

Paradigm Shift in Mountain Disaster Management: Critical Appraisal of Transboundary Mountain Tsunamis, Subsurface Tunnel Entrapments, and Buried Settlement Recovery

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Abstract: This paper deals with search, rescue and recovery efforts after disasters in the Himalayas. These disasters include transboundary mountain tsunamis and powerful debris flows that move quickly through steep river valleys. It also examines problems like people being trapped inside tunnels and buildings that get buried under several meters of rocks and debris. The paper stresses the need for decisions made by experts, stronger buildings, systems that can close tunnel entrances during emergencies and better planning that takes risk into account. A technical framework is introduced that uses hydrodynamic numerical modeling, quantitative simulations, UAV-borne LiDAR, Ground-Penetrating Radar (GPR), acoustic ground-penetrating investigations, and building resilience guidelines. The study uses disaster events in Nepal to improve how hazards are understood how emergency response is handled and how infrastructure is rebuilt after a disaster, in the context of high-risk Himalayan terrains.

Keywords: *Mountain tsunami, Subsurface tunnel entrapment, Hydrodynamic modeling, Merit-based expert curation.*

Introduction

Transboundary Mountain Tsunamis

Catastrophic floods, debris flows and other cryosphere-related hazards that start in the high-altitude areas can cross borders and bring serious damage to downstream communities and infrastructure (Salm, 1993; Julien and Leon, 2000; Huggel et al., 2004; Williams, 2013; Farooq, 2026). The Hindu Kush Himalaya (HKH) is seeing changes in glaciers, snow and permafrost. These changes make mountain hazards more complex, cause more chain reactions. Disaster risk management in the HKH faces challenges, with hazard monitoring, early warning, data availability and transboundary coordination. Many mountain hazards can appear quickly giving less time for forecasting and emergency response. Strengthening monitoring, sharing of information and effective early-warning systems is therefore essential to reduce the event like mountain Tsunami in Bhotekoshi river corridor (Figure 1).

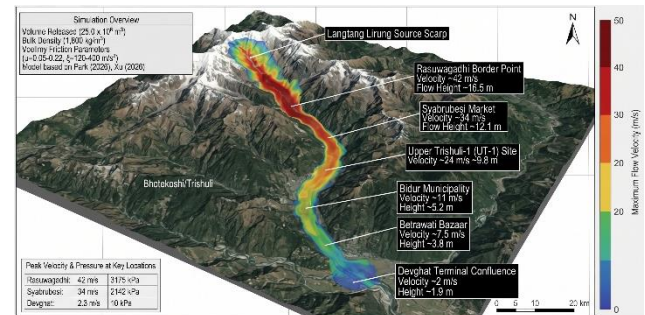


Figure 1, Mountain Tsunami in Bhotekoshi River.

Methodology

The comprehensive framework integrates mainly the numerical modeling, site investigation, merit-based expert validation, and resilient structural design.

Entrapment and extrication constraints

Rigorous domain-expert identification and curation protocol based on publication record, verified work practice, citation and research impact. Should know the critical dimension of modern infrastructure vulnerability in Himalayan river corridors. Should understand the systematic bottlenecks like portal blockage and power failure as well as atmospheric degradation. The mandatory engineering solutions for tunnel might be automated blast-resistant portal gates, independent emergency ventilation pods, and secondary escape raises.

Paradigm shift

Comparing old reactive practices with modern disaster-resilient frameworks reveals a necessary evolutionary leap in civil and geotechnical engineering. Table 1 outlines the paradigm shift across exploration, search & rescue, and post-disaster reconstruction.

Table 1, Comparison of Traditional vs. Disaster-Resilient Management Practices

Dimension	Traditional Approach	Modern Approach
Hazard Exploration	Unmonitored catchments; post-event visual checks.	Satellite telemetry, IoT early warning sensors, UAV LiDAR.
Expert Curation	Open advisory panels with unverified opinions.	Merit-based vetting via publication records and specialization.
Search & Rescue	Manual digging, lack of subsurface imaging tools	GPR, ERT arrays, acoustic locators, specialized tunneling teams.
Infrastructure Design	Standard 100-year flood lines ignoring glacial outburst bulges	Hydrodynamic zoning, automated portal gates, safe-zone pods.
Reconstruction	Rebuilding in vulnerable riverbanks.	Mandatory 50m buffer zones, elevated pile-supported structures, land-use zoning laws

Geomorphic obscuration

A recurring mystery in post-disaster assessments is why multi-story residential and commercial buildings buried under thick debris layers were frequently overlooked or difficult to locate during initial SAR operations. Technical autopsy of these events highlights several compounding factors: 1) massive overburden thickness, 2) absence of structural surface expression, and 3) limitations of conventional SAR equipment. The geomorphology has been changing and changes found significant in the location of buried structures.

Search and rescue mission

Search and rescue (SAR) operations in flooded or debris-blocked hydropower tunnels require advanced technologies such as seismic detectors, borehole cameras, gas sensors, GPR, ERT and UAV-based LiDAR. Locating buried structures after mountain tsunami-like events requires geophysical surveys, thermal imaging and controlled excavation. Changes in geomorphology, including surface depressions, cracks, uneven settlement and altered flow patterns, can help identify buried structures and guide rescue operations.

Mountain Tsunamis

Mountain tsunamis are high-energy, multiphase mass flows driven by catastrophic GLOFs or high-altitude rock-ice avalanches entering steep mountain torrents. The core physical mechanisms include: 1) impulse wave generation, 2) non-newtonian rheology and multi-phase slurry, 3) gorge/zigzag amplification, and 4) geomorphic obscuration. To simulate these phenomena across extended river corridors hydrodynamic depth-integrated governing equations of mass and momentum conservation are employed. The possible rheological constitutive models are: 1) Voellmy-Salm, 2) Quadratic, & 3) Herschel-Bulkley.

Infrastructure resilience

Should be focused on flood-resilient bridge design, and corridor spatial planning. Permanent construction must be strictly prohibited within the high-energy alluvial and debris-flow deposition zones by enforcing mandatory 50-meter buffer zones.

Conclusion & recommendations

Epistemic limitations and a lack of transboundary hydro-meteorological data sharing meant extreme mountain tsunamis were largely unforeseen prior to impact. Subsurface tunnel entrapment survivability was severely compromised by rapid portal blockage and lack of specialized subterranean rescue equipment. Buried buildings evaded immediate detection due to massive debris overburden and the limitations of surface-level SAR methods. Disaster governance and technical panels must be strictly restricted to vetted, publication- and practice-proven domain experts, filtering out unverified participants. Establishing bilateral transboundary early warnings, blast-resistant tunnel portal gates, and impact-resilient infrastructure is vital. Furthermore, enforcing merit-based expert screening, providing buffer zones, and advanced subsurface SAR technologies is essential to overcome rapid tunnel portal blockages and atmospheric degradation.

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