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# Risk Assessment of Debris Flow Disasters in the Northern Mountain Areas of the China-Pakistan Economic Corridor and the Tianshan Mountains

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## Abstract

With the increasing transnational and interregional economic, social, and cultural exchanges, the demand for large-scale debris flow research has become more urgent. The northern mountainous areas of the China-Pakistan Economic Corridor and the Tianshan Mountains exhibit diverse types of debris flows, posing serious threats to the safety of local residents and the smooth implementation of major projects. Currently, there is no research specifically targeting debris flows in this large region. By selecting the northern mountainous areas of the China-Pakistan Economic Corridor and the Tianshan Mountains as the study area, and based on the analysis of the natural geological environment and the distribution characteristics of debris flow disasters in the region, considering the diverse types of debris flows in large areas, eight evaluation factors were chosen: the average annual rainfall over the past 50 years, glacier grid ratio, average annual temperature over the past 50 years, slope, elevation difference, distance from the fault, PGA, and stratigraphic age. The debris flow disaster risk assessment in the study area was conducted using a weighted information model, and the reliability of the model was verified. The results show that areas with higher and high-risk levels are concentrated in the western section of the northern Tianshan Mountains, the southern Tianshan region, and the Pamir-Hindu Kush region, with 88.72% of disaster points distributed in the higher and high-risk areas. These findings have significant guiding implications for the development planning and disaster prevention and mitigation in the northern mountainous areas of the China-Pakistan Economic Corridor and the Tianshan Mountains.

## Subject Areas

Natural Geography

## Keywords

Debris Flow, Hazard Assessment, China-Pakistan Economic Corridor, Tianshan Mountains

## 1. Introduction

Debris flows refer to a natural phenomenon in which a wide range of granular materials mix thoroughly with water and, driven by gravity, move along channels or slopes, causing erosion or deposition downstream. The dynamic pressure generated during the rapid movement, coupled with the impact of large boulders and driftwood embedded in the flow, gives debris flows significant potential for destructive force. The duration of a debris flow typically lasts for several hours, with some events occurring in just a few minutes. Due to the sudden onset, short duration, rapid momentum, and immense destructive power, debris flows have become a significant natural hazard that poses a serious threat to the ecological environment of mountainous regions, transportation routes, and the safety of human lives and property. In a congratulatory letter to the Chinese Academy of Sciences expedition team at the launch ceremony of the second Tibetan Plateau scientific expedition, President Xi Jinping pointed out, "The Tibetan Plateau is the roof of the world, the water tower of Asia, the third pole of the earth, an important ecological security barrier and strategic resource reserve base of our country, and an important protection area for the distinctive culture of the Chinese nation. This scientific expedition should focus on water, ecology, and human activities, revealing the mechanisms of environmental change on the Tibetan Plateau, optimizing the ecological security barrier system, and building a beautiful and happy Tibetan Plateau. At the same time, we must promote the sustainable development of the Tibetan Plateau, advance national ecological civilization, and contribute to global environmental protection." Among these efforts, conducting a major risk assessment of debris flow is an important task. Debris flow risk assessment is of great significance for regional disaster prevention and mitigation, engineering risk prevention, sustainable development, and the implementation of national strategies.

The second comprehensive scientific expedition to the Tibetan Plateau is not limited to the plateau itself; the northern mountainous areas of the China-Pakistan Economic Corridor and the Tianshan Mountains are also important areas of investigation. Many scholars have conducted research on debris flow hazards in the study area. For instance, Shang Yanjun and Wei Xueli have assessed the risk of debris flows in the Obor section of the China-Pakistan Highway [1] [2], and Deng Ensong and others have evaluated the risk of rainfall-induced and glacier-induced debris flows in the same section [3] [4]. Xie Tao and his team assessed the risk of debris flows in 13 glacier debris flow channels along the Tianshan Highway [5]. These studies mainly focus on specific sections of the Tianshan Mountains and the domestic segment of the China-Pakistan Highway, as well as the northern mountainous areas of Pakistan. The research objects are mostly highway debris flows, and the types of debris flows studied are often singular. Currently, no work has been seen targeting the large-scale and multi-type debris flow risk assessment in the northern mountainous areas of the China-Pakistan Economic Corridor and the Tianshan Mountains.

The northern mountainous areas of the China-Pakistan Economic Corridor and the Tianshan Mountains are characterized by rugged terrain, high mountains, deep valleys, significant climatic variation, and active neotectonic movements. Controlled by geological structures and topographical conditions, the region has a unique geological and geographical environment featuring steep slopes, high altitudes, high seismic intensity, and high ground stress, making it one of the world's high-incidence areas for debris flow disasters [6]. The dense distribution of landslides and collapses, coupled with complex and variable climatic and hydrological conditions, provides abundant material and water sources for the formation of debris flows, resulting in frequent occurrences of debris flows in this region [7] [8]. Debris flows pose serious threats to construction and the safety of people's livelihoods in the area. To reduce casualties and economic losses caused by debris flow disasters, a systematic and scientific risk assessment of debris flows in the region is urgently needed.

With the advancement of the Belt and Road Initiative, the increasing transnational and interregional economic, social, and cultural exchanges have made the need for large-scale debris flow research more pressing. The northern mountainous areas of the China-Pakistan Economic Corridor and the Tianshan Mountains include numerous important engineering projects such as the proposed China-Pakistan Railway, the proposed China-Kyrgyzstan-Uzbekistan Railway, the proposed new Tibet Railway, the already constructed China-Pakistan Highway, the Duku Highway, and many other highways and roads both domestically and internationally. Various types of debris flows in the region seriously affect the construction and maintenance of these projects.

This paper focuses on the various types of debris flows present in the region, conducting a regional debris flow investigation and establishing a debris flow risk assessment system based on the triggering conditions and disaster-prone environment. Considering the large coverage of the area and the difficulty in obtaining some foreign data, a weighted information model based on the Analytic Hierarchy Process (AHP) is used to evaluate the risk in the study area, exploring the distribution of risk areas, which provides some reference value for the disaster prevention and mitigation strategy for debris flows in the northern mountainous areas of the China-Pakistan Economic Corridor and the Tianshan Mountains.

## 2. Disaster-Prone Environment for Debris Flows in the Study Area

The northern mountainous areas of the China-Pakistan Economic Corridor and the Tianshan Mountains are located between 33˚N-46˚N and 66˚E-96˚E. The study area includes the Tianshan region and the northern mountainous areas of the China-Pakistan Economic Corridor (Figure 1). The Tianshan region refers to the Tianshan Mountains and their surrounding geographical areas in central Eurasia, including parts of Xinjiang in China, Kazakhstan, Kyrgyzstan, and Uzbekistan. It is an important corridor and bridge connecting China with Central Asia, West Asia, and Europe. The northern mountainous areas of the China-Pakistan Economic Corridor extend from Kashgar in China to north of Islamabad in Pakistan. The typical high mountain steep slope terrain, intense tectonic activity, fragile ecological environment, and sensitive climatic conditions in the study area make debris flow disasters highly prevalent. Through literature review, remote sensing interpretation, and field investigation, it has been determined that there are a total of 4927 debris flow disaster sites in the study area (Figure 1), with diverse types of debris flows, including 1364 rainfall-induced, 1791 glacier-induced, 1727 glacial meltwater-induced, and 45 glacial lake outburst-induced.

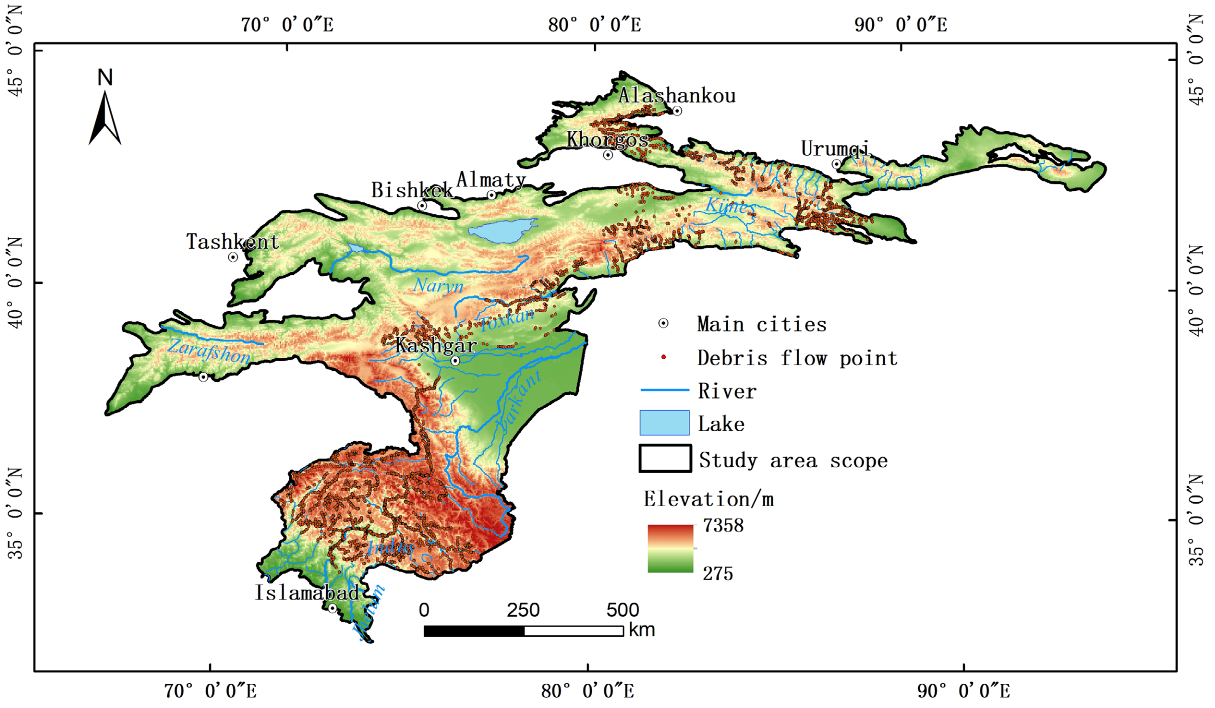


Figure 1. Location and distribution of disasters in the study area.

### Overview of the Natural Geological Environment

The northern mountainous areas of the China-Pakistan Economic Corridor and the Tianshan Mountains were formed by the collision of the Eurasian Plate and the Indian Plate. This region is characterized by significant vertical displacement along major fault zones, resulting in rugged terrain with numerous peaks and widespread continental glaciers. Influenced by intense regional tectonic activity, the area features deeply incised high mountain valleys, primarily consisting of alpine valley landforms, glacial landforms, and erosional landforms. These unique topographical conditions provide a conducive environment for the occurrence of debris flow disasters.

The Tianshan region, situated in the heart of the Eurasian continent, experiences a typical continental climate with pronounced vertical zonation. The vertical climatic characteristics range from polar to temperate zones, with precipitation patterns varying from semi-humid to extremely arid. The snowline in the mountains is near 4000 meters. The Tianshan Mountains intercept westerly moisture, resulting in abundant precipitation, snow, and glacial water resources. The northern mountainous areas of the China-Pakistan Economic Corridor experience a warm temperate continental arid climate with distinct vertical zonation, characterized by contrasting climates between high mountain glaciers and hot dry valleys. The middle and lower elevations have a typical mountain climate, with hot and humid summers and cold and dry winters. Peaks above 5000 meters are covered by permanent snow and glaciers, providing a continuous source of water from precipitation and snowmelt for debris flows.

The study area is marked by intense tectonic deformation and active faulting, with frequent moderate to strong earthquakes. Seismic activity in the Tianshan Mountains is associated with several geological fault zones, which divide the Tianshan region into three nearly east-west extending tectonic belts: the Northern Tianshan Main Fault Zone, the Central Tianshan Tectonic Belt, and the Southern Tianshan Foredeep Fault Zone [9]. The northern mountainous areas of the China-Pakistan Economic Corridor are geologically active, with complex development of major fault zones, including the Main Karakoram Thrust (MKT), the Main Mantle Thrust (MMT), and the Main Boundary Thrust (MBT). The surrounding rocks in these fault zones exhibit varying degrees of fracturing and metamorphism, complicating the geological conditions and exacerbating the occurrence of debris flow disasters.

The geological conditions in the study area are complex, with strata ranging from the Quaternary to the Archean eras. The Quaternary, Carboniferous, and Devonian strata are widely developed, with the Quaternary mainly distributed in the central and eastern parts of the Southern Tianshan and the central part of the northern mountainous areas of the China-Pakistan Economic Corridor. The Carboniferous is primarily found in the central parts of the Northern and Central Tianshan, while the Devonian is mainly distributed in the southwestern part of the Southern Tianshan and the northern part of the northern mountainous areas of the China-Pakistan Economic Corridor.

## 3. Types and Distribution Characteristics of Debris Flows in the Study Area

Rainfall-induced debris flows mainly occur from June to September (summer and autumn, especially in July and August) and are closely related to atmospheric precipitation (particularly heavy rain, torrential rain, and extreme torrential rain). These debris flows primarily develop along both sides of river valleys at relatively low elevations in non-glacial areas. They have a long duration, wide distribution, and large affected areas, often accompanied by floods. There are a total of 1364 rainfall-induced debris flows in the study area, mainly distributed in the eastern part of the Northern Tianshan, the eastern part of the Central Tianshan, the western part of the Southern Tianshan, and the western and southern parts of the northern mountainous areas of the China-Pakistan Economic Corridor.

Glacier-induced debris flows primarily develop in mid-high mountainous areas and typically occur in summer and autumn when temperatures rise and meltwater is abundant. Both continental alpine glaciers and maritime glaciers are present in the study area. Due to differences in regional environmental backgrounds, the scale and thickness of glaciers vary, leading to different melting rates, especially in the Karakoram region, where the “Karakoram anomaly” phenomenon exists. Glacier-induced debris flows are characterized by a high content of poorly rounded glacial till and often appear as dilute debris flows or even water-stone flows. Compared to rainfall-induced debris flows, glacier-induced debris flows are larger in scale and have a longer flow duration. There are 1791 glacier-induced debris flows in the study area, mainly distributed in the central parts of the Northern and Southern Tianshan and the central and northern parts of the northern mountainous areas of the China-Pakistan Economic Corridor.

Mixed glacial meltwater debris flows differ significantly from general rainfall-induced debris flows. Their formation mainly depends on water sources related to glaciers (snow). Based on field investigations and the characteristics of debris flow water sources, the mixed glacial meltwater debris flows in the study area mainly include glacier (snow) meltwater debris flows, ice (snow) avalanche debris flows, and mixed rain and glacier meltwater debris flows. There are 1727 mixed glacial meltwater debris flows in the study area, mainly distributed in the western part of the Northern Tianshan, the central and western parts of the Southern Tianshan, and the central and southern parts of the northern mountainous areas of the China-Pakistan Economic Corridor.

Glacial lake outburst debris flows are a special type of debris flow that occurs in high-cold mountain areas. Lakes near modern glacier areas can be divided into glacial-dammed lakes and moraine-dammed lakes. Glacial dammed lakes are mainly found in high latitude and continental polar glacier areas, while the glacial lakes in the study area are mainly moraine-dammed lakes, predominantly terminal moraine lakes. Therefore, glacial lake outburst debris flows in the study area are mainly of the moraine-dammed lake type. There are 45 glacial lake outburst debris flows in the study area, sporadically distributed in the central parts of the Northern and Southern Tianshan.

## 4. Hazard Assessment Indicators and Methods

### 4.1. Assessment Model

The weighted information value model [10] is widely used due to its advantages of easy and convenient determination of weights and scientifically objective quantification of indicators. This model allows the contribution of various disaster-causing factors to debris flow occurrences to be quantified through the statistical analysis of historical debris flow disaster sites. Consequently, it can be extended to dynamic hazard assessments of debris flows under future climate change scenarios. The information value model can be expressed as follows:

$$I=\sum_{i=1}^{n}\ln\left[\frac{N_i/N}{S_i/S}\right]$$

In the formula:

$I$ represents the total information value of a specific evaluation unit in the study area;

$N_i$ is the number of debris flows distributed within disaster-causing factor $x_i$;

$N$ denotes the total number of debris flow disasters occurring within the study area;

$S_i$ is the total area of disaster-causing factor $x_i$ within the study area;

$S$ represents the total area of the evaluation units in the study area.

The information value model can be enhanced using the Analytic Hierarchy Process (AHP) to determine the weight of each disaster-causing factor ( $w_i$, $i=1,2,\cdots,n$ ). By multiplying the weight with the information value, the weighted information value is obtained. The weighted information value model can be expressed as follows:

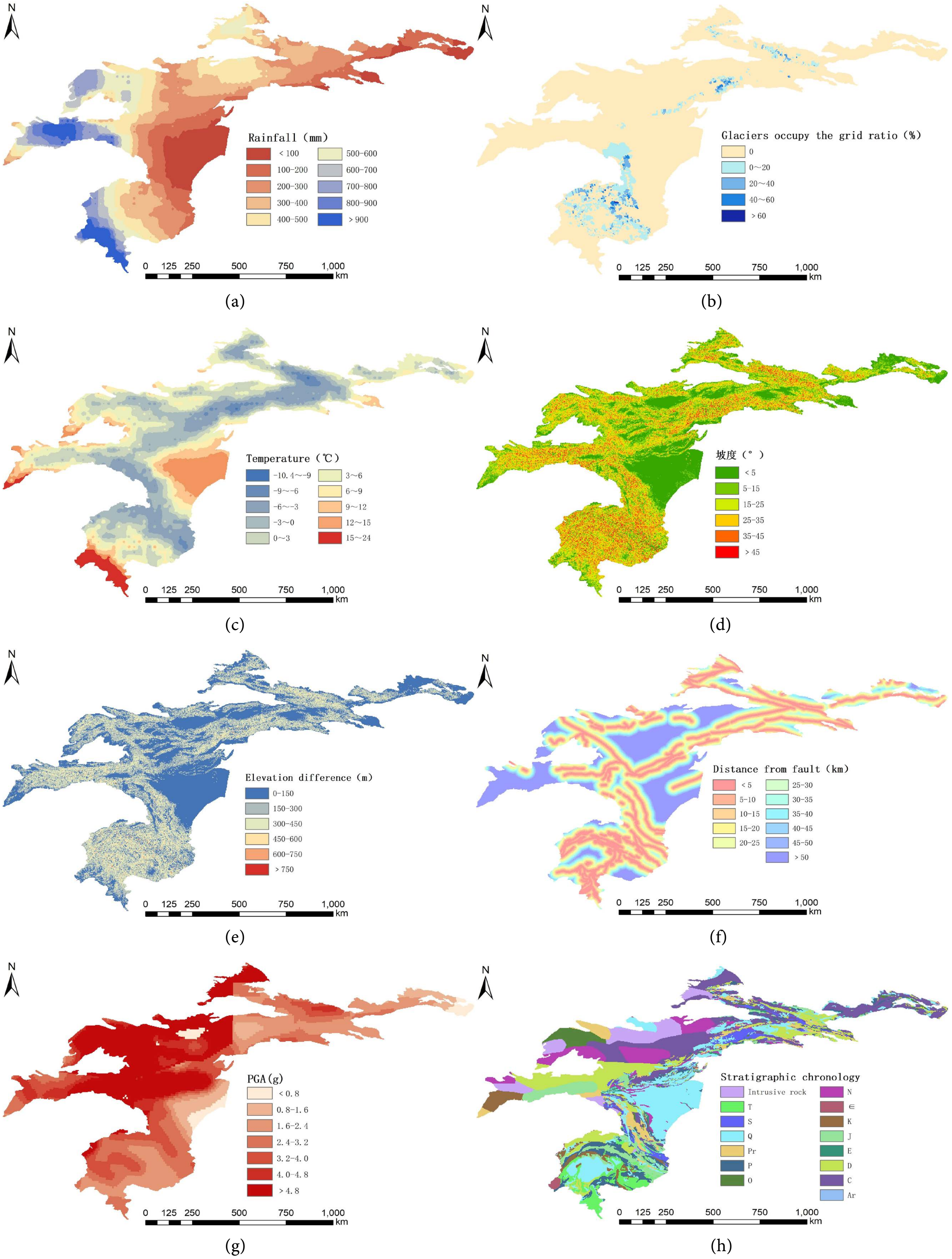
$$I'=\sum_{i=1}^{n}w_i\ln\left[\frac{N_i/N}{S_i/S}\right]$$

The use of the Analytic Hierarchy Process (AHP) to determine weights and to weight the information values has significantly improved the accuracy of the debris flow hazard assessment results.

### 4.2. Selection of Evaluation Factors

Debris flow disasters in the northern mountainous regions of the China-Pakistan Economic Corridor and the Tianshan Mountains are closely linked to their unique geomorphological, geological, hydrological, and climatic environments. This study selects eight factors from the past 50 years to construct a debris flow hazard assessment index system: annual average rainfall, glacier coverage ratio, annual average temperature, slope, elevation difference, distance to fault lines, peak ground acceleration (PGA), and stratigraphic age (**Figure 2**).

Rainfall is the primary hydrodynamic force triggering debris flows and serves as an initiating factor; the annual average rainfall over the past 50 years is used to represent this rainfall-triggering factor. Glacier melt provides water sources for



(a) (b)

(c) (d)

(e) (f)

(g) (h)

**Figure 2.** Evaluation factor layer.

debris flow occurrences. The annual average temperature over the past 50 years represents the temperature distribution in the study area; rising temperatures increase glacier melt, supplying water for debris flows in glacier regions. Slope and elevation difference in the disaster-prone environment reflect slope stability to some extent and directly influence the accumulation and distribution of material and water on slopes. Stratigraphic age determines rock type and hardness, indicating the rock's weathering and erosion resistance [11]. Fault zones are characterized by active tectonic activity and fractured rocks, containing abundant loose deposits; the closer the distance to fault lines, the greater the likelihood of loose deposits. Moderate to strong earthquakes can induce numerous landslides and other geological disasters, providing ample material for debris flows. Surface damage (including geological disasters) caused by earthquakes is primarily due to seismic inertial forces, which can be directly measured by peak ground acceleration (PGA).

## 5. Debris Flow Hazard Assessment

### 5.1. Information Value Calculation

The information value III for each evaluation factor is calculated according to Equation (1), as shown in **Table 1**.

The information values include both positive and negative values. The larger

**Table 1.** Classification and information value of debris flow hazard factors

| Factor | Classification | Information Value Calculation (Grid Units) | | |
|---|---|---|---|---|
| | | $A_i$ | $S_i$ | Information Value |
| 50-year average annual rainfall (mm) | <100 | 39 | 100,908 | −2.713 |
| | 100 - 200 | 600 | 114,759 | −0.109 |
| | 200 - 300 | 965 | 157,500 | 0.049 |
| | 300 - 400 | 1237 | 146,799 | 0.368 |
| | 400 - 500 | 986 | 117,792 | 0.361 |
| | 500 - 600 | 562 | 69,165 | 0.331 |
| | 600 - 700 | 259 | 35,424 | 0.226 |
| | 700 - 800 | 154 | 42,813 | −0.483 |
| | 800 - 900 | 76 | 25,713 | −0.679 |
| | >900 | 49 | 34,155 | −1.402 |
| Glacier grid ratio (%) | 0 | 3243 | 764,766 | −0.318 |
| | 0 - 20 | 1317 | 61,128 | 1.307 |
| | 20 - 40 | 291 | 15,012 | 1.201 |
| | 40 - 60 | 73 | 3915 | 1.163 |
| | >60 | 3 | 207 | 0.911 |

**Continued**

| | | | | |
|---|---|---|---|---|
| 50-year average annual temperature (˚C) | −10.4 - −9 | 6 | 333 | 1.128 |
| | −9 - −6 | 115 | 13,401 | 0.386 |
| | −6 - −3 | 689 | 119,853 | −0.014 |
| | −3 - 0 | 1077 | 149,121 | 0.214 |
| | 0 - 3 | 1303 | 187,434 | 0.175 |
| | 3 - 6 | 1010 | 155,088 | 0.110 |
| | 6 - 9 | 435 | 74,934 | −0.004 |
| | 9 - 12 | 240 | 57,708 | −0.337 |
| | 12 - 15 | 49 | 62,883 | −2.012 |
| | 15 - 24 | 3 | 24,273 | −3.853 |
| Slope (˚) | <5 | 464 | 194,580 | −0.894 |
| | 5 - 15 | 928 | 193,527 | −0.195 |
| | 15 - 25 | 1021 | 179,271 | −0.023 |
| | 25 - 35 | 1534 | 188,505 | 0.333 |
| | 35 - 45 | 843 | 79,011 | 0.604 |
| | 45 - 60 | 137 | 10,134 | 0.841 |
| Elevation difference (m) | 0 - 150 | 1085 | 357,282 | −0.652 |
| | 150 - 300 | 1742 | 292,293 | 0.022 |
| | 300 - 450 | 1650 | 167,418 | 0.525 |
| | 450 - 600 | 411 | 25,605 | 1.013 |
| | 600 - 750 | 37 | 2223 | 1.049 |
| | 750 - 900 | 2 | 207 | 0.505 |
| Distance to fault (km) | 0 - 5 | 1250 | 130,635 | 0.495 |
| | 5 - 10 | 905 | 113,355 | 0.314 |
| | 10 - 15 | 602 | 98,226 | 0.050 |
| | 15 - 20 | 570 | 82,962 | 0.164 |
| | 20 - 25 | 368 | 68,877 | −0.087 |
| | 25 - 30 | 281 | 55,152 | −0.135 |
| | 30 - 35 | 261 | 43,128 | 0.037 |
| | 35 - 40 | 213 | 35,640 | 0.025 |
| | 40 - 45 | 146 | 30,960 | −0.212 |
| | 45 - 50 | 112 | 26,352 | −0.316 |
| | >50 | 219 | 159,741 | −1.448 |
| PGA (g) | 0 - 0.8 | 9 | 27,189 | −2.869 |
| | 0.8 - 1.6 | 109 | 51,147 | −1.006 |

**Continued**

| | | | | |
|---|---|---|---|---|
| | 1.6 - 2.4 | 1478 | 160,398 | 0.458 |
| | 2.4 - 3.2 | 1567 | 161,244 | 0.511 |
| | 3.2 - 4 | 1203 | 114,156 | 0.592 |
| | 4 - 4.8 | 115 | 63,432 | −1.168 |
| | 4.8 - 10.68 | 446 | 267,462 | −1.252 |
| Stratigraphic age | Q | 1176 | 171,000 | 0.165 |
| | E | 17 | 6084 | −0.736 |
| | J | 278 | 58,428 | −0.203 |
| | N | 82 | 67,410 | −1.567 |
| | K | 271 | 27,342 | 0.531 |
| | 1 | 13 | 59,121 | −3.277 |
| | S | 289 | 27,540 | 0.588 |
| | Pr | 230 | 42,003 | −0.063 |
| | ∈ | 0 | 4059 | 0 |
| | C | 517 | 150,210 | −0.527 |
| | O | 24 | 23,949 | −1.761 |
| | D | 849 | 120,906 | 0.186 |
| | P | 716 | 48,033 | 0.939 |
| | T | 435 | 38,340 | 0.666 |
| | Ar | 30 | 603 | 2.144 |

the positive value, the higher the probability of hazard occurrence; conversely, the smaller the negative value, the lower the probability of hazard occurrence. This leads to the identification of factor categories that significantly influence the occurrence of debris flow hazards in the northern mountainous region of the China-Pakistan Economic Corridor and the Tianshan Mountains: the 50-year average annual rainfall of 300 - 400 mm, glacier grid ratio of 0 - 20%, 50-year average annual temperature of −10.4˚C to −9˚C, slope of 45˚ - 60˚, elevation difference of 600 - 750 m, distance to fault of 0 - 5 km, PGA of 3.2 - 4, and stratigraphic age of Ar. In these factor categories, the probability of debris flow hazards is relatively high.

## 5.2. Hazard Assessment Based on the Weighted Information Model

Considering the actual conditions of the study area and using the debris flow hazard assessment index system as the overall objective, the criteria layers of excitation conditions and hazard-forming environments are further refined into several indicators based on their affiliations, establishing the debris flow hazard assessment index system for the study area (**Figure 3**). According to the Analytic

Hierarchy Process (AHP), the eight debris flow hazard indicators are analyzed to establish a hierarchical structure and determine the weight of each factor. The weights of the hazard indicators are shown in Table 2.

Drawing on previous experiences in hazard classification, the natural breaks method in ArcGIS was employed to classify hazard coefficients into five levels: low, relatively low, medium, relatively high, and high. A statistical analysis of the

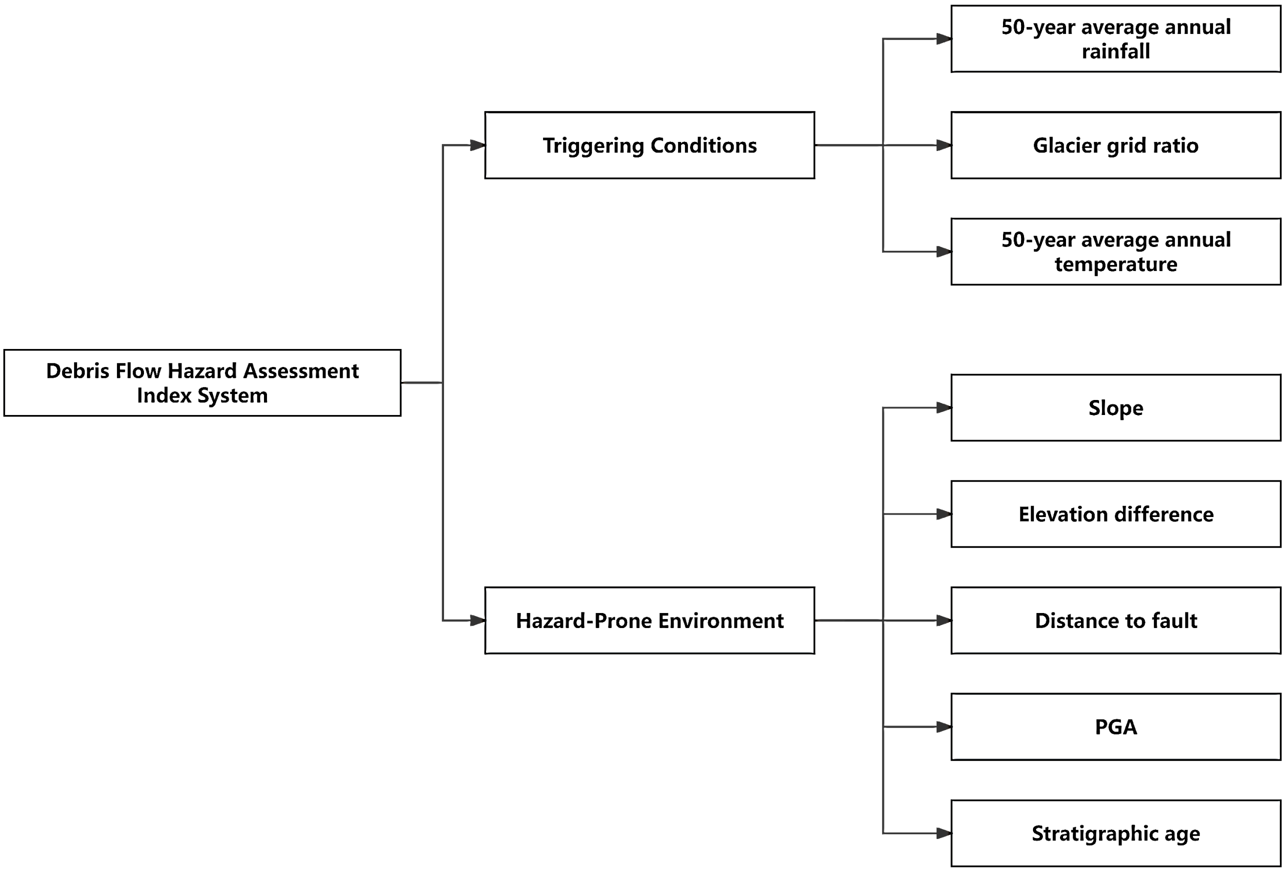


Figure 3. Debris flow hazard assessment index system.

Table 2. Weights of hazard assessment factors.

| Highest Level | Intermediate Level | Weight | Lowest Level | Weight | Total Weight |
|---|---|---|---|---|---|
| Debris Flow Hazard Assessment Indicator System | Triggering Conditions | 0.333 | Average Annual Rainfall in the Past 50 Years | 0.493 | 0.1645 |
| | | | Glacier Coverage | 0.196 | 0.0653 |
| | | | Average Annual Temperature in the Past 50 Years | 0.311 | 0.1036 |
| | Hazardous Environment | 0.667 | Slope | 0.298 | 0.1986 |
| | | | Elevation Difference | 0.158 | 0.1052 |
| | | | Distance to Fault | 0.158 | 0.1052 |
| | | | PGA | 0.088 | 0.059 |
| | | | Geological Age | 0.298 | 0.1986 |

area and number of disaster occurrences in each hazard level showed a positive correlation between higher hazard levels and an increase in both the number and density of debris flow disaster points. Approximately 88.72% of disaster points were located in areas classified as relatively high and high hazard, while only 1.46% of disaster points were found in areas classified as relatively low and low hazard (Table 3). The evaluation results correspond well with actual conditions, indicating the model's high reliability in assessing debris flow hazard in the region. The hazard zoning map (Figure 4) demonstrates that high-hazard areas for debris flow disasters in the northern mountainous regions of the China-Pakistan Economic Corridor and the Tianshan Mountains are primarily concentrated in the western section of the northern Tianshan, southern Tianshan, and the Pamir-Hindu Kush regions.

**Table 3.** Debris flow hazard zone statistics.

| Hazard Level | Area ($km^2$) | Area Proportion (%) | Number of Debris Flows | Proportion of Debris Flow Points (%) | Debris Flow Density ($units \cdot 10^{-2} \cdot km^{-2}$) |
|---|---|---|---|---|---|
| Low | 92,628 | 10.96 | 8 | 0.16 | 0.0086 |
| Relatively Low | 131,814 | 15.60 | 64 | 1.30 | 0.0486 |
| Medium | 215,766 | 25.53 | 484 | 9.82 | 0.2243 |
| Relatively High | 249,957 | 29.58 | 1687 | 34.24 | 0.6749 |
| High | 154,863 | 18.33 | 2684 | 54.48 | 1.7331 |

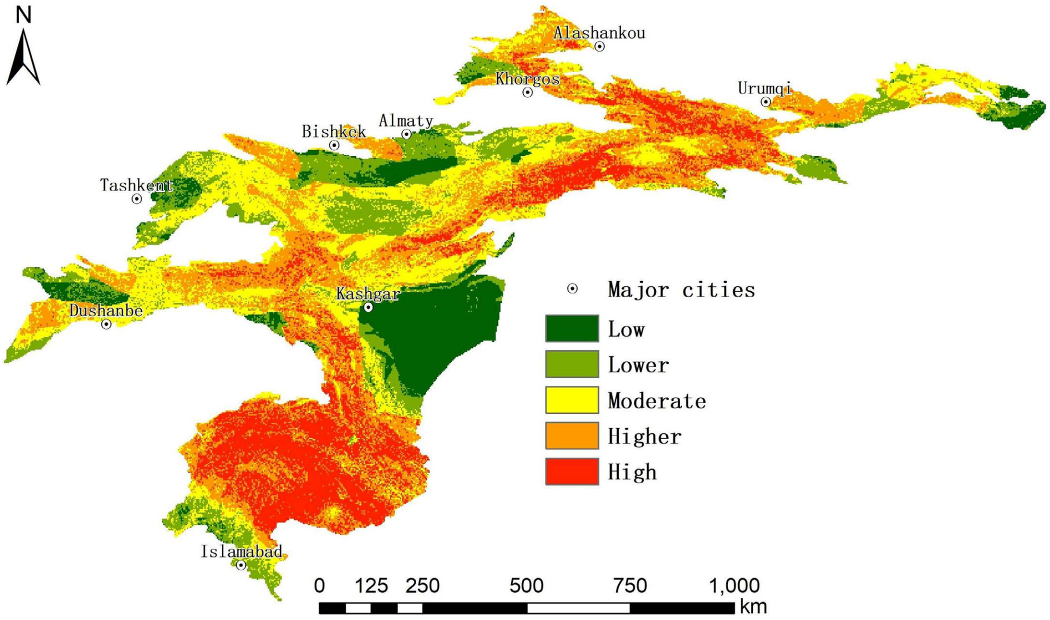


**Figure 4.** Hazard zoning map.

## 6. Conclusions

A study was conducted in the northern mountainous regions of the China-Pakistan Economic Corridor and the Tianshan Mountains using the Weighted Information Model to assess the regional debris flow hazard. The conclusions are as follows:

1) Based on literature review, remote sensing interpretation, and field investigation, a total of 4,927 debris flow disaster sites were identified in the study area. Rainfall-induced debris flows are primarily distributed in the eastern section of the northern Tianshan, the eastern section of the central Tianshan, the western section of the southern Tianshan, and the western and southern parts of the northern mountainous region of the China-Pakistan Economic Corridor. Glacier-induced debris flows are mainly found in the central section of the northern Tianshan, the central section of the southern Tianshan, and the central and northern parts of the northern mountainous region of the China-Pakistan Economic Corridor. Mixed glacial and water-induced debris flows are primarily distributed in the western section of the northern Tianshan, the central and western sections of the southern Tianshan, and the south-central part of the northern mountainous region of the China-Pakistan Economic Corridor.

2) An eight-factor debris flow hazard index system was constructed using the following factors: average annual rainfall over the past 50 years, glacier coverage ratio, average annual temperature over the past 50 years, slope, elevation difference, distance to fault, peak ground acceleration (PGA), and geological age of strata. The model calculation produced a hazard distribution map, which indicated that areas with relatively high and high hazard levels are concentrated in the western section of the northern Tianshan, the southern Tianshan region, and the Pamir-Hindu Kush region. Statistical analysis of the proportion of disaster points within each hazard level revealed that 88.72% of disaster points are located in relatively high and high-hazard areas. Moreover, the density of disaster points increases with higher hazard levels, indicating the model's high reliability.

## 7. Limitations and Future Prospects

This study utilizes the spatial analysis capabilities of GIS to conduct a quantitative assessment of debris flow hazards in the research area. While certain achievements have been made, there are still limitations due to personal expertise and objective constraints. The primary issues are as follows:

1) The identification of debris flow hazards in the study was based on the interpretation of remote sensing images and historical records. Given the vast scope of the research area, which encompasses the entire China-Pakistan highway corridor across both countries, conducting a detailed examination of each disaster point poses significant challenges. The traces of some older debris flow events have been destroyed, making it difficult to interpret them from remote sensing images, resulting in potential errors or omissions in the location or attribute data of debris flows. This, in turn, may affect the accuracy of the study's findings.

2) Due to the extensive scope of the study area, the collected research data were relatively coarse, and the grid-based evaluation units used were also large, resulting in a lack of precision in the evaluation outcomes. Future studies could focus on conducting more refined hazard assessments specifically for areas classified as relatively high or higher hazard zones.

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## Conflicts of Interest

The author declares no conflicts of interest.

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