



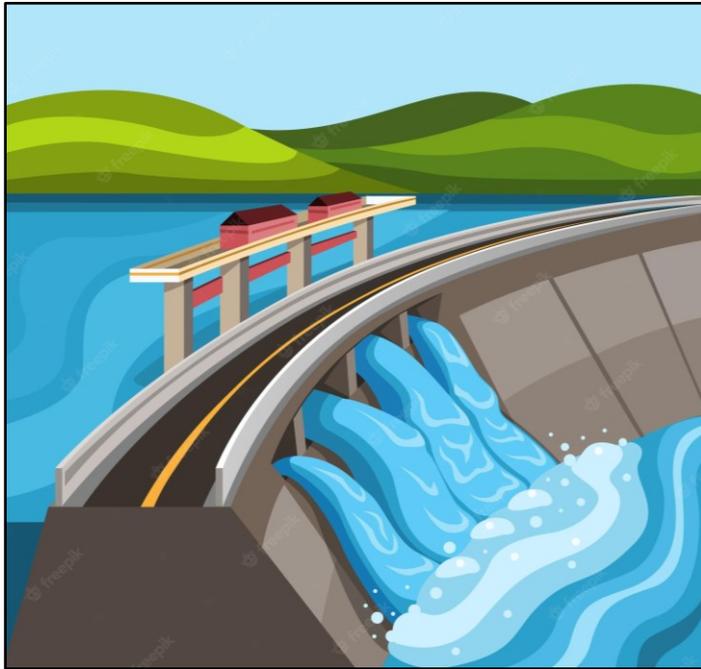
**CLIMATE-RESILIENT DAMS AND  
HYDROPOWER INFRASTRUCTURE  
INTEGRATING  
ENVIRONMENTAL SUSTAINABILITY  
IN PLANNING AND DEVELOPMENT**

**CLIMATE RESILIENT HYDROPOWER PROJECTS –  
EXPERIANCE FROM THE HIMALAYAS**

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# We will discuss.....



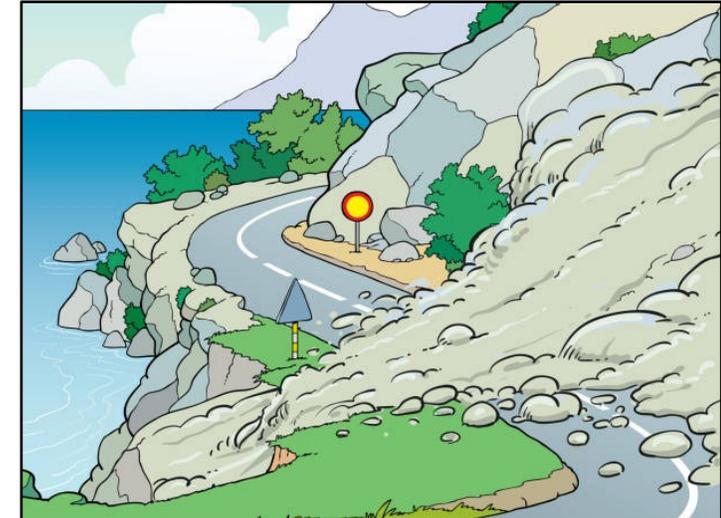
**What is Climate change**

**Its Impact on Hydro Projects**

**Adaptation Techniques**

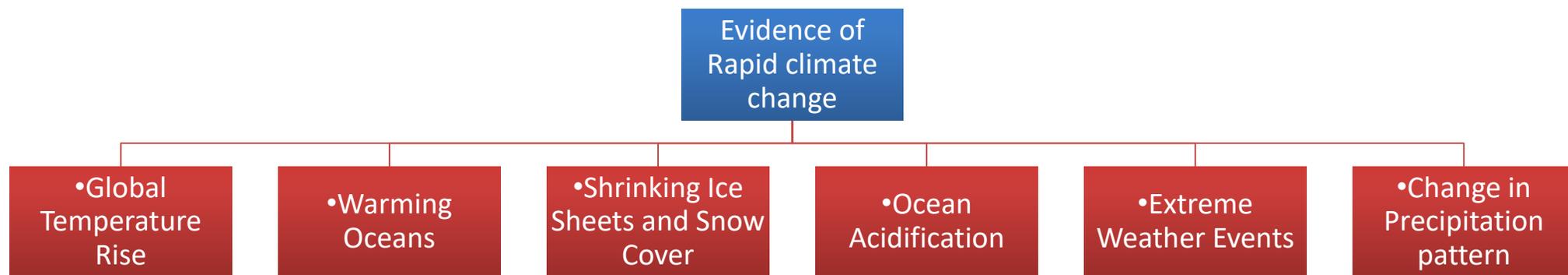
**Mitigation Techniques**

**How impacts of Climate change  
can be minimized**

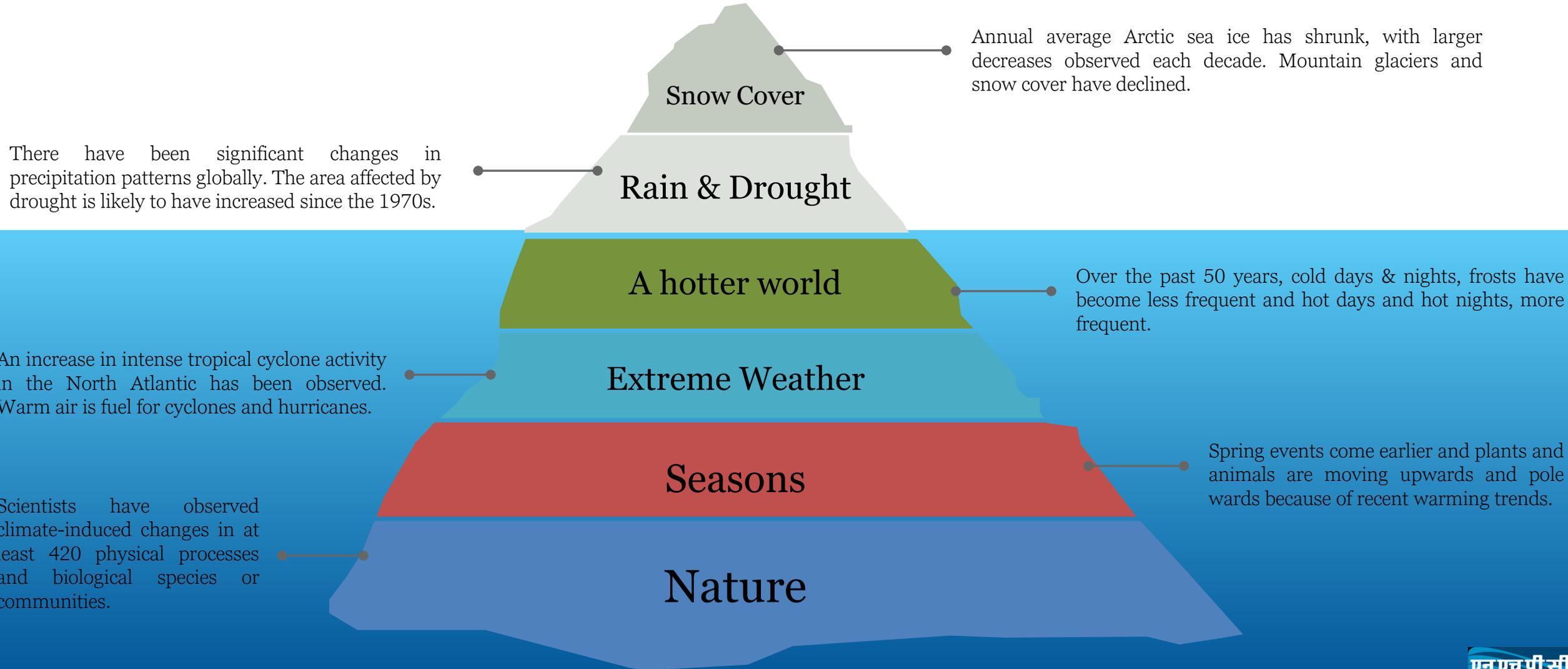


# CLIMATE CHANGE

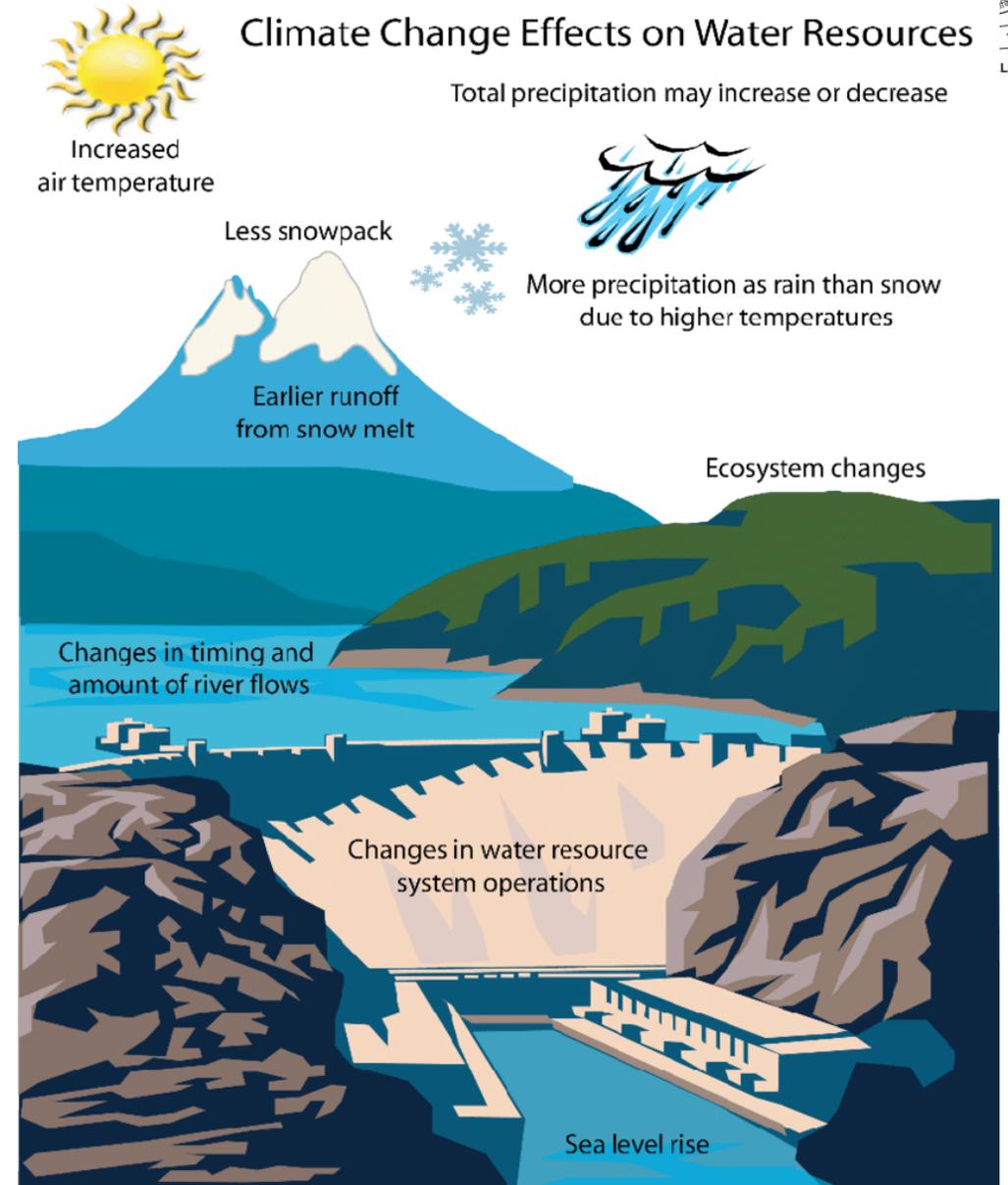
- United Nations Framework Convention on Climate Change (UNFCCC) defines “climate change” as:  
**‘a change of climate which is attributed directly or indirectly to human activities that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods’**
- As per INTERGOVERNMENTAL PANEL FOR CLIMATE CHANGE (IPCC) :  
**Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.**



# Assessment of global change in temperature by IPCC ( Intergovernmental panel on climate change)

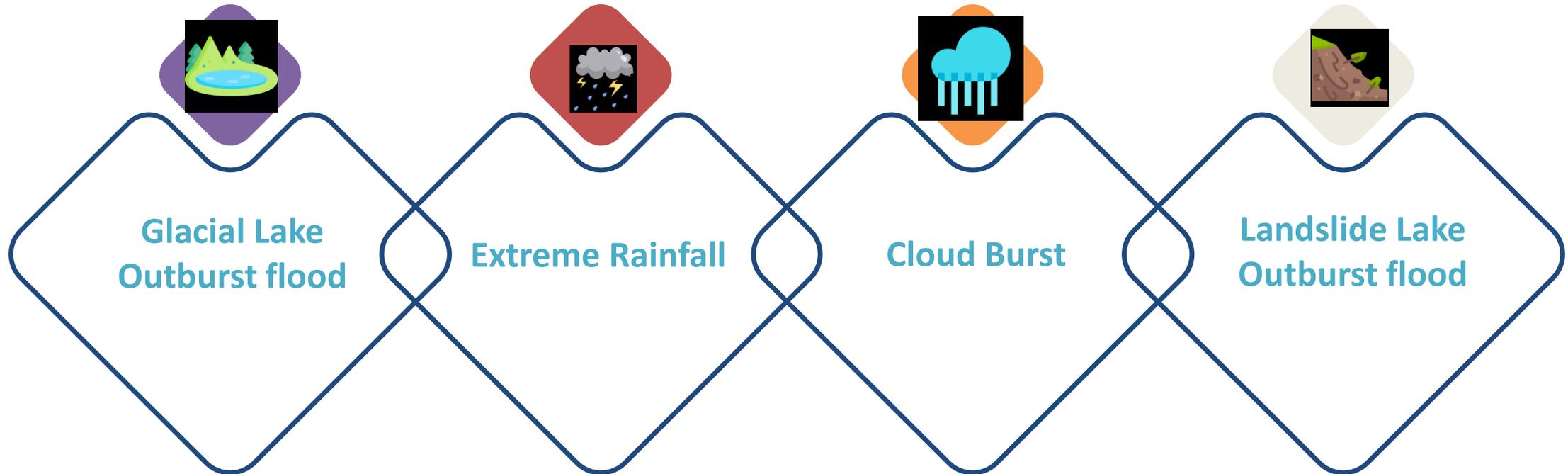


- The Paris Agreement set an unprecedented ambition to stabilise global temperature rise to between 1.5°C and 2°C. Assessing the consequences of climate change on key infrastructure assets and systems is a fundamental part of these considerations.
- As hydropower is a key component of the renewable energy portfolio and is critical in reducing greenhouse gas emissions (GHGs), assessing its potential under changing climatic conditions is imperative.
- Identifying climate risks on hydropower development in terms of three concepts viz. Hazard, Exposure and Vulnerability creates a helpful framework.
- Governments and operators can address potentially hazardous events that could affect a hydropower system, identify assets and resources exposed to the hazards, and pinpoint adaptive capacity needs to reduce vulnerability to these impacts.



# Some of the Impacts of Climate Change on Hydro Projects

- The Himalayan region is one of the most geologically active and environmentally fragile landscapes on Earth, making dam construction and operation particularly challenging.
- The impact of climate change on hydropower, especially in the Himalayas can broadly be classified into following major heads:





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# Impacts of Climate Change on Hydro Projects

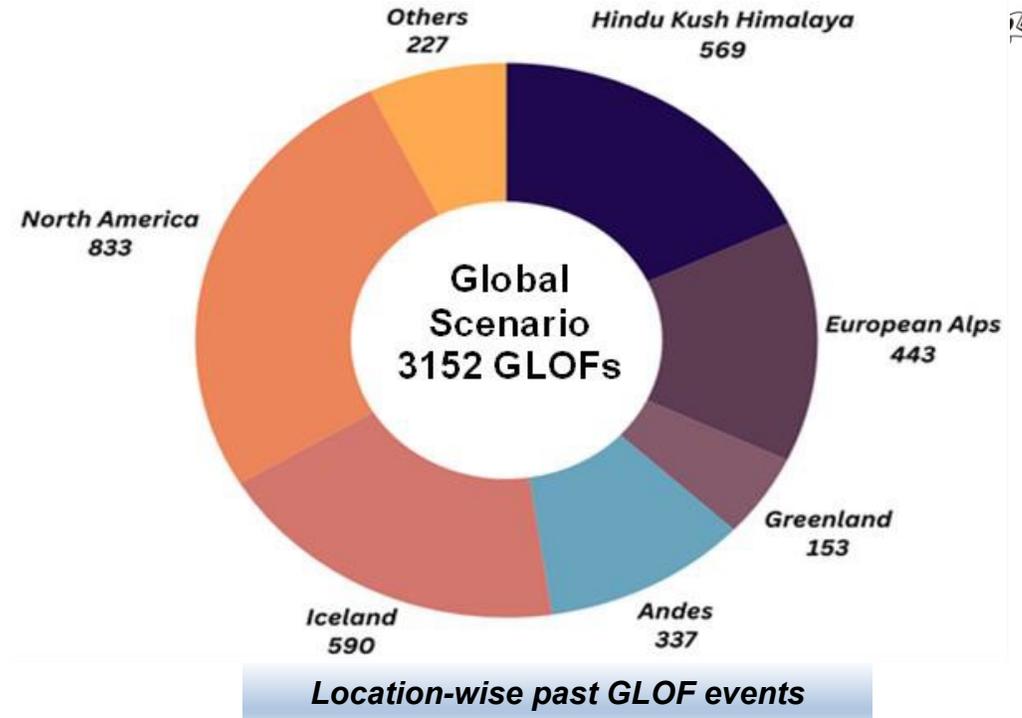


## Glacial Lake Outburst flood (GLOF)

- ❖ A glacier lake is a water body existing in sufficient quantities and extending with a free surface over an ice shelf and/or glacier floor.
- ❖ One of the most severe hydrological threats in the Himalayas is GLOFs, which occur when unstable glacial lakes breach their natural or artificial barriers, releasing large volumes of water downstream.
- ❖ Results in huge loss of property and life at downstream.
- ❖ Rising temperatures due to climate change have led to the rapid retreat of glaciers, forming hundreds of new proglacial lakes in the region.
- ❖ In 2023, Teesta-III and Teesta-V Hydro-Electric Projects in Sikkim suffered extensive damage due GLOF triggered by the collapse of Lhonak Lake.

**Basin-wise details of Glacial Lakes / Water Bodies in Himalayan Region (having water spread area more than 10 Ha)**

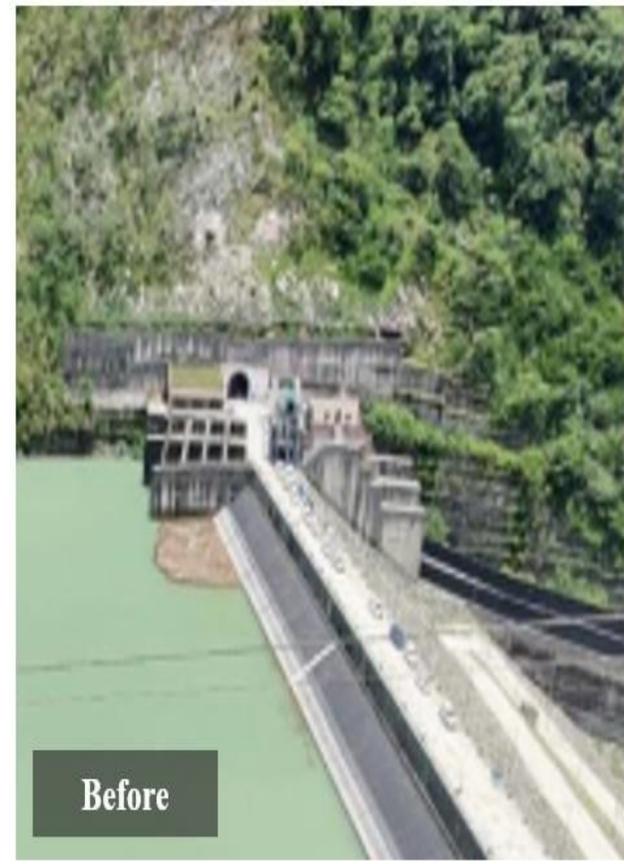
Source: CWC Report, 2025



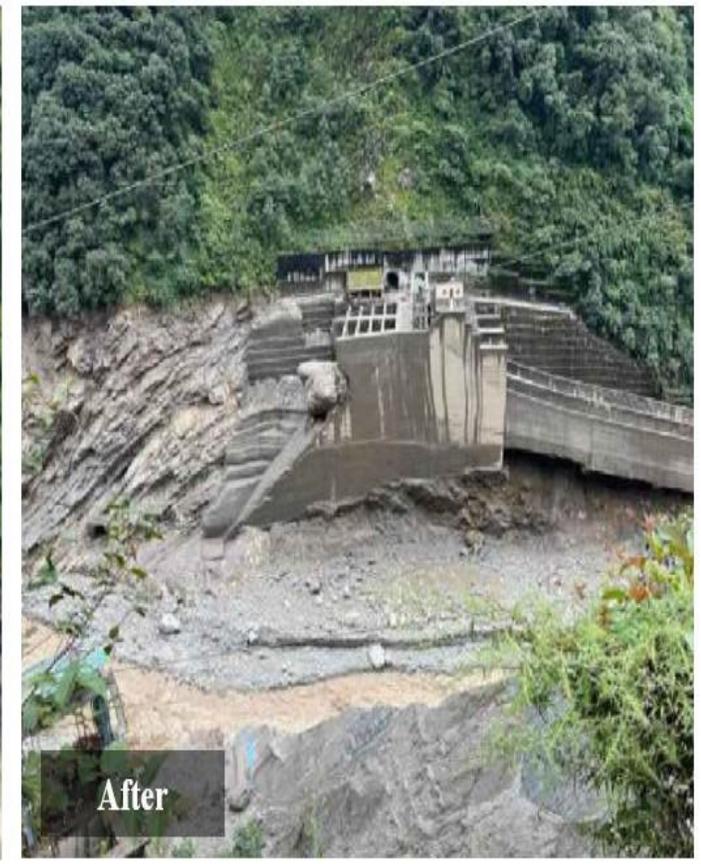
Sno.	Basin	Number of Glacial Lakes	Number of Water bodies	Total
1	Brahmaputra	294	1099	1393
2	Ganga	178	105	283
3	Indus	31	321	352
	<b>TOTAL</b>	<b>503</b>	<b>1525</b>	<b>2028</b>



***Conditions of South Lhonak glacial lake before and after the outburst event***



**Before**



**After**

***Teesta-III Dam before and after the GLOF event on 04.10.2023***

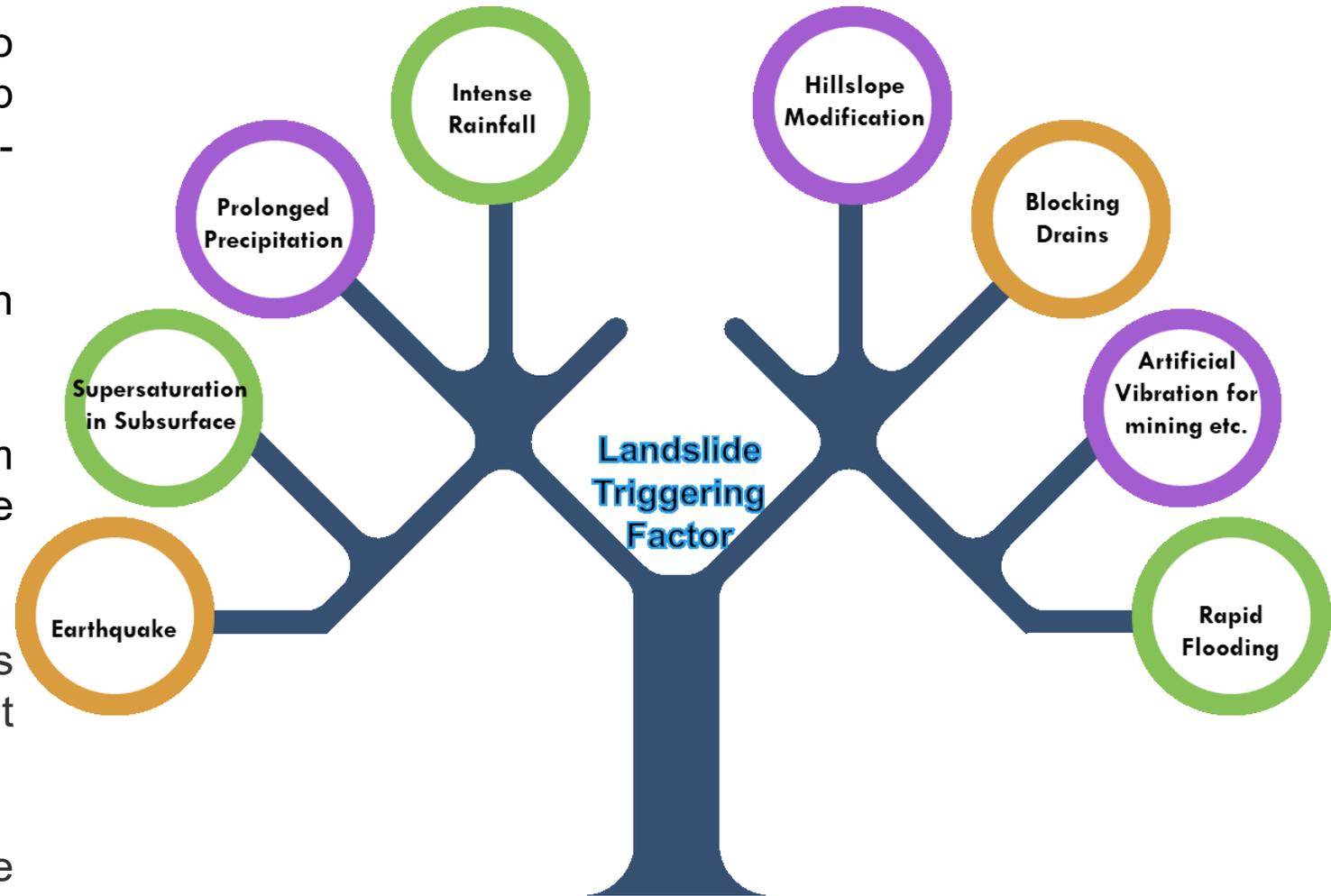


# Impacts of Climate Change on Hydro Projects



## • Landslides and debris flow

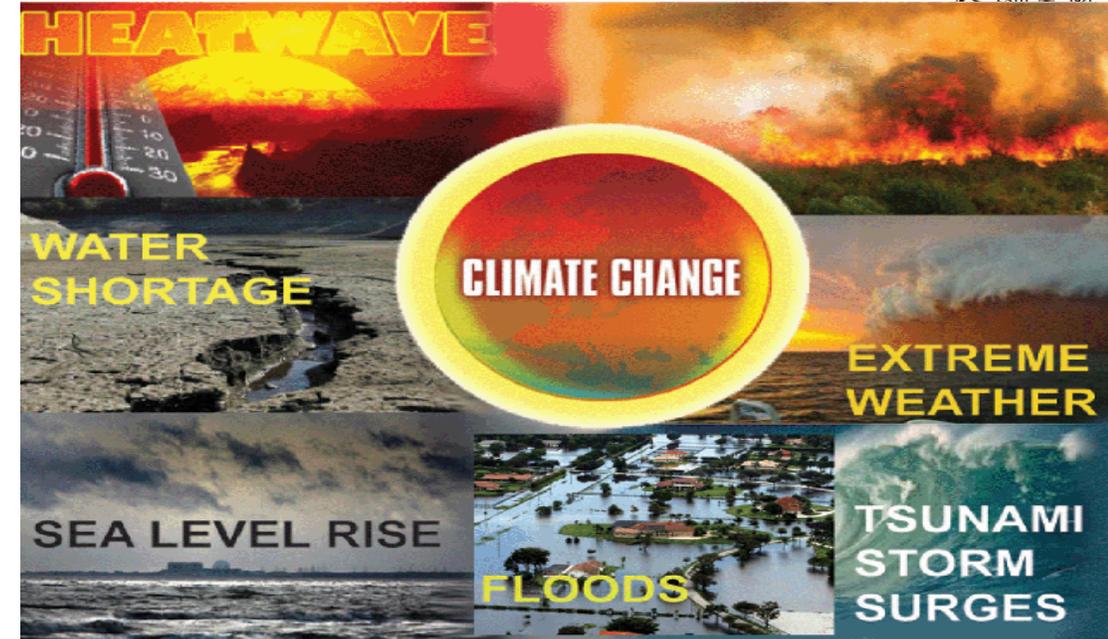
- ❖ Landslides are a persistent threat to Himalayan dam infrastructure due to steep slopes, unstable rock formations, and high-intensity rainfall.
- ❖ Seismic activity and excessive deforestation further exacerbate slope instability.
- ❖ Landslides can block rivers, obstruct dam spillways, damage reservoirs, and even cause sudden dam failures.
- ❖ When this obstruction in the river finally gives way to the force of accumulating water, it creates a situation similar to a lake burst.
- ❖ In the case of an avalanche, snow adds to the volume of water.



# Impacts of Climate Change on Hydro Projects

## Extreme Weather events

- ❖ The Himalayas are highly susceptible to extreme rainfall events, particularly cloudbursts, which result in intense localized flooding, flash floods, and rapid sediment transport.
- ❖ South and Southeast Asia's climate concerns are particularly associated with concentrated rainfall and floods, which are closely related to monsoon systems and tropical cyclones.
- ❖ Climate projections show that heavy and concentrated rainfall during the summer monsoon period is likely to become **more intense and frequent** in Asia.
- ❖ The Hindu Kush Himalayan region is projected to see a continuous **decrease in snow-covered areas and glacier volumes** during the 21st century due to increasing temperature and extreme heat episodes
- ❖ Hydropower projects around the Himalayas are directly affected by the consequences of melting glaciers, such as changing streamflow and glacier lake outburst floods.





# Impacts of Climate Change on Hydro Projects



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For instance, a glacial lake burst in the Rishiganga River of India damaged the 520 MW Tapovan Vishnugad Hydropower Project which was under construction, and destroyed the 13.2-MW Rishiganga Hydropower Project in February 2021.



Before & After image of Tapovan-Vishnugad HEP

The under construction project was adversely affected (sediment deposition in desilting tanks, HRT and ADIT tunnels filled with thick debris, 11-13 m debris deposition around the Tapovan plant, damage to sluices gates, and other structures).

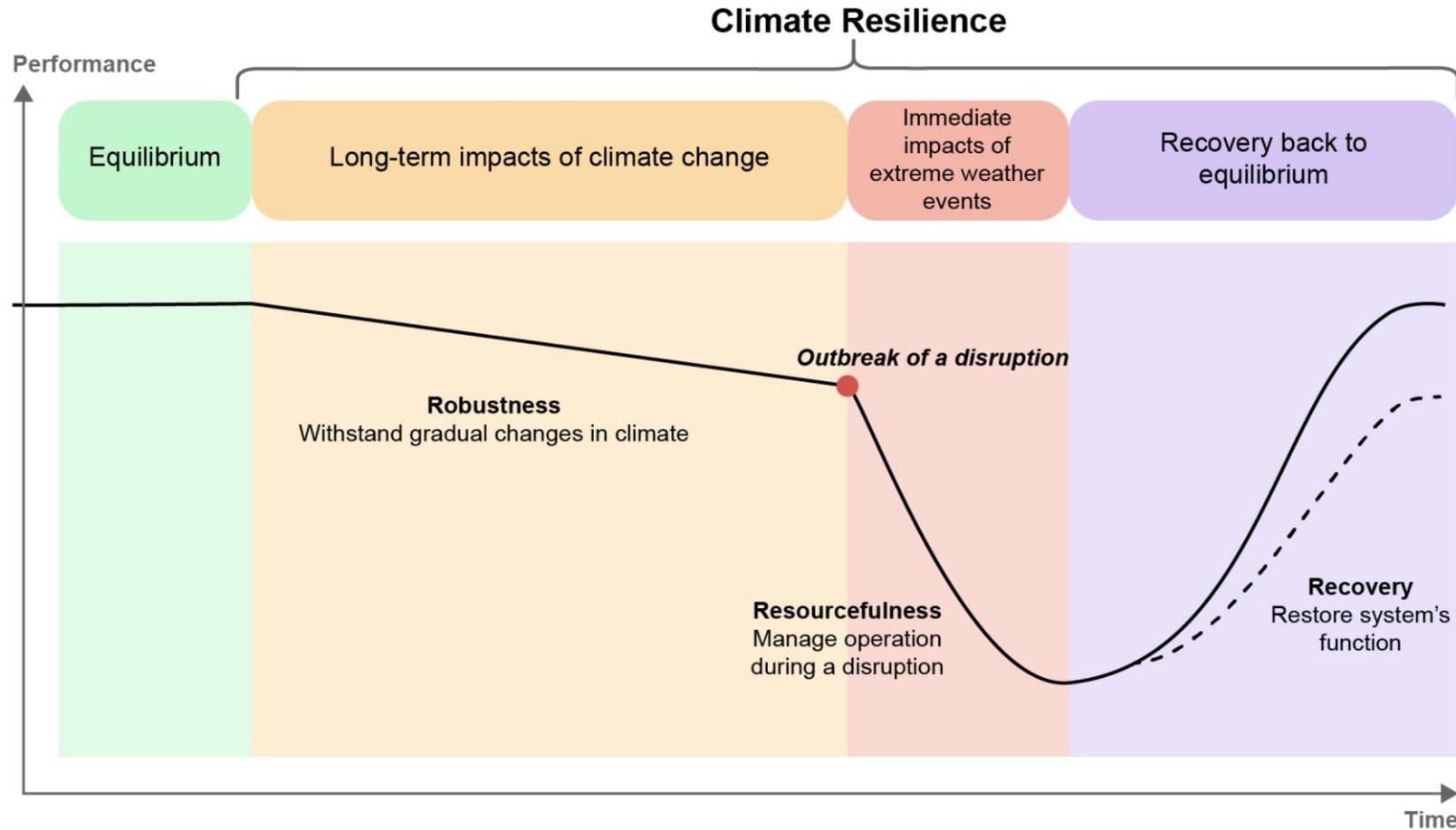
# Impacts of Climate Change on Hydro Projects



Damaged Barrage of Tapovan-Vishnugad HEP



Before and after images of the Rishiganga HEP

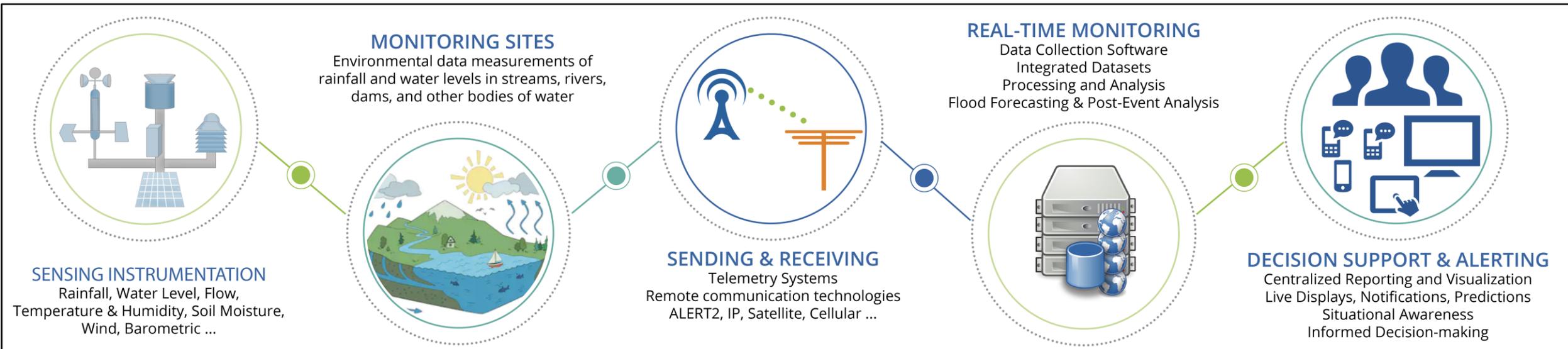


- Climate Resilience is essential for hydropower to continue delivering both electricity and flexibility on the path to clean energy transitions.
- Addressing the challenges of climate change requires an integrated approach, combining mitigation measures that reduce risk exposure with adaptation strategies that enhance resilience and operational efficiency.

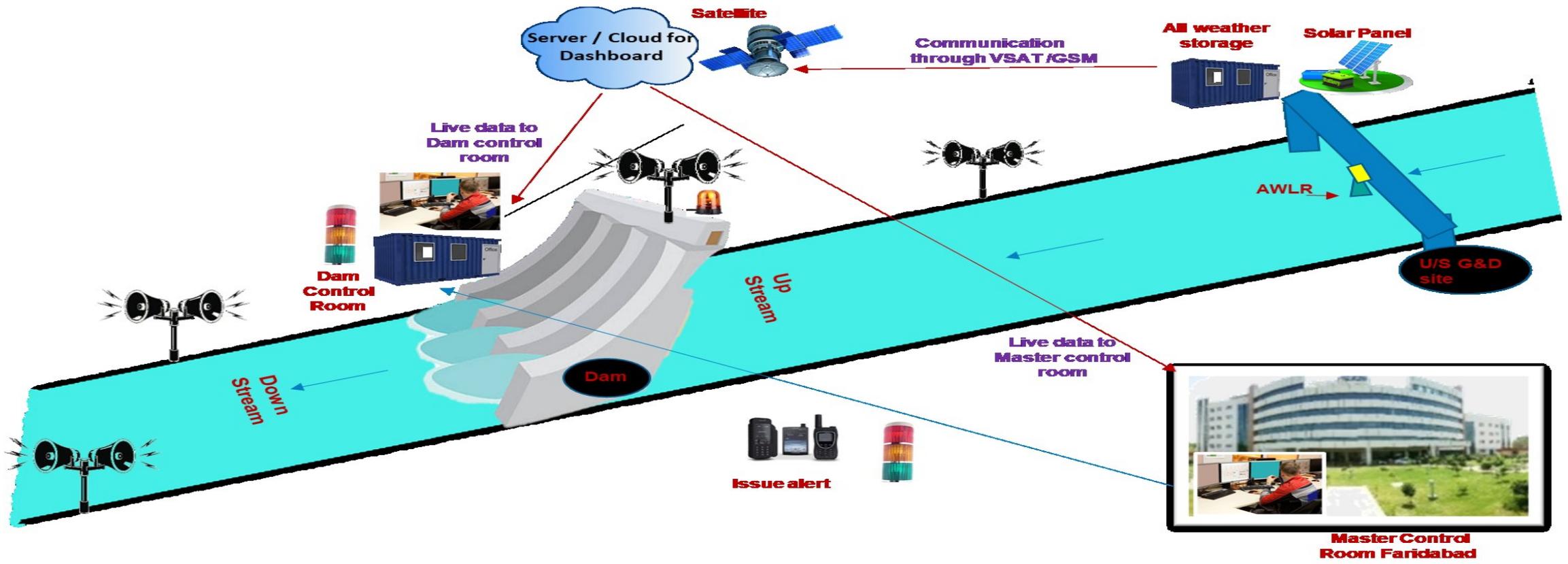
Conceptual framework for climate resilience and hydropower systems

# Real Time Monitoring and Early Warning System

- **Automated Early Warning Systems:** Integrate remote sensing data with hydrological models and weather forecasts to develop robust early warning systems.
- **Advanced Remote Sensing & AI:** Implement real-time monitoring of glacial lakes using satellite imagery, drone technology, and AI-powered image analysis to detect changes in lake volume, moraine dam stability, and surrounding terrain. Develop algorithms to predict potential GLOFs based on these data.
- **AI-Powered Decision Support Systems:** Develop centralized control rooms with AI-driven risk assessment models to assist dam operators in making real-time decisions.



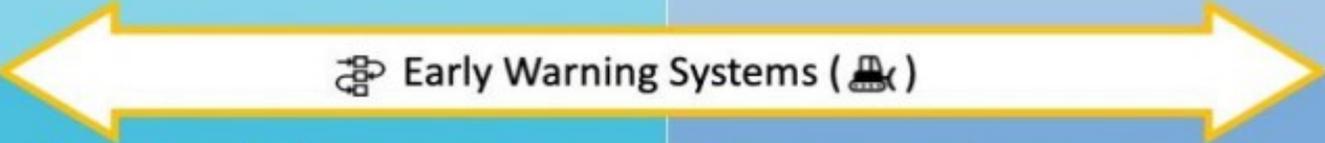
# Early Warning System Established at NHPC



# GLOF Mitigation and Structural Measures

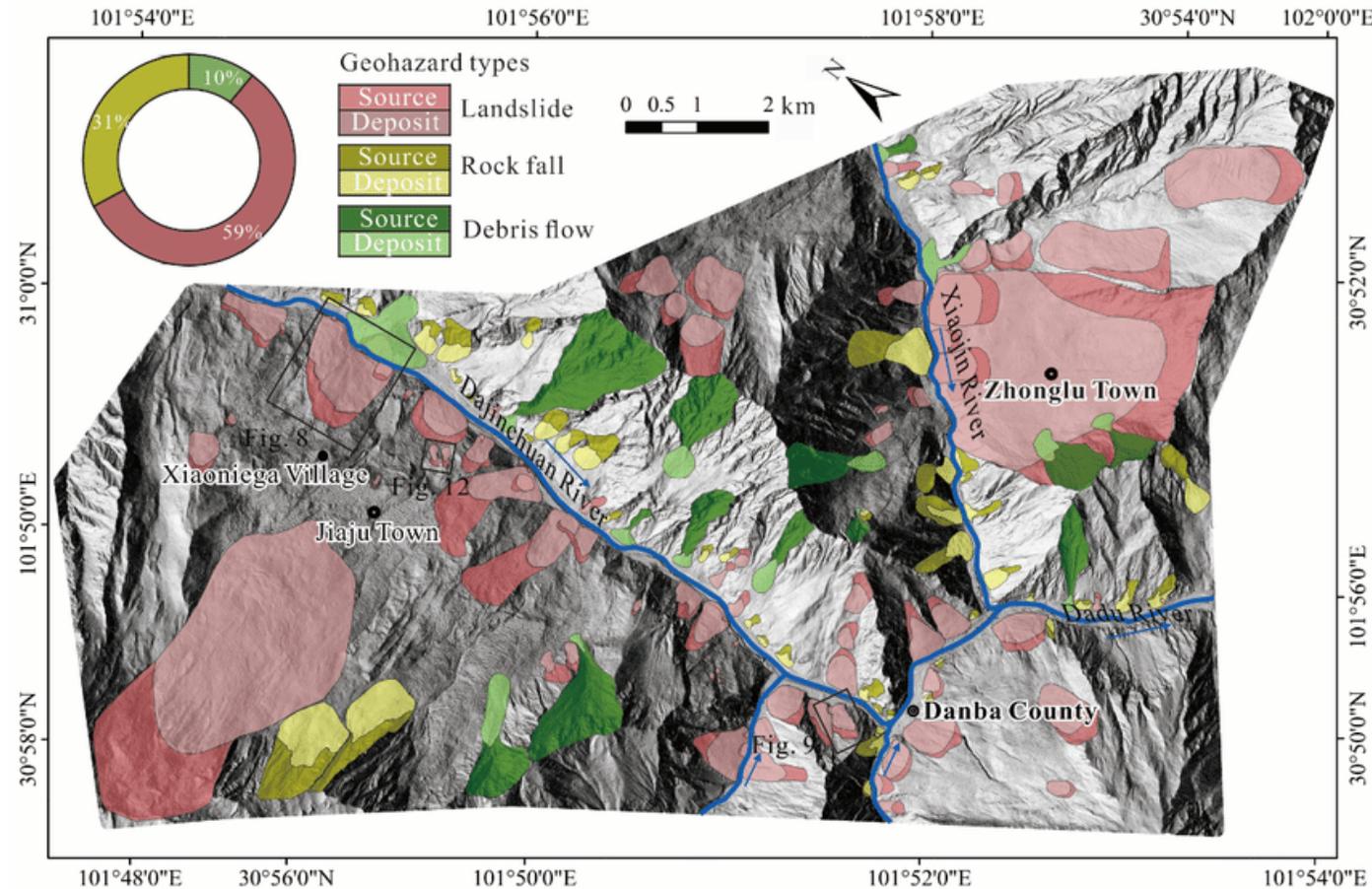
Risk reduction can be effective on each of the three components of risk (hazard, exposure, vulnerability). The selection of an adequate action depends on the urgency of the situation, the available resources as well as the specific characteristics of the site.

	REDUCTION OF HAZARD	REDUCTION OF EXPOSURE	REDUCTION OF VULNERABILITY
Short term actions	 Lowering of lake level (siphoning or pumping)	 Evacuation (based on monitoring / Early Warning)	n/a
Long term actions	 Artificial drainage channel (lowering of lake level)  Reinforcement / increase of dam  Enhancement of river cross section / protection from erosion	 Spatial planning according to hazard maps  Protective structures (e.g. retention or deflection dams)	 Information (capacity & data)  Institutional setup  Economic diversity  Disaster relief 


 Early Warning Systems (  )

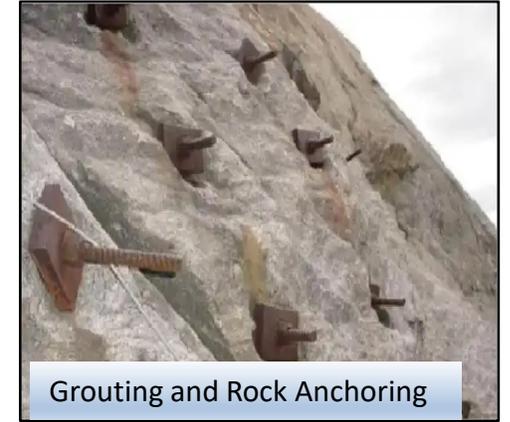
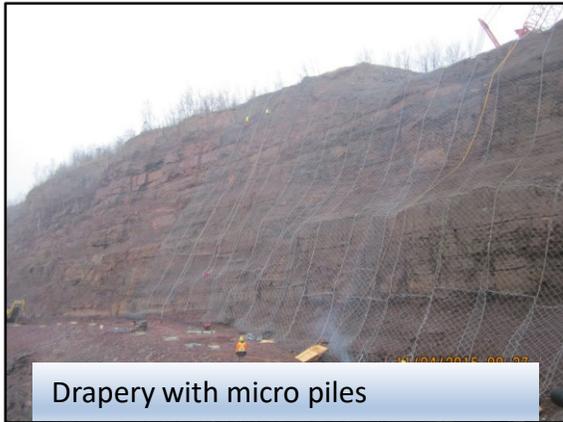
 Structural measures    
  Non-structural (organizational) measures

- Advanced Geological & Geophysical Surveys:** Conduct detailed geological and geophysical surveys using techniques like ground-penetrating radar, seismic surveys, and LiDAR to map unstable slopes and identify potential landslide triggers.
- Slope Stabilization Techniques:** Implement slope stabilization measures such as retaining walls, soil nailing, and bioengineering to reinforce unstable slopes.
- Real-time Slope Monitoring:** Install real-time slope monitoring systems using sensors (inclinometers, strain gauges) to detect movement and provide early warning of potential landslides. Integrate these systems with early warning systems for downstream communities.
- AI-Based Landslide Prediction:** Utilize machine learning models and ground-based radar to predict landslide-prone zones and trigger preventive measures.
- Geothermal Mapping:** Conduct deep thermographic and resistivity surveys before tunnelling to identify weak zones.



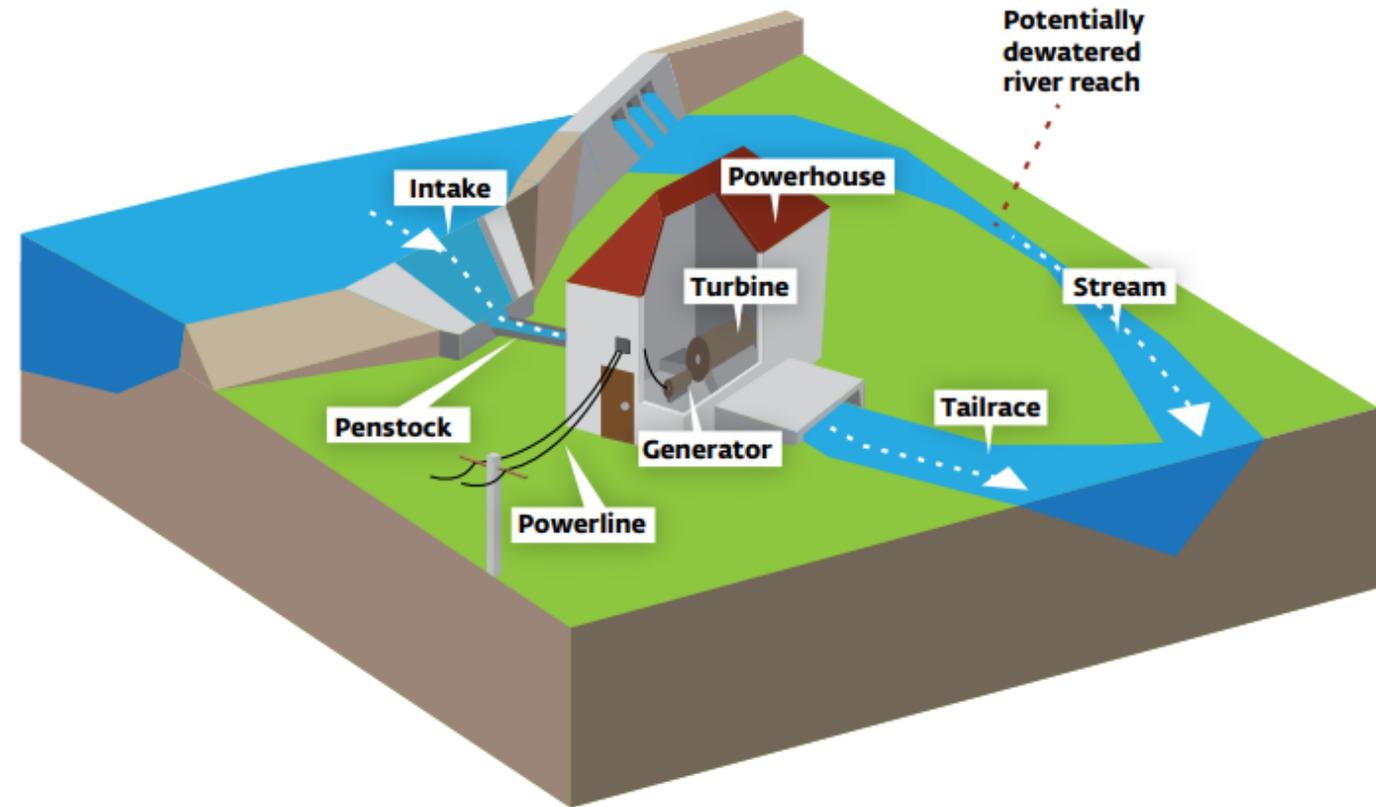
**LiDAR-based Geohazard Inventory Map of a Study Area**

## Various practices used to mitigate and prevent Landslide



# Environmental Flow Management

- E-Flows are defined as the **quantity, frequency and timing of water and sediment flows** necessary to sustain freshwater and estuarine ecosystems.
- **Loss of longitudinal connectivity** in terms of sediment, water and fish restrict their free movement along the system.
- Provisions for releasing a minimum threshold e-flow through should be made in the diversion structures.
- The released e-flow coupled with the proposed reservoir operations can reduce the environmental impact on riverine ecology and lead to sustainable development of hydropower.
- Use of Scientific modelling and real-time monitoring to optimize water releases and ensure ecological health.



# Community Engagement and Capacity Building

- **Community-based Monitoring:** Engage local communities in monitoring of glacial lakes, slopes, and other potential hazards. Utilize citizen science initiatives and mobile technology for data collection and sharing.
- **Participatory Planning:** Involve local communities in all stages of project planning and implementation to ensure that their concerns and traditional knowledge are considered.
- **Capacity Building:** Conduct training programs for local communities on disaster preparedness, early warning systems, and emergency response procedures.
- **Worker Safety Protocols:** Implementing automated hazard detection and emergency evacuation drills to minimize casualties in case of sudden disasters.



# Building Resilient Hydropower systems requires actions from all

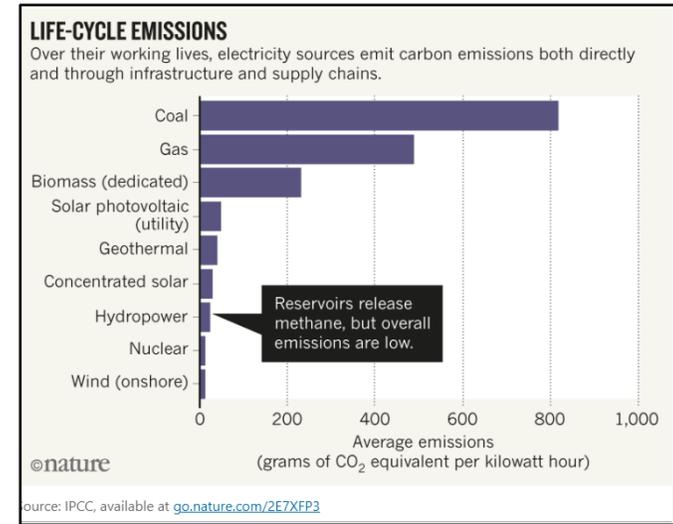
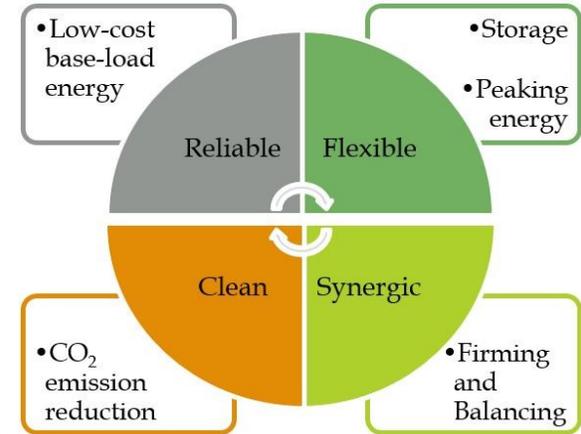
Types	Measure	Readiness	Robustness	Resourcefulness	Recovery
Supply side	Conduct climate risk and impact assessment	Green			
	Implement physical system improvement		Orange	Red	
	Switch to water-efficient and heat-resilient production process		Orange	Red	
	Diversify energy supply chain		Light Orange	Red	Blue
	Better monitor for early warning and emergency response	Light Green		Red	Blue
Demand side	Ensure climate proofing in design and performance	Green	Light Orange		
	Increase awareness and promote behavioural changes	Green	Light Orange		
	Improve energy efficiency		Orange		
	Use smart and advanced technologies for better management		Orange	Red	
	Adopt nature-based solutions		Orange	Red	
	Switch to climate-resilient materials		Light Orange	Red	Blue
Authorities and governments	Enhance knowledge about climate risks and impacts	Green			
	Establish appropriate policy frameworks	Green			
	Mainstream climate resilience into relevant regulations	Green	Light Orange	Red	
	Mobilise financing and investment		Orange	Red	
	Support adequate climate insurance				Blue
	Ensure emergency preparedness				Blue

**Governments and energy regulators are expected to play a particularly important role in building resilience.**

# CONCLUSION

- The impacts of climate change on dam performance are profound and far-reaching. Already with the continued warming, dramatic changes in precipitation patterns, river flows, and temperature are occurring, affecting the hydrology of many regions. These are likely to intensify over the coming decades and pose new challenges to the continued viability and effectiveness of existing and future dam infrastructure.
- The integration of climate change projections during planning, design, and operation is, therefore, of particular importance to make hydropower projects resilient to the complex and interconnected challenges posed by natural hazards and climate change, ensuring their long-term sustainability and safety.
- Build robust climate databases and strengthen climate impact assessments.
- Enhance regional cooperation to coordinate sustainable resource development and achieve mutual benefits.

**Hydropower is also a key asset for building secure, clean, electricity systems and reaching global net zero targets.**





**Thank You**