

# Rethinking Hydropower Tunnel Design in the Nepal Himalaya after Extreme Flood, GLOF, and Debris-Flow Events: Lessons from the Rasuwa Disaster

Kanchan Chaulagai<sup>1\*</sup>

<sup>1</sup>Underground Space Engineering Pvt. Ltd., Kathmandu, Nepal

\*(Corresponding E-mail: [geologistkanchan@gmail.com](mailto:geologistkanchan@gmail.com))

**Abstract:** Hydropower development in the Nepal Himalaya faces significant engineering challenges due to steep terrain, active tectonics, fragile geological formations and increasing climatic variability. Natural hazards such as extreme floods, landslides, debris flows and glacial lake outburst floods (GLOFs) pose serious threats to hydropower infrastructure, particularly during the monsoon season. The August 2026 Rasuwa disaster highlights the potential impacts of cascading hazards, where multiple natural processes interact and produce severe downstream consequences. This paper examines the vulnerability of critical underground hydropower structures, including tunnel portals, headrace tunnels and underground powerhouses, to flooding, slope failures, river erosion and changing river channel conditions. It also discusses how conventional engineering design approaches, largely based on historical records and established hazard assessments, may not adequately address emerging and interconnected risks. The study emphasizes the importance of understanding geological, hydrological and climatic interactions when planning and designing hydropower projects in mountainous regions. Improved geological investigations, continuous monitoring, remote sensing and integrated multi-hazard assessments are essential for reducing infrastructure vulnerability. Adopting climate-resilient engineering practices and considering cascading disaster scenarios can strengthen the long-term safety, reliability and sustainability of hydropower development across the Nepal Himalaya under increasingly uncertain environmental conditions

**Keywords:** Nepal himalaya, Hydropower tunnels, Rasuwa disaster, GLOF, Extreme flood, Debris flow, Landslide, Multi-hazard, Cascading hazards, Climate resilience, Tunnel design.

## Introduction

Hydropower development in the Nepal Himalaya faces significant engineering challenges due to steep terrain, active tectonic movements and fragile geological formations. The region is highly exposed to natural hazards such as landslides, extreme floods, debris flows and glacial lake outburst floods (GLOFs). These hazards become more complex during the monsoon season, when intense rainfall can trigger multiple events simultaneously.

## Multi-Hazard risks in hydropower development

Multi-hazard events occur when two or more natural hazards interact or take place simultaneously. In the Himalaya, extreme rainfall can trigger landslides and debris flows, while sudden floods can cause riverbank erosion and destabilize nearby slopes. Similarly, glacial lake outburst floods can transport large quantities of sediment and debris downstream, affecting hydropower structures located along river valleys.

These hazards may create cascading effects, where one event leads to another and increases the overall damage. Hydropower projects are particularly vulnerable because many of their critical structures are located near rivers, steep slopes and geologically unstable areas.

## The August 2026 Rasuwa disaster and its implications

The August 2026 Rasuwa disaster provides an important case for understanding the impact of cascading hazards on Himalayan infrastructure. Preliminary accounts describe an ice-rock avalanche entering the Lhende Khola and producing downstream flooding and debris movement along the Bhoté Koshi–Trishuli river system.

The event demonstrates how sudden high-altitude slope failures can generate destructive flows affecting infrastructure located far from the original source. Rapid changes in river channels, sediment transport and riverbank erosion can increase the risk to hydropower facilities. The disaster also highlights the importance of assessing upstream hazards when planning projects in downstream river valleys.

## Vulnerability of underground hydropower infrastructure

Underground hydropower infrastructure faces several risks during extreme natural events. Tunnel portals are especially vulnerable because they are commonly located near steep slopes and river valleys. Landslides,

rockfalls and debris flows can block tunnel entrances, damage protective structures and interrupt access.

Headrace tunnels may experience additional risks from unstable geological conditions, groundwater pressure and deformation of surrounding rock masses. Flooding and erosion near tunnel portals or shallow tunnel sections can also affect their stability. Underground powerhouses, although protected by surrounding rock, may still be exposed to water ingress through access tunnels, ventilation openings and other connected structures.

These vulnerabilities show that underground construction alone does not guarantee protection against extreme natural hazards.

## **Improving hydropower design and climate resilience**

Conventional hydropower design generally relies on geological investigations, historical flood records and estimated return periods. However, changing climatic and geomorphological conditions may produce events that exceed the original design assumptions.

A more comprehensive engineering approach is therefore necessary. Detailed geological mapping, slope stability assessments, hydrological modelling and continuous monitoring should be incorporated into project planning. Remote sensing and LiDAR technologies can help identify unstable slopes and changes in river channels.

In addition, multi-hazard scenario analysis, improved drainage systems, tunnel portal protection and effective early-warning systems can reduce infrastructure vulnerability. Regular reassessment of hazards throughout the project life cycle is equally important.

## **Conclusion**

Hydropower development in the Nepal Himalaya is increasingly challenged by the interaction of geological, climatic and hydrological hazards. The August 2026 Rasuwa disaster highlights how cascading events can threaten critical infrastructure beyond the immediate disaster source.

Tunnel portals, headrace tunnels and underground powerhouses require careful consideration of flooding, landslides, debris flows and changing river conditions. Conventional design approaches remain important but should be strengthened through integrated multi-hazard assessments, continuous monitoring and climate-resilient engineering practices. Understanding these interacting hazards is essential for improving the long-term safety, reliability and sustainability of hydropower infrastructure in Nepal.