IRDR Special Report

Risk assessment of Debris Flows along the China-Nepal Transportation Corridor

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Editorial Note:

On 26 August 2026, a massive ice avalanche occurred in the border area between China and Nepal, triggering severe debris flows and flash floods that caused extensive damage to the China-Nepal Transportation Corridor and downstream communities and infrastructure across Nepal. This report is excerpted from the research outputs of the IRDR Flagship Project "Silk Road Disaster Risk Reduction." It systematically assesses the distribution, formation conditions, and risk levels of debris flows along the China-Nepal Transportation Corridor, identifying the spatial patterns of high-hazard and high-risk road sections. The findings provide a scientific basis for post-disaster recovery and reconstruction efforts, and offer critical references for the development of transboundary multi-hazard early warning systems, disaster risk management along transport corridors, and bilateral cooperation on disaster risk reduction between China and Nepal.

1. Introduction

The China-Nepal Transportation Corridor, connecting Lhasa with Zhangmu Port and Gyirong Port, is located in the Yarlung Zangbo River Valley and the Himalayan region of the southern Tibetan Plateau. It serves as a major “golden corridor” for tourism in the Tibet Autonomous Region, with relatively well-developed socioeconomic conditions along the corridor, and is a key area for regional development in the central One River and Two Tributaries region of Tibet and for implementing the Western Development Strategy.

The main axis of the corridor is approximately NE–SW trending. From Lhasa, at an elevation of approximately 3,660 m a.s.l., to Gyirong County, at approximately 4,130 m a.s.l., the elevation generally increases along the corridor; from Gyirong County to Gyirong Port, situated at approximately 1,900 m a.s.l., the elevation decreases sharply along the transportation route. The corridor is characterized by complex geological structures, stratigraphy, and lithology; intense neotectonic activity; pronounced spatial variations in hydroclimatic conditions; intensive glacial activity; and widespread debris-flow hazards. Moreover, ongoing global climate change has increased the frequency of extreme precipitation and extreme heat events, contributing to frequent debris-flow events throughout the region. Frequent debris-flow hazards seriously disrupt the normal operation of the China-Nepal Transportation Corridor, constrain local socioeconomic development, and hinder the smooth development of bilateral trade between China and Nepal.

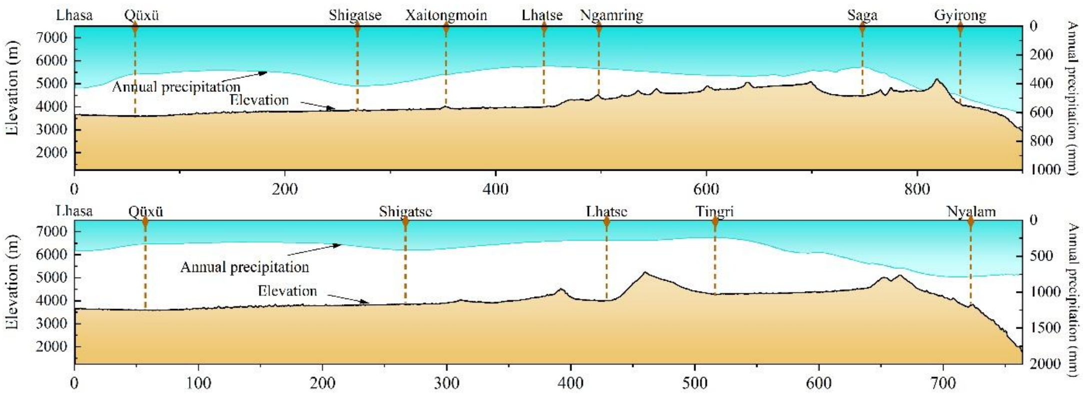

Fig. 1. Topographic and precipitation profiles along the Lhasa-Zhangmu and Lhasa-Gyirong sections of the China–Nepal Transport Corridor.

2. Debris Flows Distribution

More than 700 debris-flow gullies have developed along the China-Nepal Transport Corridor. Debris flows are concentrated mainly along the eastern Lhatse-Qüshui section of the Yarlung Zangbo River and around Gyirong County in the west. In contrast, the plateau surfaces between Tingri and Gyirong counties are generally not prone to debris-flow activity. According to their water-source conditions, debris flows along the corridor can be classified into three major categories: rainfall-induced debris flows, glacial debris flows (including ice–water mixed debris flows, ice- and snowmelt-induced debris flows, and other types genetically related to glacial activity), and GLOF-induced debris flows. Among these, 659 rainfall-induced debris flows are distributed in the Yarlung Zangbo River valley; 28 GLOF-induced debris flows are mainly located in Gyirong County and the area north of Nyalam County; and 22 glacial debris flows are mainly distributed in southern Gyirong County and northeastern Saga County. Debris flows are mainly concentrated in areas characterized by a local relief of 400-800 m, slope gradients of 8-12°, and moderately hard lithology. They exhibit a belt-like distribution along fault zones, and their number tends to decrease with increasing distance from the faults.

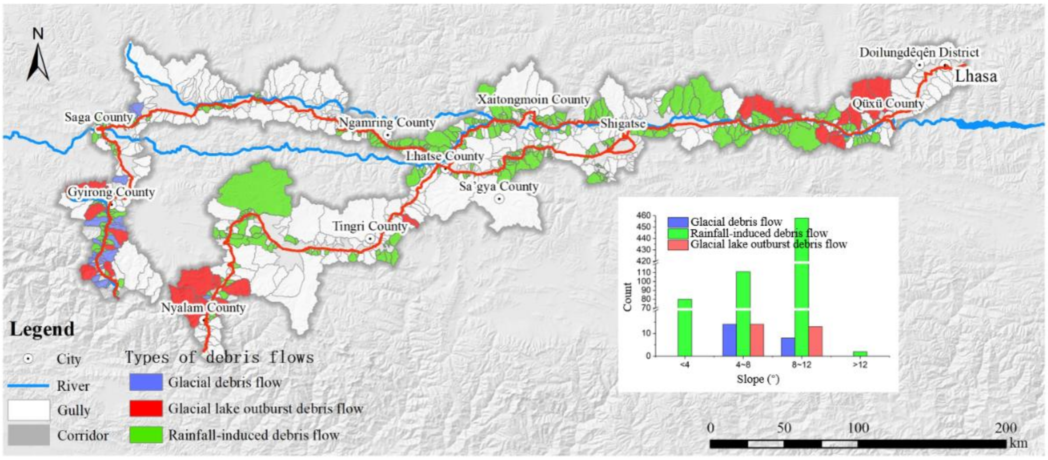

Fig. 2. Distribution of debris flows along the China-Nepal Transport Corridor.

3. Formation Conditions of Debris Flow

The China-Nepal Transportation Corridor is located in the Yarlung Zangbo River Valley and the Himalayan region along the southern margin of the Tibetan Plateau, where complex geological structures, intense neotectonic activity, and highly fractured rock masses prevail. The corridor is characterized by pronounced topographic relief. Elevation generally increases from Lhasa, at approximately 3,660 m a.s.l., to Gyirong County, at approximately 4,130 m a.s.l.. In contrast, it decreases sharply from Gyirong County to Gyirong Port, at approximately 1,900 m a.s.l., resulting in steep and highly dissected terrain. The region exhibits pronounced variations in hydroclimatic conditions and intense glacial activity. Under ongoing global climate change, increasingly frequent extreme precipitation and extreme heat events increase the production and concentrated infiltration of snow- and ice-meltwater and intense rainfall. The combined effects of highly fractured rock masses, steep terrain, and concentrated water supply create favorable conditions for frequent debris-flow occurrence, posing serious threats to transportation operations and regional socioeconomic development.

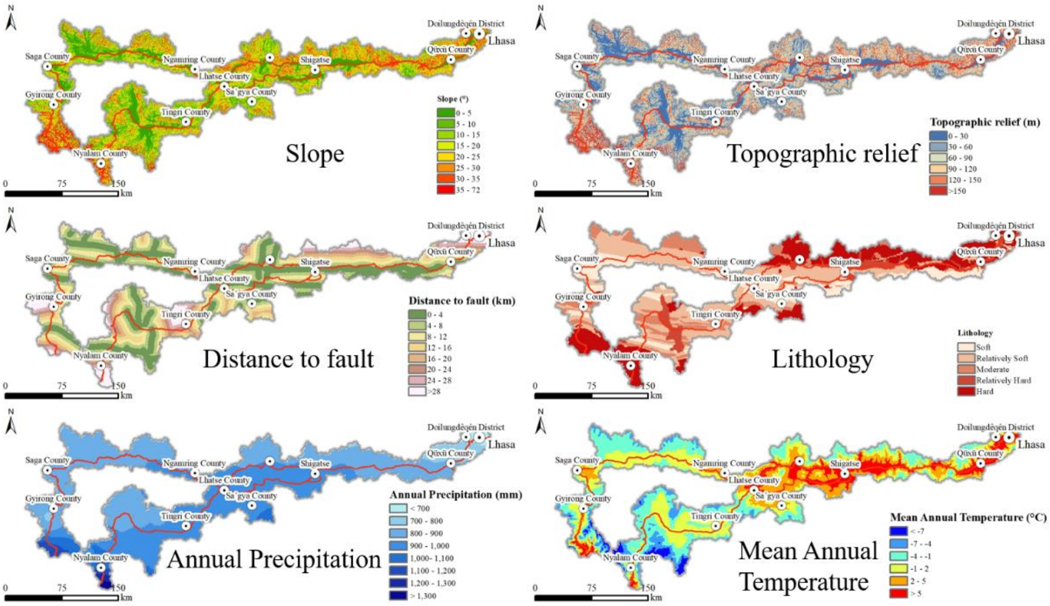

Fig. 3. Debris Flow Conditioning Factors along the China-Nepal Transport Corridor

4. Debris-Flow Risk Assessment

Based on an analysis of field investigation data for different types of debris flows along the China–Nepal Transportation Corridor, a debris-flow hazard assessment indicator system was established, comprising sediment-source factors, including stratigraphy and lithology, distance to faults, and glacier area; energy-related factors, including relative relief of the watershed and slope gradient; and triggering factors, including peak ground acceleration, maximum daily precipitation, maximum daily air temperature, and glacial lake area. The weights of the assessment factors were determined using grey relational analysis (GRA), based on which the debris-flow hazard index was calculated for each small-watershed catchment unit; the resulting hazard values were then classified into different hazard levels using the Jenks natural breaks method.

Considering the spatial heterogeneity of all small-watershed catchment units along the corridor, debris-flow hazard values were calculated for 1,021 small watersheds within the China-Nepal Transportation Corridor. The assessment results in Figure 4 indicate that 295 debris-flow gullies (28.86%) were classified as low hazard level, 223 (21.82%) as relatively low hazard level, 283 (27.69%) as moderate hazard level, 156 (15.26%) as relatively high hazard level, and 65 (6.36%) as high hazard level. Debris-flow gullies with a high hazard level are particularly concentrated in the Gyirong Zangbo basin south of Gyirong County and in the northern area of Nyalam County, primarily because widespread glaciers and glacial lakes in these areas provide abundant sediment sources. These conditions favor glacial and GLOF-induced debris flows. These areas lie on the southern slope of the Himalayas and coincide with two major moisture-transport corridors, providing abundant water sources for mixed-type and rainfall-induced debris flows. Debris-flow gullies with relatively high hazard levels are widely distributed along the Lhasa-Lazi section of the China-Nepal Transportation Corridor. In contrast, debris-flow gullies along the Lazi-Gyirong and Lazi-Dingri sections are generally characterized by moderate or lower hazard levels, which is broadly consistent with the actual debris-flow conditions observed along the corridor.

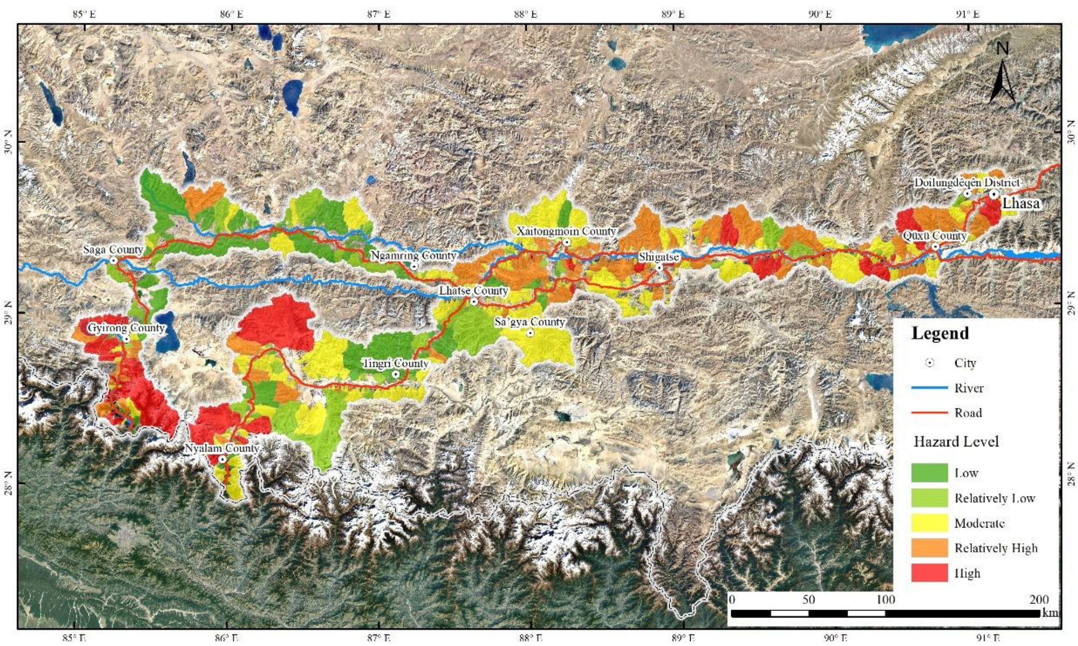

Fig. 4. Debris Flow Hazard Assessment Map of the China–Nepal Transport Corridor

The main elements at risk along the China-Nepal Highway are bridges, culverts, and roadbeds. The distance between the highway and debris flows and the engineering geological conditions were selected to characterize the exposure of the elements at risk; structure type and comprehensive disaster-resistance capacity were used to characterize their vulnerability; and construction cost and distance to the nearest town were selected to represent their recovery capacity. Based on this, a vulnerability assessment indicator system for the elements at risk along the China-Nepal Transportation Corridor was established. A multi-factor comprehensive evaluation method was employed to assess the vulnerability of the elements at risk along the corridor, and the results are shown in Fig. 5.

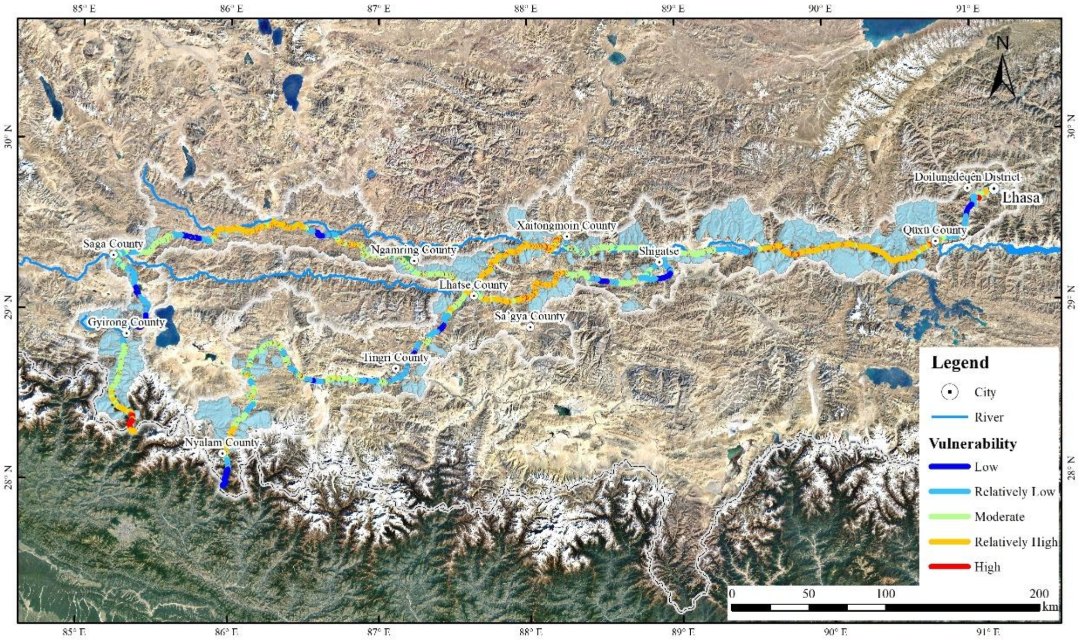

Fig. 5. Vulnerability of the China-Nepal Transport Corridor

Based on the integrated analysis of debris-flow hazard assessment and vulnerability assessment of highway elements at risk, the debris-flow risk along the China-Nepal Transportation Corridor was calculated using the risk expression proposed by the United Nations: Risk = Hazard × Vulnerability. The resulting risk values were classified using the Jenks natural breaks method in ArcGIS, and the study area was divided into five risk levels: low, relatively low, moderate, relatively high, and high risk. The results of the debris-flow risk assessment along the China-Nepal Transportation Corridor are shown in Fig. 6.

The debris-flow risk assessment results indicate that Low-Risk road sections are mainly distributed along the Ngamring-Gyirong section, the southern Nyalam section, and the Lazi–Dingri section, with a total length of 251.82 km, accounting for 17.41% of the entire highway. Relatively low-risk sections occur not only adjacent to the low-risk sections but also in the western part of Shigatse, with a total length of 408.93 km, accounting for 28.27% of the entire highway. Debris flows are less active along the low- and relatively low-risk sections, resulting in a low probability of highway damage and an overall low level of risk. Moderate-risk road sections are mainly distributed along the Shigatse-Xaitongmoin and Lazi-Ngamring sections, with scattered occurrences along the Dingri-Nyalam section. These sections total 359.92 km, accounting for 24.89% of the entire highway. Debris flows are relatively sparsely distributed along these sections, and highway damage is generally limited, resulting in a moderate overall risk level. Relatively high-risk road sections are mainly distributed along the Xaitongmoin-Lazi section, the southern part of Gyirong County, and the Qushui-Shigatse section, totaling 253.26 km and accounting for 17.51% of the entire highway. These sections exhibit the highest concentration of debris flows and relatively severe highway damage, resulting in a relatively high overall risk level. High-risk road sections occur sporadically within the same areas as the relatively high-risk sections, with a total length of 172.36 km, accounting for 11.92% of the entire highway. Although this risk class represents the smallest proportion of the entire highway, these sections contain numerous debris-flow gullies. They are characterized by severe roadbed deformation and settlement, resulting in a high risk of highway damage caused by debris flows.

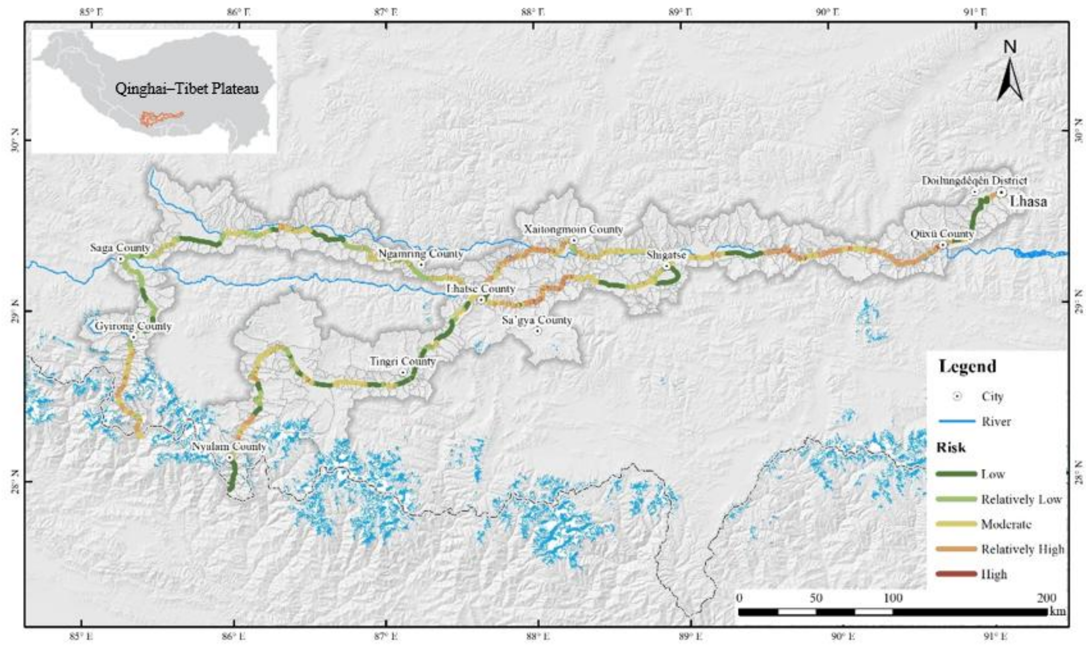

Fig.6. Debris Flow Risk Classification of the China-Nepal Highway Corridor

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[1] Peng CUI, Qiang ZOU, et al. ATLAS OF DISASTER RISK, Science Press, China, 2021.

[2] Investigation and Risk Assessment of Debris Flow in the Himalayas in the Second Tibetan Plateau Scientific Expedition and Research Program (STEP), Grant No. E0A3340341.

[3] IRDR Flagship Project: Silk Road Disaster Risk Reduction