

## Analysis of Distribution Characteristics and Main Controlling Factors of Geological Hazards in the Ili Valley (Postprint)

**Authors:** Liang Shichuan

**Date:** 2023-07-19T00:00:00+00:00

### Abstract

The Ili Valley frequently experiences geological hazards such as landslides, collapses, debris flows, and ground collapse, with diverse influencing factors for hazard formation. Based on the geological hazard database of the Ili Valley, statistical analysis methods including the frequency ratio method and Receiver Operating Characteristic curve (ROC) were employed to investigate the distribution characteristics of geological hazards in the Ili Valley and analyze the main controlling factors of hazard development. The results indicate that: (1) The overall development intensity of geological hazards in the Ili Valley is greater in the eastern part than in the western part, concentrated in medium-low mountain areas at elevations of 500–3500 m. Temporally, they are mainly concentrated in the spring and summer snowmelt and rainy seasons. (2) The development of geological hazards is influenced by multiple factors including lithology, geological structure, topography and geomorphology, and precipitation, but the main controlling factors differ among different types of hazards: landslides are most significantly affected by lithology, elevation, slope gradient, and annual precipitation; collapses are mainly controlled by slope gradient, elevation, and distance to fault; ground collapse is significantly influenced by elevation, distance to fault, and precipitation, and is primarily induced by underground mining activities; distance to fault and elevation are the main controlling factors for debris flow development.

### Full Text

## Distribution Characteristics and Main Controlling Factors of Geohazards in Ili Valley

**LIANG Shichuan, QIAO Hua, LYU Dong, HE Qiang**

*(Xinjiang Uygur Autonomous Region Institute of Geological Environment Mon-*

*itoring, Urumqi 830000, Xinjiang, China)*

## Abstract

Geohazards such as landslides, rock falls, debris flows, and ground collapse occur frequently in the Ili Valley, with diverse influencing factors for their formation. Based on the geohazard database of the Ili Valley, this study employs statistical analysis methods including the frequency ratio method and receiver operating characteristic (ROC) curve to investigate the distribution characteristics and analyze the main controlling factors of geohazard development. The results indicate that: (1) The overall development degree of geohazards in the Ili Valley is greater in the east than in the west, concentrated in low mountainous areas (500–3500 m). Temporally, geohazards mainly occur during spring and summer snowmelt and rainfall seasons. (2) Geohazard development is influenced by multiple factors including stratigraphic lithology, geological structure, topography, and precipitation. However, the main controlling factors differ among geohazard types. Landslides are most significantly affected by stratigraphic lithology, elevation, slope gradient, and annual precipitation. Rock falls are primarily controlled by slope gradient, elevation, and distance from faults. Ground collapse is significantly influenced by elevation, distance from faults, and precipitation, and is basically induced by underground mining activities. Distance from faults and elevation are the main controlling factors for debris flow development.

**Keywords:** geohazards; distribution characteristics; main controlling factors; frequency ratio; ROC curve; Ili Valley

---

## 1 Study Area Overview

The Ili Valley is located in the western section of the Tianshan Mountains in China, characterized by complex topographic and geological conditions, a semi-arid climate with cold winters and hot summers, large diurnal temperature differences, strong weathering and denudation, and a fragile geological environment. The area experiences highly developed geohazards including landslides, rock falls, and debris flows, making it a geohazard-prone region in Xinjiang. Frequent geohazards not only cause tremendous damage to the ecological environment but also seriously threaten local lives and property, constraining sustainable socio-economic development.

Specific major events include: a large-scale loess landslide in 2004 at the Xinyuan County Bee Farm–Zeketai road section (13 km) that caused long-term traffic disruption; a 2012 loess landslide in Mohuer Township, Gongliu County that resulted in 4 missing persons and direct economic losses of  $2.4 \times 10^6$  yuan; and a landslide in the Guozigou section in 2013 that blocked traffic. Investigating geohazard distribution characteristics and identifying the main controlling factors are crucial for geohazard assessment and disaster prevention.

Previous studies have identified various influencing factors. An Haitang et al. [?] suggested that loess landslide formation in the Ili region is affected by loess characteristics, precipitation and snowmelt, earthquakes, vegetation, and engineering activities. Cao Xiaohong et al. [?] used statistical induction methods based on field surveys to propose a positive correlation between landslide frequency and precipitation amount/frequency in the Ili Valley, with landslides most concentrated in the 1300–2000 m elevation range of middle-low mountains and low hilly areas. Zhang Hongyi et al. [?] studied loess landslides in Xinyuan County’s mountainous area and concluded that geomorphological and geological conditions form the basis for landslide formation, while atmospheric precipitation is the main triggering factor. However, existing research has mainly focused on loess landslides, lacking systematic understanding of the main controlling factors for all geohazard types in the Ili Valley.

This paper, based on years of field survey data and using statistical induction methods such as the frequency ratio method, investigates the distribution characteristics of geohazards including rock falls, landslides, debris flows, and ground collapse in the Ili Valley. It analyzes the main controlling factors for these geohazards, revealing the characteristics of how topography, geological structure, stratigraphic lithology, precipitation, and human engineering activities affect geohazards. The findings provide references for geohazard assessment and disaster prevention in the Ili region, serving the implementation of the “Belt and Road” Initiative.

The Ili Valley is situated in the western Tianshan Mountains of Xinjiang, between the North Tianshan and South Tianshan branches, presenting a “three mountains 夹着 two valleys and one basin” geomorphological pattern with complex geological conditions. The study area encompasses the Kunes River Valley and Kashgar River Valley between the North Tianshan, Wusun Mountain, and A’wula Mountain, as well as the Tekes–Zhaosu Basin in the south. The primary tectonic unit belongs to the Tianshan fold system, including three secondary units: the Boluokenu anticlinorium, Ili block, and Ha’erkeshan anticlinorium. Major faults include the Nileke Fault, Nileke East Jirentai buried fault, Kunes River buried fault, Nalati Fault, A’wula Mountain West End Fault, Yamadu Fault, Qiaobo River Fault, Ha’erkeshan Fault, and Zhaosu–Tekes Fault [?].

The stratigraphic lithology is complex, with strata from the Proterozoic to the Cenozoic distributed throughout the study area. Quaternary (Lower Pleistocene–Holocene) loess is widely distributed, primarily along the piedmont zones on both sides of the valley, covering bedrock slopes in mountainous areas where geohazards frequently occur. Vertically, it extends up to the forest belt and down to the valley plain, with elevations of 600–2200 m and thicknesses generally ranging from several meters to nearly 100 m, reaching up to 200 m locally [?]. Although the Ili Valley is a continental semi-arid region far from the ocean, its north, east, and south sides are surrounded by high mountains forming a trumpet-shaped valley opening to the west. Moist air currents from the Arctic and Atlantic Oceans can directly enter through the western

opening, frequently creating rainy and snowy weather with relatively abundant precipitation, thus exhibiting characteristics of a humid continental temperate climate with annual precipitation of 220–464 mm [?]. Under endogenic and exogenic forces, geohazards such as landslides, rock falls, and debris flows are highly developed (Fig. 1).

---

## 2 Data and Methods

### 2.1 Data Sources

This study is based on the 2011–2020 Xinjiang Geohazard Database, combined with field surveys and remote sensing interpretation (using Google Earth imagery) to establish a geohazard database for the Ili Valley. The database includes 1,102 geohazard sites: 551 landslides, 294 rock falls, 215 debris flows, and 42 ground collapses. Topographic data including slope gradient, aspect, and elevation were extracted from 30 m resolution digital elevation model (DEM) data (<http://www.gscloud.cn/>) using ArcGIS. Fault data were obtained from the fault dataset of the National Earthquake Active Fault Research Center (<https://www.igl.ac.cn/gjdzhdscyjzx/index.html>). Mean annual precipitation data were downloaded from WorldClim (<https://www.worldclim.org/data/index.html>).

### 2.2 Methods

**2.2.1 Frequency Ratio Method** To investigate the influence of geological structure, topography, and precipitation on geohazards, ArcGIS tools including “Zonal Statistics as Table” were used to analyze distance from faults, elevation, slope gradient, aspect, precipitation, and other information [?]. Elevation was classified into 8 levels at 500 m intervals; distance from faults was divided into 7 classes: 0–100 m, 100–200 m, 200–400 m, 400–800 m, 800–1600 m, 1600–3200 m, and >6400 m; slope gradient was divided into 8 levels at 5° intervals; aspect was divided into 8 categories using the natural breaks method; and precipitation was divided into 5 classes at 50 mm intervals. Based on these classifications, the “Reclassify” tool was used to process elevation, slope, and aspect data. The raster area and number of disasters in each category were counted to calculate the frequency ratio (FR) of geohazard influencing factors:

$$FR_i = \frac{H_i/A_i}{H/A}$$

where a certain influencing factor for a geohazard type is assumed to be divided into  $i$  classes (e.g., slope factor divided into 0–5°, 5–10°, ...,  $i$  classes).  $H_i$  is the number of a certain geohazard type in the  $i$ th class of the influencing factor;  $A_i$  is the area of the  $i$ th class of the influencing factor in the study area;  $H$  is the total number of that geohazard type in the study area; and  $A$  is the total area of the study area. In this paper,  $H_i$  and  $H$  are represented by disaster counts.

A higher FR value indicates that disasters are more likely to occur within that factor range.

**2.2.2 ROC Curve** To further analyze the influence degree of various geohazard factors, the receiver operating characteristic (ROC) curve was used to evaluate the effect of different influencing factors [?]. The  $x$ -axis represents the false positive rate ( $FPR = FP/(FP + TN)$ ), and the  $y$ -axis represents the true positive rate ( $TPR = TP/(TP + FN)$ ). FP represents false positives (predicted as having geohazards but actually none), TN represents true negatives (predicted as no geohazards and actually none), TP represents true positives (predicted as having geohazards and actually having them), and FN represents false negatives (predicted as no geohazards but actually having them). The frequency ratio values of different categories or levels under each influencing factor were sorted in descending order, and the area under the curve (AUC) was calculated. A higher AUC value indicates a stronger effect of the influencing factor on a certain geohazard type. The AUC values for different influencing factors are shown in Table 1.

---

## 3 Results and Analysis

### 3.1 Distribution Characteristics

**3.1.1 Spatial Distribution Characteristics** Horizontally, geohazard development in the Ili Valley is greater in the east than in the west (Fig. 1), particularly in the middle-low mountainous areas between the Wusun, A'wula, and Boluokenu Mountains. Landslides and debris flows are widely distributed across the mountainous hilly areas between the north-south Tianshan Mountains and the Ili River Valley. Rock falls are mainly distributed in the Wusun Mountain, Kashgar River Valley, and southern Keqigu Mountain. Ground collapse shows clustered distribution, primarily in the low hilly areas of northwest Yining County, east Nileke County, and both sides of the Wusun Mountain.

Vertically, geohazards in the Ili Valley exhibit certain zonation patterns, concentrated in the 500–3500 m elevation range. Specifically: landslides and ground collapse mainly occur at 500–1000 m; rock falls, landslides, and debris flows dominate at 1000–2500 m; and rock falls and debris flows are primary at 2500–3500 m. High and middle-high mountainous areas are dominated by rock falls and debris flows; middle and middle-low mountainous areas host rock falls, landslides, and debris flows; low hilly areas in the west and along the southern Kashgar River bank feature landslides and ground collapse; and geohazards are not developed in valley plains and low hilly areas.

**3.1.2 Temporal Distribution Characteristics** Temporally, geohazards in the Ili Valley are concentrated in spring and summer snowmelt and rainfall seasons, particularly during May–August, which is the high-incidence period.

Among major geohazards, landslides show typical temporal patterns, with most being new landslides. Statistical analysis of 100 landslides with recorded months shows that 94% occurred during May–August rainfall and snowmelt seasons (Fig. 3).

### 3.2 Main Controlling Factors

**3.2.1 Stratigraphic Lithology** Most geohazards in the Ili Valley are distributed in loess areas: 78.00% of landslides, 79.95% of ground collapses, and 55.68% of debris flows occur in loess regions. Loess is a special geological body formed relatively recently, with loose and porous structure, well-developed vertical joints, and strong collapsibility. Compared with other rock and soil masses, loess areas have fragile geological environments and broken surfaces, making them more susceptible to loess landslides, ground collapse, and debris flows [?]. The loess in the Ili Valley is distributed in belts along river terraces, low hilly areas, and piedmont slopes (Fig. 4), mostly as shallow high-level deposits with thicknesses ranging from several meters to nearly 100 m [?]. Formed during the last interglacial period under drier and colder climatic conditions, the loess has weak chemical weathering and low cementation, representing typical aeolian loess samples. Compared with loess in the Loess Plateau, Ili Valley loess is dominated by silt, rich in  $\text{CaCO}_3$ , coarser in grain size, and better sorted [?]. Additionally, it contains numerous lattice pores, is highly water-sensitive, has low erosion resistance, strong self-weight collapsibility, and a calculated collapsibility correction coefficient greater than that of other regions in China [?]. The low mechanical strength of Ili Valley loess is the main reason for frequent loess landslides, ground collapse, and debris flows.

Furthermore, Neogene sandy mudstone and thin-bedded sandstone, Paleogene and Jurassic conglomerate, sandstone, and mudstone, and Carboniferous clastic rock, siltstone, and marl are also prone strata for landslides and rock falls. The existence of low-strength weak interlayers makes slope integrity poorer than general slopes, and weak interlayers amplify dynamic responses to rainfall, reservoir impoundment, and engineering excavation, which is unfavorable for slope stability [?]. For example, the Taxhe Formation's sandy mudstone interbedded with sandstone, Dushanzi Formation's argillaceous sandstone interbedded with sandstone, Anjihai Formation's gray-green mudstone interbedded with marl and thin-bedded sandstone, and coal-bearing strata are all high-incidence strata for collapse and landslide disasters.

**3.2.2 Geological Structure** Near faults and other geological structures, dynamic action often creates fractured zones with broken rock masses and poor integrity, developing structural landforms such as fault scarps with large surface relief. Fault planes and joint surfaces often become boundaries controlling collapse and landslide development, while loose and broken rock and soil materials provide source conditions for landslides and debris flows. Areas near faults are often prone to geohazards. As shown in Fig. 2, rock falls, landslides, and

debris flows are mainly distributed within 3200 m of faults, with areas within 1600 m being high-incidence zones. Ground collapse, as a disaster caused by deformation and failure of underground rock and soil masses, most easily occurs within 0–100 m of faults. Table 1 shows that the AUC value for distance from faults is 0.72 for debris flows, higher than for other geohazards, indicating the greatest influence on debris flows. Loose rock and soil masses near faults such as the Wusun Mountain Fault and Kashgar River Fault provide sufficient material conditions for debris flow formation, while fault rift valleys and other landforms with large topographic changes offer favorable terrain conditions [?]. Secondly, ground collapse and rock falls have AUC values of 0.71 and 0.68 for distance from faults, respectively, higher than landslides' 0.62.

**3.2.3 Topography and Geomorphology** Topographic factors affecting geohazard development include slope gradient, aspect, and elevation. Table 1 shows that debris flows and ground collapse have low AUC values for slope gradient (0.53 and 0.51), indicating weak influence. In contrast, landslides and rock falls have AUC values of 0.71 and 0.75, respectively, showing strong slope influence, with rock falls being more susceptible. Landslides are mainly distributed in 10°–35° slope ranges (Fig. 2), which are high-incidence zones. High-incidence zones for rock falls are concentrated in 20°–50° slope ranges. No obvious rock fall development occurs in 0–20° slopes, which constitute less than 0.1% of the study area. Ground collapse appears to occur easily in 0–20° slopes because development areas are basically reclaimed lands of underground mining areas. Due to local reclamation slope requirements, gradients generally do not exceed 20°, so these results cannot serve as evidence for slope influence on ground collapse development (Fig. 2).

For aspect influence, AUC values are relatively low, and frequency ratio variations among different aspects are not significant, indicating that aspect has minimal influence on rock falls, landslides, debris flows, and ground collapse in the Ili Valley. Regarding elevation, geohazards are concentrated in 1000–3000 m, 1000–2000 m, and 1000–3500 m ranges (Fig. 2). AUC values for elevation are 0.74 for landslides, 0.73 for debris flows, 0.70 for rock falls, and 0.69 for ground collapse, all higher than those for slope gradient and aspect. Overall, among topographic factors, the main controlling factors for geohazards in the Ili Valley are elevation and slope gradient, while aspect shows minimal influence.

**3.2.4 Precipitation** Table 1 shows that landslides and ground collapse have high AUC values for mean annual precipitation (0.73 and 0.72), significantly higher than rock falls (0.58) and debris flows (0.56), indicating stronger influence of annual precipitation on landslides and ground collapse. Both are concentrated in areas with 200–350 mm mean annual precipitation, where middle-low mountainous landforms are distributed and represent high-incidence zones for landslides and ground collapse (Fig. 2). As shown in Fig. 3, monthly mean precipitation in the Ili Valley is closely correlated with monthly landslide frequency, with landslide occurrences increasing with monthly precipitation. Most

landslides and ground collapse in the Ili Valley occur in loess areas. The strong water sensitivity of loess leads to low mechanical strength when wet, and ground collapse areas often develop certain scale fissures, making landslides and ground collapse clearly precipitation-influenced.

Debris flows in the Ili Valley are basically distributed in the 1000–3500 m elevation range, with rainfall and snowmelt as the main hydrodynamic conditions. Rapid warming in spring causes large-scale snowmelt in middle and low mountainous areas [?]. Both precipitation amount and temperature changes affect debris flow development. Moreover, different precipitation types have different effects on debris flow occurrence; for example, rainstorms are more likely to trigger debris flows. Therefore, the relationship between single precipitation data and debris flow distribution in the Ili Valley is not very close.

**3.2.5 Engineering Activities** Engineering activities are intense in the Ili Valley, mainly including water conservancy projects, power engineering, mining exploration and extraction, and transportation engineering. Statistical analysis of engineering-disturbed disasters (Table 2) shows that the vast majority of ground collapses and nearly half of rock falls are induced by engineering disturbance.

Field surveys reveal that intense engineering activities destroy topographic and geomorphological landscapes, altering the original stress balance and exacerbating geohazard occurrence. For example, road cutting in mountainous areas creates free faces at slope toes, exposing bedrock and causing original internal stress imbalance, inducing rock falls, landslides, and debris flows (Fig. 5a). Reservoir impoundment increases water content in slope rock and soil masses, increasing self-weight and driving forces, while also causing water-rock chemical interactions within the water level fluctuation zone, reducing shear strength and triggering landslides (Fig. 5b). Open-pit mining excavation and blasting vibrations in mountainous areas also easily induce rock falls and landslides. Unreasonable stacking of mining waste provides important material sources for landslides and debris flows, creating disaster hazards. Underground mining creates large goaf areas, making ground collapse likely to occur (Fig. 5c).

---

## 4 Discussion

Geohazards including rock falls, landslides, debris flows, and ground collapse in the Ili Valley are constrained by factors such as topography, stratigraphic lithology, geological structure, and precipitation, showing certain regularities in spatial and temporal distribution. However, the main controlling factors differ among geohazard types. For example, rock falls are most influenced by slope gradient compared with other geohazards, while ground collapse is less obviously affected by slope gradient. This is closely related to the formation mechanisms of different geohazard types—ground collapse is caused by deformation and failure

of underground rock and soil masses, having little relationship with surface slope changes. Therefore, when conducting geohazard assessment in the Ili Valley, it is important to select strongly correlated influencing factors for different hazard types [?].

The relationships between influencing factors such as stratigraphic lithology, human engineering activities, and geohazards are complex, and coupling relationships exist among different influencing factors. For example, precipitation distribution is coupled with elevation—precipitation in middle-high mountainous areas prone to rock falls is mostly 300–500 mm, while in middle-low mountainous areas prone to landslides and ground collapse, precipitation is mostly 200–350 mm. This paper has not systematically analyzed these coupling relationships using quantitative methods, which needs strengthening in future work. Additionally, although the disaster dataset used has been verified and improved multiple times, the Ili Valley covers a large area, and some regions are inaccessible for field surveys, so omissions are inevitable. Future geohazard investigation and research will continue to deepen, establishing richer disaster databases for geohazard assessment and disaster prevention in the Ili Valley.

---

## 5 Conclusions

1. Landslides and debris flows are widely distributed across the mountainous hilly areas between the north-south Tianshan Mountains and the Ili River Valley. Rock falls are mainly distributed in the Wusun Mountain, Kashgar River Valley, and southern Keqigu Mountain. Ground collapse shows clustered distribution, primarily in low hilly areas of northwest Yining County, east Nileke County, and both sides of the Wusun Mountain. Vertically, landslides and ground collapse occur in low hilly areas and low mountains along the southern Kashgar River bank; rock falls, landslides, and debris flows dominate middle and middle-low mountainous areas; and debris flows and rock falls are primary in high and middle-high mountainous areas. Temporally, landslides and debris flows are concentrated in spring and summer snowmelt and rainfall seasons, particularly during May–August.
2. Stratigraphic lithology, faults, topography, and other factors influence geohazard development in the Ili Valley, but the main controlling factors differ among geohazard types. Landslides and ground collapse are mainly distributed in loess areas, though some strata with weak interlayers are also prone to collapse and landslide disasters. Landslides are more affected by elevation, slope gradient, and precipitation. Rock falls are mainly controlled by slope gradient, elevation, and distance from faults. Ground collapse is significantly influenced by elevation and distance from faults, is closely related to precipitation, and is basically induced by underground mining activities. Distance from faults and elevation are the main con-

trolling factors for debris flows, while aspect shows minimal influence on geohazards in the Ili Valley.

---

## References

- [1] Hu Weizhong. Arid environment, landslides and debris flow in Xinjiang and its preservation and controlling[J]. *Geological Hazards and Environment Preservation*, 1994(3): 1-7.
- [2] Chen Yaning, Li Weihong. Zoning of geological hazards and countermeasures for its reduction in Xinjiang arid region[J]. *The Chinese Journal of Geological Hazard and Control*, 1995(4): 75-80.
- [3] Yin Jianhong, Xu Yuyang. Analysis of climate change characteristics in Ili Valley[J]. *Desert and Oasis Meteorology*, 2007, 1(6): 20-23.
- [4] Yin Guanghua, Wang Lanmin, Yuan Zhongxia, et al. Physical index, dynamic property and landslide of Ili loess[J]. *Arid Land Geography*, 2009, 32(6): 899-905.
- [5] Liu Yi. Analysis of geological features, cause and stability of the loess landslide in Ili[D]. Shihezi: Shihezi University, 2015.
- [6] Zhang Hongyi, Huang Hongbiao, Yan Zhongxue. Forming conditions and prevention treatment of loess landslide in the Xinyuan mountain area, Xinjiang[J]. *Xinjiang Geology*, 2004, 22(3): 233-237.
- [7] An Haitang, Liu Ping. Genesis and influencing factors of loess landslides in Yili region in Xinjiang[J]. *Geological Hazards and Environment Preservation*, 2010, 21(3): 22-25.
- [8] Zhao Liangjun, Li Hu, Liu Yufeng, et al. Evaluation on geological hazard risk and disaster causing factors in the Guozigou Valley in Ili, Xinjiang[J]. *Arid Zone Research*, 2017, 34(3): 693-700.
- [9] Mao Wei, Muhemaier Ruheyian, He Qiang. Formation mechanism and prevention measures of landslide geological hazards in Yili Valley, Xinjiang[J]. *Journal of Western Resources*, 2018(3): 131-133.
- [10] Cao Xiaohong, Meng He, Shang Yanjun, et al. The development and distribution of loess landslides in Yili Valley and its causes[J]. *Xinjiang Geology*, 2020, 38(3): 405-411.
- [11] Zhang Linfan, Wang Jiayun, Zhang Maoxing, et al. Evaluation of regional landslide susceptibility assessment based on BP neural network[J]. *Northwestern Geology*, 2022, 55(2): 260-270.
- [12] Qiao Guowen. Analysis of loess properties and slope stability in Yili area, Xinjiang—A case study of Jialangputu landslide on provincial highway 316[J]. *Southwest Road*, 2016(3): 163-167.

- [13] Liu Jiang. Rainfall-induced mechanism of Jialangputu loess landslide-debris flow in Yili, Xinjiang[J]. *Journal of Engineering Geology*, 2017, 25(5): 1230-1237.
- [14] Li Yanyong, Wang Chenghu, Zhu Haoqing, et al. The focal mechanism and stress field inversion in northern Tianshan Mountain[J]. *Earthquake*, 2020, 40(2): 117-129.
- [15] Ye Wei. Characteristics of physical environment and conditions of loess formation in Ili area, Xinjiang[J]. *Arid Land Geography*, 1999, 22(3): 9-16.
- [16] He Hui, Rusuli Yusufjiang. Analysis of the relative role of vegetation cover changes and its influencing factors in Yili area from 2001 to 2015[J]. *Journal of Central South University of Forestry & Technology*, 2019, 39(10): 76-87.
- [17] Wang Ruiqi, Wang Xueliang, Liu Haiyang, et al. Identification and main controlling factor analysis of collapse and landslide based on fine DEM: Taking Jiacha-Langxian section of Yarlung Zangbo suture zone as an example[J]. *Journal of Engineering Geology*, 2019, 27(5): 1146-1152.
- [18] Li Langping, Lan Hengxing, Guo Changbao, et al. Geohazard susceptibility assessment along the Sichuan-Tibet railway and its adjacent area using an improved frequency ratio method[J]. *Geoscience*, 2017, 31(5): 911-929.
- [19] Zhao Liangjun, Chen Donghua, Li Hu, et al. A method to assess landslide susceptibility by using logistic regression model for Guozigou region, Xinjiang[J]. *Mountain Research*, 2017, 35(2): 203-211.
- [20] Peng Jianbing, Lin Hongzhou, Wang Qiyao, et al. The critical issues and creative concepts in mitigation research of loess geological hazards[J]. *Journal of Engineering Geology*, 2014, 22(4): 684-691.
- [21] Ye Wei, Sang Changqing, Zhao Xingyou. Spatial-temporal distribution of loess and source of dust in Xinjiang[J]. *Journal of Desert Research*, 2003, 23(5): 38-44.
- [22] Song Yougui, Shi Zhengtao. Distribution and compositions of loess sediments in Yili Basin, Central Asia[J]. *Scientia Geographica Sinica*, 2010, 30(2): 267-272.
- [23] An P, Zhang A, Xing Y, et al. Experimental study on settling characteristics of thick self-weight collapsible loess in Xinjiang Ili region in China using field immersion test[J]. *Soils and Foundations*, 2018, 58(6): 1476-1491.
- [24] Zhang Jiaming. State of art and trends of rock slope stability with soft interlayer[J]. *Journal of Engineering Geology*, 2020, 28(3): 626-638.
- [25] Hanati Gulimire, Zhang Yin, Su Litan, et al. Response of water and heat of seasonal frozen soil to snow melting and air temperature[J]. *Arid Land Geography*, 2021, 44(4): 889-896.

*Note: Figure translations are in progress. See original paper for figures.*

*Source: ChinaXiv — Machine translation. Verify with original.*