flow
- ✓ Scenario-based Debris Flow Run-out Simulation and Hazard-Risk Assessment
- ✓ Relocation & Reconstruction for Resilient Township
- ✓ Community-centric Awareness & Capacity Building

**Simulation based Event Reconstruction for understanding debris flow Dynamics & Mechanism**

# DHARALI DEBRIS FLOW (2025)



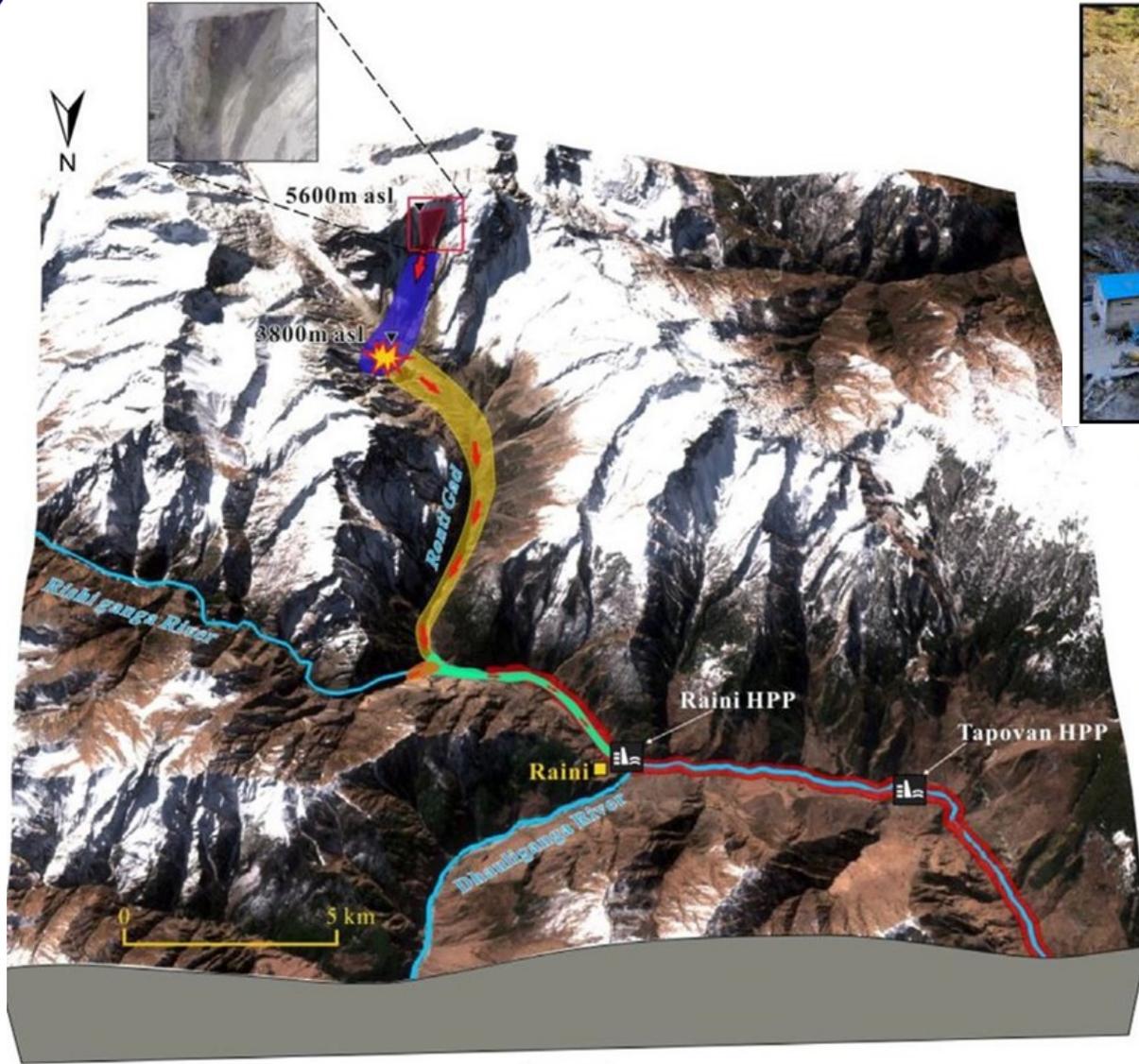
**Dharali debris flow can be termed as rainfall-cum-snowmelt water induced debris flow**



## CAUSES FOR DHARALI DEBRIS FLOW

- Localized, high-intensity rainfall as the primary trigger
- Snowmelt and saturation of moraine deposits
- Abundant unconsolidated sediments in steep, confined catchments
- Surge sequencing due to valley morphology
- Geological control of weak rock formations
- Regional hydro-meteorological forcing

# CHAMOLI ROCK ICE AVALANCHE (2021)



Legend



## Works of CSIR-CBRI



 Schweizerische Eidgenossenschaft  
Confédération suisse  
Confederazione Svizzera  
Confederaziun svizra

Swiss Agency for Development  
and Cooperation SDC

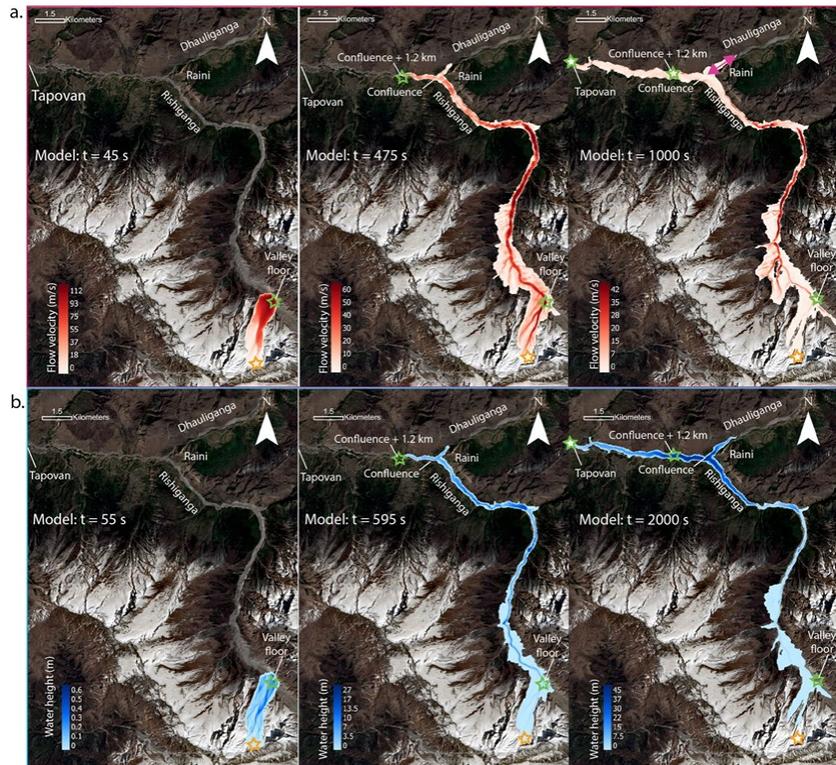


## Causes

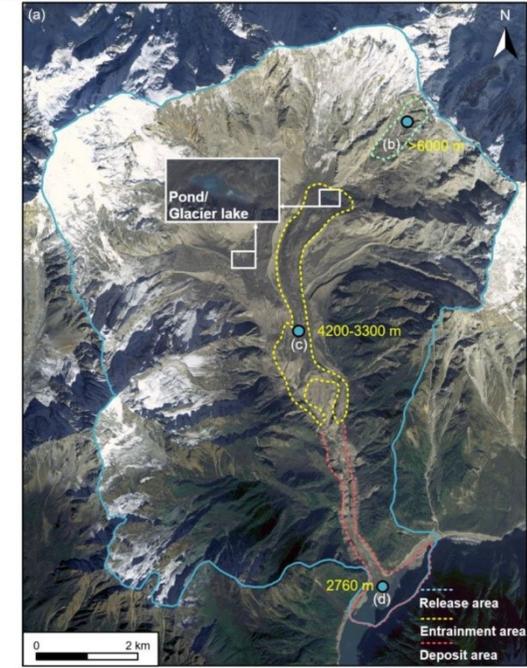
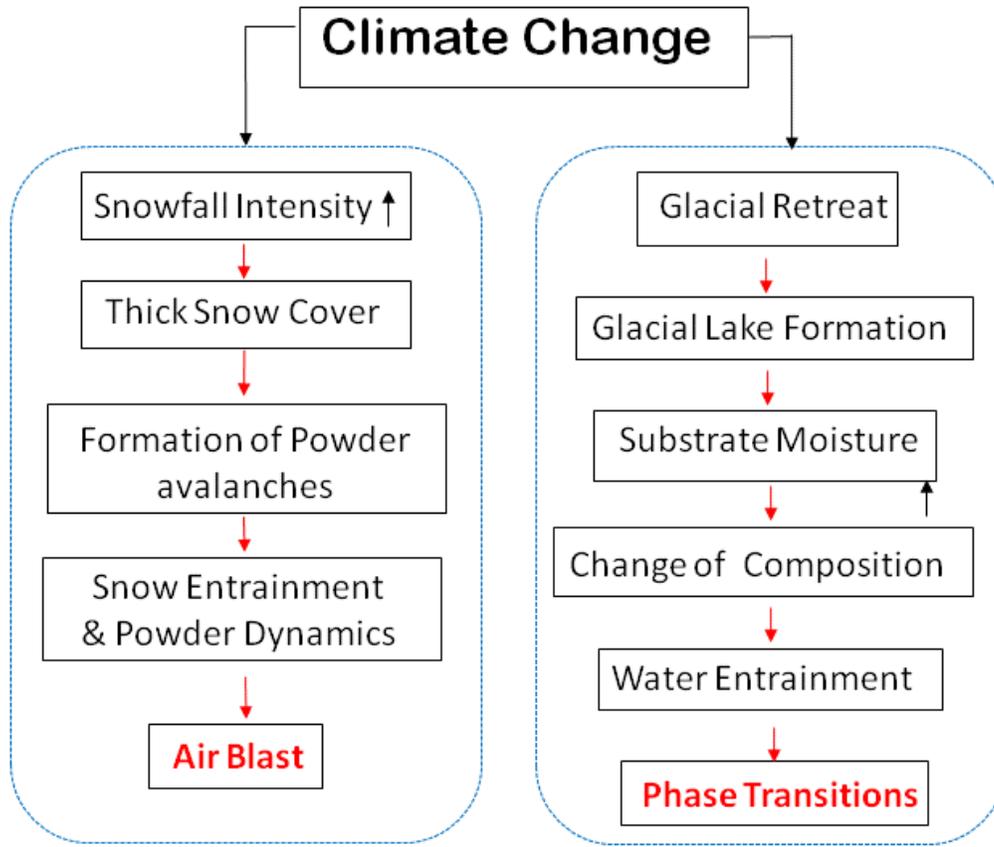
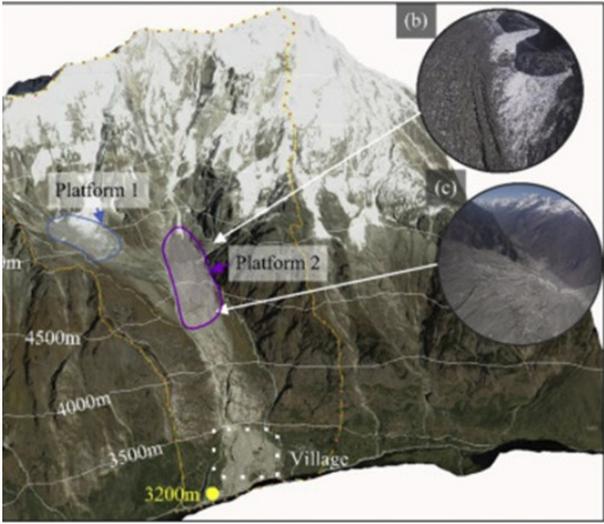
- ❑ Release : ~ 27 million M3
- Composition : 80 % Rock & 20 % Ice
- ❑ Detached from the Rontigad peak
- ❑ Initiated as a rock ice avalanche, which later transitioned into a debris flow and a flash flood.
- ❑ Huge entrainment
- ❑ Water saturation exacerbated this event during flow
- ❑ River Played the role of major driver

## Lessons Learnt

- ✓ Rock Ice Avalanche can occur at any season irrespective of winter (snowfall) / Summer (glacial Retreat) even without an Earthquake
- ✓ Hazard-Vulnerability-Risk mapping of high-altitude regions susceptible to avalanches/other mass movement processes
- ✓ Large Scale Hazard Indication Mapping should be carried out



# CLIMATE CHANGE IMPACT ON MOUNTAIN HAZARDS



Langtang Rock Ice Avalanche, Nepal (25 Apr 2015)

Release Volume : ~3.5 million M<sup>3</sup>

**Air blast** generated by the avalanche destroyed large parts of the village and caused over **350 deaths**

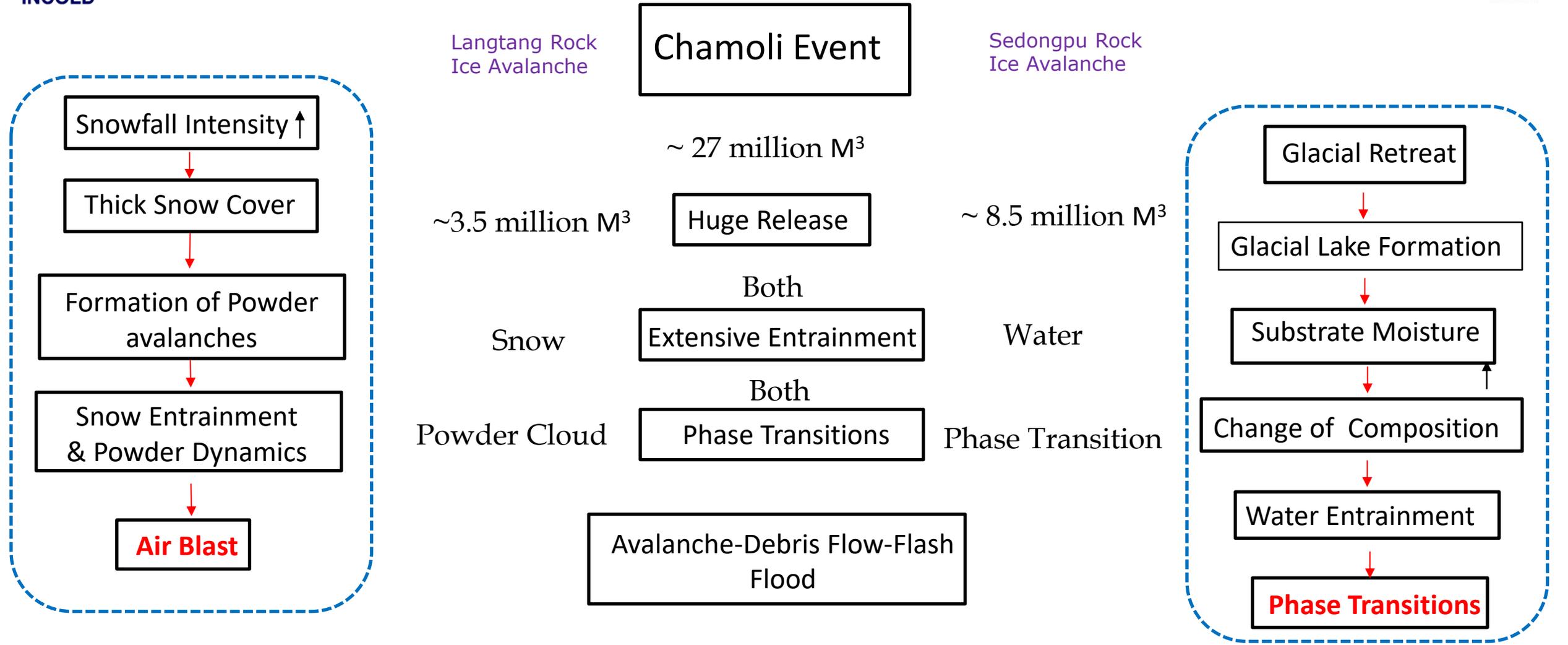
Sedongpu Rock Ice Avalanche, Tibet (17 Oct 2018)

Release Volume : 8.5 million M<sup>3</sup>

Run out : Approx. 10km

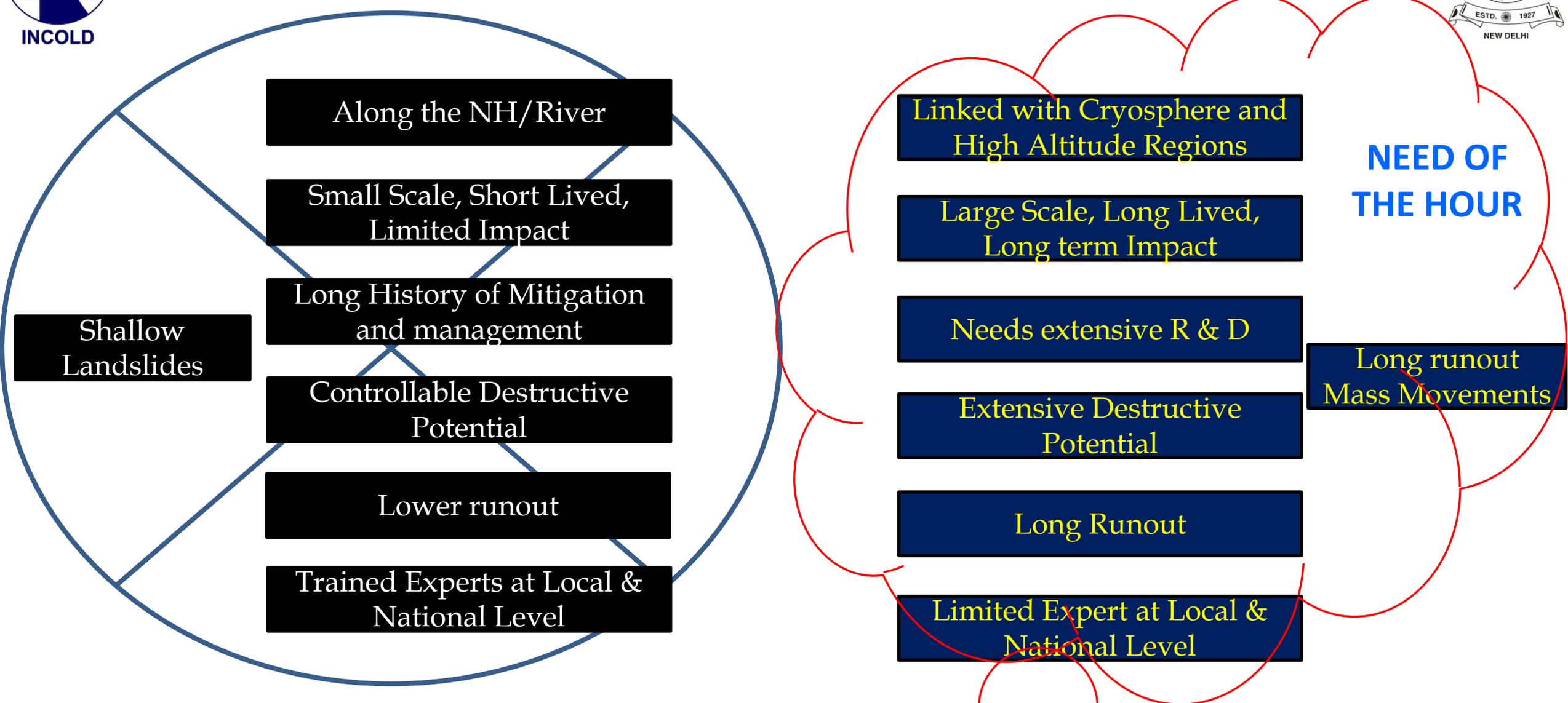
People Affected : > 16,000

# DIVERSE NATURE OF HIMALAYAN MASS MOVEMENT PROCESSES



To quantify & forecast, monitor & measure and mitigate & prepare towards extreme weather mass movement processes of Himalayan hazards

- ❑ **Large-scale hazard indication mapping** along the major river valleys (Ganga, Indus & Brahmaputra)
- ❑ **Vulnerability & Risk assessment** of the river valley projects, population & other infrastructures and facilities
- ❑ **Evaluation of the large scale mass movement processes, entrainment, & phase transitions** along the flow path and their effect on runout
- ❑ Real time and periodic **monitoring and mitigation strategy**



Vertical - I

Vertical - II

Vertical - III

Vertical - IV

Mapping & Modelling

Vulnerability & Risk Assessment

Ground & Space based Monitoring & Early Warning

Knowledge Dissemination & Capacity Building

<b>Phase I:</b>	<b>Identification of Potential Release Zones</b>	<b>Delineation and Demarcation of Risk Elements</b>	<b>Long term ground based real time monitoring (WSN-IoT) and development of early warning systems</b>	<b>Community centric awareness</b>
<b>Phase II:</b>	<b>Integrated field-remote sensing-modelling based study on effects of large scale mass movement processes, entrainment &amp; phase-transitions</b>	<b>Vulnerability and Risk Assessment</b>	<b>Long term space based periodic monitoring (SAR Interferometry) and development of early warning systems</b>	<b>Community and local body participation</b>
<b>Phase III:</b>	<b>Scenario-based Hazard Assessment</b>	<b>Mitigation and Management Strategy</b>	<b>Installation of Strong Motion Accelerometer (SMA) along the MBT &amp; MCT</b>	<b>Capacity building at local and State levels</b>

## Debris Flow Hazard Indication Mapping

- Identification of Potential Debris Flow Channel with Habitation
- Identification, Mapping & Characterisation of Debris at Channel Source & Flow Path

## Defining Rainfall Threshold for Debris Mobilisation and Correlating with IMD Rainfall Forecast for Early Warning (Temporal)

- Optimum Water bearing capacity of debris (Experimentation)
- Optimum external water needed for attaining Optimum Water bearing capacity and debris mobilisation (Experimentation)
- Converting External Water Requirement in terms of Rainfall (Threshold)
- Correlating Rainfall Threshold with IMD Forecast (Yellow, Orange & Red) for Early Warning (Temporal)

## Numerical Modelling based Futuristic Hazard & Risk Assessment for Early Warning (Spatial)

- Debris Flow Process Initiation at Release Area
- Entrainment along Flow Path
- Phase Transition along Flow Path
- Run-out at Depositional Area

## Real Time Monitoring & Mitigation Strategy for Future Debris Flow

- Installation of AWS to correlate IMD Rainfall & Location Specific Rainfall
- Mitigation Strategy to Control/Reduce Impact of Impending Disaster

## Facility/Resource Requirement

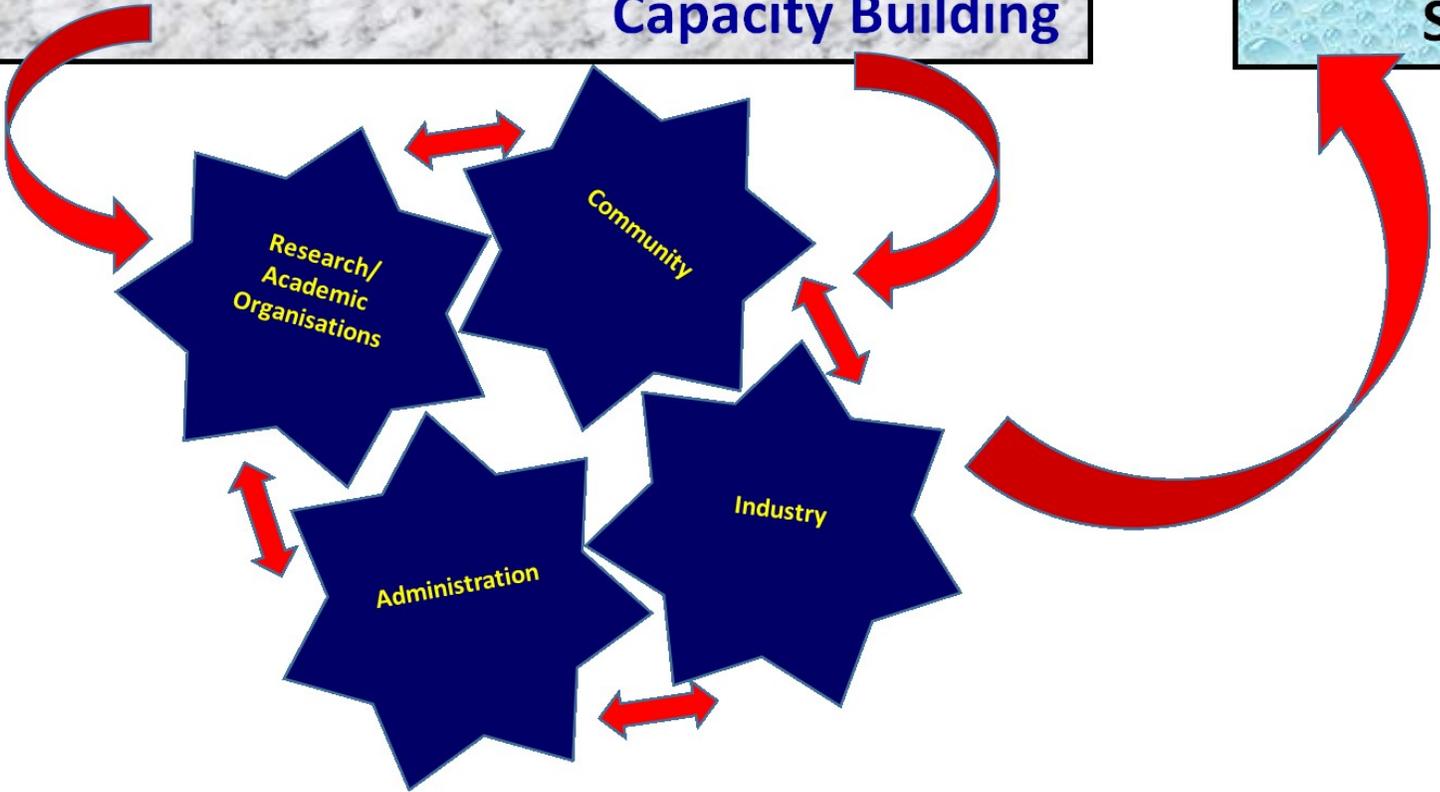
- **High Resolution Satellite Data:** Drainage Channel Mapping; Habitation Mapping; Debris source zone Mapping; Potential erosion zone mapping.
- **Digital Elevation Model:** Satellite based/ Drone based/ LIDAR based
- **Drone:** Digital Elevation Model (DEM); Debris source zone Mapping; Potential erosion zone mapping.
- **Multi-Institutional Human Resources**

**Diverse nature and destructive potential of mass movement process occurred in last few years in the Indian Subcontinent**

- ❑ **Indian Himalayan** region is affected by **Climate change** and results in large scale, long runout, destructive mass movement processes
- ❑ Intensive effort on Mapping, Monitoring, Hazard Prediction & Forecasting required
- ❑ Scenario based approach for **Hazard Assessment** and Disaster Preparedness for DRR
- ❑ Low cost, time efficient and User friendly approach including capacity building for Disaster Resilience

**Ruins to Resilience**

**Coordination**  
**Collaboration**  
**Co-Development**  
**Co-Creation**  
**Capacity Building**



**Safe & Sustainable  
Himalayan Eco-  
System**

**Safe**  
**Sustainable**  
**Resilient**  
**Aesthetics**  
**Economical**



**Thank You**