

# Geological Environment and Geohazards in the Qinghai–Xizang Plateau, China

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**Abstract:** The Qinghai–Xizang Plateau, known as the “Third Pole,” is one of the most environmentally sensitive and geologically dynamic regions on Earth. Its changes influenced more than two billion people across Asia. Since 1951, two major scientific expeditions have investigated geology, environment, and geohazards. The latest expedition focuses on water–ecology–human interactions and aims to clarify geohazard mechanisms and risks. High-altitude tectonics, extreme topography, and climate warming drive frequent disasters such as earthquakes, debris flows, landslides, and disaster chains. A comprehensive geohazard database and major scientific breakthroughs now support engineering safety, transboundary corridor planning, and risk zoning across the plateau.

**Keywords:** Tibetan plateau, Geohazards database, Engineering safety.

## Introduction

The Qinghai–Xizang Plateau (QXP), also known as the Tibetan Plateau, is the world’s highest and largest high-altitude landmass, covering 2.57 million km<sup>2</sup> with an average elevation exceeding 4000 meters. Often referred to as the “Third Pole”, it plays a crucial climatic and ecological role comparable to the Arctic and Antarctic. Extending from the Pamir Plateau in the west to the Hengduan Mountains in the east, the plateau influences atmospheric circulation, hydrological systems, ecosystems, and human livelihoods across more than two billion people in Asia. With increasing climate variability and intensified human activities, the plateau has become a global hotspot for environmental research and hazard assessment. Recent studies highlight that the region exerts strong thermal and dynamical forcing on the Asian monsoon system, regulates major river basins, and supports diverse yet

fragile ecosystems that are highly sensitive to environmental change. Furthermore, ongoing uplift, cryospheric degradation, and the expansion of infrastructure on unstable terrain have increased the frequency and complexity of geohazards, underscoring the need for integrated geoscientific investigations (Chen et al., 2021; Yao et al., 2015).

## Scientific expeditions on the Qinghai–Xizang Plateau

The first comprehensive scientific expedition, spanning four decades, marked a major milestone in the understanding of the plateau’s natural environment. The survey covered about 2.5 million km<sup>2</sup>, mainly encompassing the Xizang (Tibet) Autonomous Region, Hengduan Mountain area, Karakoram–Kunlun Mountains, and the Kekexili region. This monumental effort produced 87 scientific monographs, establishing the earliest large-scale knowledge base on geology, climate, ecology, hydrology, and natural hazards of the plateau. Beyond providing detailed baseline data, the expedition offered critical insights into glacial dynamics, permafrost distribution, river systems, and biodiversity patterns, forming a foundation for long-term environmental monitoring and research.

The ongoing second scientific expedition, launched in 2017, adopts a holistic and multidisciplinary approach. Its research scope encompasses the entire Qinghai–Xizang Plateau, with an overall focus on the interactions among water resources, ecological systems, and human activities (Yao et al., 2022). This phase integrates advanced technologies such as remote sensing, high-precision geospatial mapping, and climate modeling to assess environmental changes

in real time. The expedition aims not only to deepen scientific understanding but also to inform sustainable development strategies, disaster risk reduction, and policy making, addressing the pressing challenges posed by climate change, infrastructure expansion, and ecosystem vulnerability across the plateau.

Among its several thematic tasks, the “Geological Environment and Geohazards” component aims to:

- Clarify the background conditions of geohazards,
- Uncover formation and evolution mechanisms,
- Predict hazard development and risk levels, and
- Support the safety of major engineering projects, settlements, and ecological barriers.

This expedition integrates modern technologies such as remote sensing, AI-based hazard identification, real-time monitoring, and digital simulation to push QXP research into a new era.

### Drivers of geohazards on the plateau

The Qinghai–Xizang Plateau exhibits one of the highest geohazard susceptibilities in the world. This vulnerability is driven by three core geological and environmental factors (Willett et al., 2006).

First, the continued convergence between the Indian and Eurasian plates causes crustal shortening, active faulting, and strong seismicity. The plateau hosts thousands of active faults, producing high-frequency and high-magnitude earthquakes that trigger secondary hazards such as landslides and river damming (Ding et al., 2022; Wang et al., 2025).

Second, the region’s extreme elevation differences, deeply incised valleys, and steep slopes amplify gravitational forces, promoting landslides, debris flows, rock avalanches, and large-scale mass movements. The steep topography often concentrates runoff and accelerates erosion, further destabilizing slopes.

Third, rapid warming accelerates glacier melt, permafrost degradation, and seasonal freeze–thaw cycles, which weaken slope stability and greatly increase the risk of landslides, debris flows, and complex disaster chains. These processes, combined with ongoing human activities such as infrastructure construction, mining, and urban expansion, compound the vulnerability of the plateau, making it a global hotspot for geohazard research and mitigation planning.

### Comprehensive geohazard database

A major achievement of recent research is the establishment of an extensive geohazard database for the Qinghai–Xizang Plateau. The database includes:

- 2644 active faults
- 9404 earthquakes

- 24,573 debris flows
- 73,932 freeze–thaw landslides
- 7566 disaster chains (multi-stage, interconnected hazards)

Such a database provides an unprecedented foundation for hazard assessment, spatial modeling, early warning systems, and engineering decision-making across the plateau.

### Key scientific breakthroughs

The expeditions have produced several cutting-edge scientific discoveries that advance global understanding of high mountain geohazards:

- A new conceptual and numerical model explains how rock and ice masses disintegrate and accelerate over long distances, often exceeding several kilometers. This finding is crucial for understanding catastrophic events such as the 2021 Chamoli disaster (Lin et al., 2020).
- Researchers identified the detailed physical processes governing needle-ice formation and their role in weakening frozen soils. This mechanism links permafrost degradation to increased landslide frequency in warming climates (Li et al., 2021).
- An AI-driven, high-resolution landslide detection system was developed using satellite imagery, deep learning, and big-data analysis. It significantly improves the accuracy and speed of regional hazard mapping.
- A refined classification identifies multiple types of avalanches and two main types with seven subtypes of landslide-to-debris-flow transformation mechanisms, improving prediction and mitigation strategies for cascading disasters.

### Engineering and monitoring technologies

Several advanced technologies have been developed to support hazard mitigation across the Qinghai–Xizang Plateau:

- Numerical simulation platforms for watershed-scale disaster evolution, capable of modeling landslide initiation, debris-flow routing, and river-blocking events, which allow researchers and engineers to predict hazard behavior under various scenarios.
- Frozen-soil engineering protection technologies provide innovative solutions for maintaining infrastructure stability in permafrost zones, including thermosyphons, insulation layers, and slope reinforcement techniques.
- Real-time geohazard monitoring systems, integrating GNSS, InSAR, automatic sensors, and

communication networks, to detect early warning signs of slope failure, debris flow mobilization, and permafrost degradation.

These technologies greatly enhance the region's capacity to prevent, manage, and respond to geohazards. By combining predictive modeling, field-based engineering interventions, and continuous monitoring, they enable timely decision-making, improving the safety of critical transportation and energy infrastructure, and reducing socioeconomic impacts on communities in high-risk areas. Moreover, the integration of these advanced tools into hazard management frameworks serves as a model for similar mountainous and permafrost regions worldwide.

### Applications for major engineering projects and corridors

The scientific results have provided direct benefits to national and transboundary development projects, especially in the areas highlighted by Qi et al. (2022):

- Optimization of the Sichuan–Tibet Transportation Corridor
- Risk assessment for China–Nepal and China–Pakistan economic corridors
- Technical support for natural disaster risk zoning across the Qinghai–Xizang region

By identifying hazardous zones, assessing stability conditions, and suggesting mitigation measures, these findings ensure the safety and resilience of large-scale infrastructure in some of the world's most challenging geologic environments. Beyond infrastructure safety, the results support regional planning, environmental protection, and sustainable development by providing critical guidance for land-use policies, ecosystem preservation, and climate adaptation strategies. Moreover, the integration of advanced monitoring technologies and hazard modeling into engineering practices has improved decision-making efficiency, reduced construction risks, and enhanced disaster preparedness for communities along high-risk corridors. Collectively, these achievements demonstrate the practical and societal value of systematic geoscientific research in high-altitude and geohazard-prone regions, serving as a model for similar initiatives in other mountainous and tectonically active areas.

### Conclusions

The Qinghai–Xizang Plateau is a globally significant geologic and ecological system with exceptional geohazard complexity. Over seven decades of scientific expeditions have substantially advanced knowledge of its environment and hazards. Modern geohazard databases, breakthroughs in hazard mechanics, AI-based detection, and real-time monitoring technologies now provide powerful tools for safeguarding

infrastructure, ecosystems, and communities. These achievements play a vital role in strengthening engineering resilience, improving risk zoning, and enhancing disaster prevention capacity across the “Third Pole.” In addition, integrated research combining geology, hydrology, climatology, and ecology have enabled the development of predictive models for landslides, debris flows, and permafrost degradation. The application of such multidisciplinary approaches supports early warning systems, informs sustainable land-use planning, and guides the design of resilient infrastructure in this high-altitude environment. As climate change and human activity continue to intensify, these scientific and technological advancements are increasingly critical for minimizing geohazard impacts and ensuring the long-term sustainability of human and ecological systems on the plateau.

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