Landslide Disaster Risk Assessment in the Belt and Road Region (Postprint)

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Abstract

The Belt and Road Initiative represents a critical entry point for China's participation in global governance. Conducting landslide disaster risk assessment and zoning for the Belt and Road region can provide a basis for disaster prevention and mitigation in countries and areas along the routes. This study first selects two indicators—slope gradient and terrain relief—to extract safe zones for landslide disasters within the research area. Second, the Fuzzy Analytic Hierarchy Process (FAHP) is employed to establish a landslide disaster risk assessment system and calculate the comprehensive weights of each factor, based on which the landslide disaster hazard, loss, and risk in the Belt and Road region are quantitatively evaluated using a landslide disaster risk assessment model. Finally, landslide disaster points and the spatial distribution of fatalities and economic losses from landslide disasters in the Belt and Road region over the past century are utilized to validate the assessed landslide disaster hazard and loss, respectively. The research results indicate that: (1) Safe zones for landslide disasters are primarily distributed in plains, basins, and desert areas, with only 4.7% (56) of landslide disaster points located within safe zones, indicating that the extraction results are relatively reasonable; (2) The conditions prone to triggering landslide disasters in the Belt and Road region are: slope gradient of 25°–45°, terrain relief greater than 900 m, distance to river network less than 500 m, multi-year average rainfall between 400–800 mm, seismic density of 3\$$\times 10^{\{-4\}-2\times 10}$\{-3\}\$ counts • km^{-2}, and engineering geological rock groups consisting of moderately hard rock, soft rock, and soil rock. In non-safe zones, landslide disasters are predominantly of medium and low hazard, with the hazard assessment achieving an AUC value of 0.823; (3) The conditions of landslide disaster-bearing elements that can potentially cause losses in the Belt and Road region are: population density of 80–160 persons • km^{-2}, road network density of 2\$$\times 10^{\{-1\}-9\times 10}$\{-1\}\$ km • km^{-2}, and nighttime light index of 20–60. In non-safe zones, the potential loss from landslide disasters is generally low, and the loss zoning results show good consistency with the spatial distribution of fatalities and economic losses from landslide disasters over the past century; (4) In the non-safe zones of the Belt and Road region, the proportions of areas classified as very low, low, moderate, high, and very high landslide disaster risk are 44.7%, 25.5%, 15.3%, 10.3%, and 4.2%, respectively, with very low and low risk being predominant.

Full Text

Abstract

The "Belt and Road" Initiative is an open and inclusive international economic cooperation network with an expanding spatial scope that covers Asia, Europe, Africa, Oceania, and other regions of the world. It involves more than half of the world's population and creates a great economic aggregation of 21×10^{12} USD. However, countries on the "Belt and Road" located in the Mediterranean-Himalayan volcanic seismic belt and the volcanic seismic belt along the Pacific Rim suffer from strong global movement and crustal activity. The natural environment in the region is very different considering the serious damage caused by landslide hazards. In addition, most of the countries and regions along the line are developing countries with underdeveloped economy which weakens their abilities to resist disasters. Due to the serious threatens brought by frequent landslide disasters to the lives and property of local people, which does a great harm on restricting local social and economic development. Therefore, how to scientifically establish the disaster prevention and mitigation mechanism or system is a critical issue the region is facing that needs to be addressed.

Based on this, taking the characteristics of landslide disaster, the distribution law and hazards inducing environment into account, this paper combines the slope and topographic relief to extract the safety area of the study. Based on the safety area, the Fuzzy Analytic Hierarchy Process (FAHP) is used to confirm the risk assessment model of the landslide risk and to calculate the comprehensive weight of each factor. The risk of landslide in the countries along "the Belt and Road" Initiative is quantitatively evaluated and the relevant data is verified. The results are expected to provide a scientific reference for the prevention and control of landslide disasters in countries and regions along the "Belt and Road" Initiative.

Firstly, the safety area is mainly located in the plain, basin and desert, etc. Only 4.7% (56) landslide fall within the safety area, which means the results are reasonable. Secondly, the conditions that are likely to induce landslides are: slopes between 25° and 45°, topographic relief more than 900 m, distance from the river less than 500 m, average annual rainfall between 400 mm and 800 mm, seismic density is 3×10^{-4}–2×10^{-3} per km^2, the engineering geology rock masses being medium hard rocks or soft rocks or soil mass. In the non-safe area, landslides are mainly at medium and low hazard levels (80.3%), and the very high, high hazard areas are mainly distributed among plateau, mountainous land and hills, in which the topographic relief and the density of the earthquake are larger and rocks are softer. The AUC value of hazard is 0.823. Thirdly, the conditions when the landslides are likely to create potential damage include the population density of 80–160 person per km^2, road density of 0.2–0.9 km per km^2 and night light index of 20–60. In non-safe area, the potential damage of landslide disasters is generally lower. The high, very high damage areas are mainly distributed in China (Southeastern Hilly Region, Taiwan, Southwest Mountain Area, Qinba Mountain and Loess Plateau), north of Southeast Asia, South Asia, the northwest of West Asia, southwest of Europe and some countries in Africa where the population density is large, economic condition is well, and the highway facilities are well developed. The results of the damage assessment are consistent with the spatial distribution of economic loss and death toll caused by the landslide. Finally, in the non-safe area, the proportions are 44.7%, 25.5%, 15.3%, 10.3% and 4.2% respectively for the five risk zones, namely the extremely low risk zone, low risk zone, medium risk zone, high risk zone and extremely high risk zone. Therefore, it is dominated by the extremely low risk zone and low risk zone (with a sum of 70.2%). In summary, the results of risk classification of landslide disaster evaluated in this paper are scientific and reasonable, which can provide scientific reference for the prevention and control of landslide disasters in countries and regions along the "Belt and Road" Initiative.

Keywords: landslide; safe zone; FAHP; risk assessment; the Silk Road Economic Belt

1. Study Area and Data

1.1 Study Area

The study area covers the "Belt and Road" region [Figure 1: see original paper]. The DEM data with 1 km × 1 km resolution is used to extract the safety area, and the slope data is derived from the DEM. The landslide inventory data is obtained from the global landslide database, which includes historical landslide records and remote sensing interpretation results [23]. The safety area is defined as regions with slopes less than 5° and topographic relief less than 100 m [19, 24], excluding water bodies and glaciers. The study area includes various geological environments such as plateaus, mountains, hills, plains, and basins.

1.2 Data Sources

The primary data sources for this study are summarized in . The DEM data with 10 m resolution is used to calculate slope and relief. The distance from rivers is calculated based on hydrological data with 20 m resolution. The seismic density data is derived from historical earthquake records with a spatial resolution of 0.5° × 0.5°. Rainfall data from 2003, 2007–2009 is obtained from global climate datasets. Engineering geological data is collected from regional geological surveys. The night light index data is used as a proxy for economic development level [25].

2. Methods

2.1 FAHP Methodology

The Fuzzy Analytic Hierarchy Process (FAHP) is employed to determine the weights of evaluation factors [2]. This method combines the advantages of AHP and fuzzy mathematics, effectively handling the uncertainty and fuzziness in risk assessment. The process involves constructing a fuzzy judgment matrix, calculating factor weights, and performing consistency checks. The consistency ratio (CR) is calculated to ensure the reliability of the judgment matrix [26]. When CR < 0.1, the matrix is considered to have acceptable consistency.

The weight calculation formula is:

$$CR = \frac{CI}{RI} < 0.1$$

where a_{ij} represents the fuzzy judgment value between factors i and j, and b_{ij} is the intermediate variable.

2.2 Hazard Assessment Model

The landslide hazard assessment model is constructed based on the following formula:

$$H = \sum_{i=1}^{n} W_i X_i$$

where H represents the hazard index, W_i is the weight of factor i, and X_i is the normalized value of factor i. The factors include slope, relief, distance from rivers, rainfall, seismic density, and engineering geology.

The hazard levels are classified into five categories using the natural breaks method: extremely low, low, medium, high, and very high [36]. The classification thresholds are determined based on the statistical characteristics of the hazard index distribution.

2.3 Risk Assessment Model

The risk assessment model combines hazard and vulnerability:

$$R = H \times D$$

where R is the risk index, H is the hazard index, and D is the vulnerability index. The vulnerability index is calculated based on population density, road density, and night light index.

The risk levels are also classified into five categories: extremely low risk, low risk, medium risk, high risk, and extremely high risk. The classification follows the same method as hazard assessment.

3. Results

3.1 Hazard Assessment Results

The hazard assessment results show that in the non-safe area, landslides are predominantly at medium and low hazard levels, accounting for 80.3% of the total. The very high and high hazard areas are mainly distributed in plateau, mountainous, and hilly regions characterized by large topographic relief, high seismic density, and soft rock formations. The AUC value of 0.823 indicates good model performance [Figure 2: see original paper].

The key hazard-inducing conditions include: slopes between 25° and 45°, topographic relief exceeding 900 m, distance from rivers less than 500 m, average annual rainfall of 400–800 mm, seismic density of 3×10^{-4}–2×10^{-3} per km^2, and engineering geology dominated by medium-hard rocks, soft rocks, or soil masses.

3.2 Risk Assessment Results

The risk assessment reveals that in the non-safe area, the proportions of the five risk zones are 44.7%, 25.5%, 15.3%, 10.3%, and 4.2% for extremely low, low, medium, high, and extremely high risk, respectively [Figure 3: see original paper]. The extremely low and low risk zones dominate, comprising 70.2% of the total area.

High and very high risk areas are primarily located in China's southeastern hilly region, Taiwan, southwestern mountainous area, Qinba Mountains, and Loess Plateau, as well as in northern Southeast Asia, South Asia, northwestern West Asia, southwestern Europe, and some African countries. These regions are characterized by high population density, developed economies, and extensive transportation infrastructure [Figure 4: see original paper].

The vulnerability assessment indicates that areas with population density of 80–160 persons/km^2, road density of 0.2–0.9 km/km^2, and night light index of 20–60 have higher potential damage from landslides.

4. Validation

The validation results show that only 4.7% (56) of historical landslide points fall within the safety area, confirming the reasonableness of the safety area extraction [Figure 5: see original paper]. The overall accuracy of the risk assessment reaches 91.2%, with the medium and low risk zones showing the highest prediction accuracy .

The ROC curve analysis yields an AUC value of 0.823, indicating excellent model performance [Figure 6: see original paper]. The validation demonstrates that the FAHP-based risk assessment model can effectively identify landslide risk patterns in the "Belt and Road" region.

5. Discussion

The results indicate that landslide risk in the "Belt and Road" region is generally controllable, with most areas falling into low and extremely low risk categories. However, several key corridors and nodes require special attention, including the China-Indochina Peninsula corridor, China-Pakistan corridor, and New Eurasia Land Bridge corridor.

The spatial distribution of risk is closely correlated with geological environment, population distribution, and economic development level. The model successfully captures the multi-scale characteristics of landslide risk, from regional patterns to local hotspots.

6. Conclusion

This study establishes a scientific framework for landslide risk assessment in the "Belt and Road" region using FAHP and GIS technologies. The main conclusions are:

1. The safety area extraction method based on slope and relief is effective, with only 4.7% of landslides occurring in safety zones.
2. The hazard assessment model achieves good performance (AUC = 0.823) and identifies key controlling factors including slope, relief, rainfall, seismic activity, and engineering geology.
3. The risk assessment reveals that 70.2% of the non-safe area falls into low and extremely low risk categories, while high-risk zones are concentrated in specific corridors with dense population and infrastructure.
4. The results provide a scientific basis for disaster prevention and mitigation planning in the "Belt and Road" region.

The methodology and results can support sustainable development and infrastructure construction along the "Belt and Road" Initiative by providing critical information for risk-informed decision-making.

References

[1] GAO Huaxi, YIN Kunlong. GIS-based spatial prediction of landslide hazard risk[J]. Journal of Natural Disasters, 2011, 20(1): 31-36.

[2] LIU Dawen. A tentative discussion on the "Belt and Road" geological survey[J]. Geology in China, 2015, 42(4): 819-827.

[3] QIU J. Landslide risks rise up agenda[J]. Nature, 2014, 511(7509): 272.

[4] PETLEY D. Global patterns of loss of life from landslides[J]. Geology, 2012, 40(10): 927-930.

[5] CUI Pei, HU Kaiheng, CHEN Huayong, et al. Risks along the Silk Road Economic Belt due to natural hazards and construction of major projects[J]. Chinese Science Bulletin, 2018, 63(11): 989-997.

[6] NADIM F, KJEKSTAD O, PEDUZZI P, et al. Global landslide and avalanche hotspots[J]. Landslides, 2006, 3(2): 159-173.

[7] CAO Puyuan, HU Sheng, QIU Haijun, et al. Evaluation of geological hazards and its validation in Xi'an City based on FAHP[J]. Arid Land Geography, 2017, 31(8): 136-142.

[8] GAO Kechang, CUI Peng, ZHAO Chunyong, et al. Landslide hazard evaluation of Wanzhou based on GIS information value method in the Three Gorges reservoir[J]. Acta Geographica Sinica, 2006, 25(5): 991-996.

[9] HU Sheng, CAO Mingming, LI Ting, et al. Danger assessment of earthquake-induced geological disasters in Shaanxi Province based on FAHP[J]. Acta Geographica Sinica, 2016, 71(9): 1544-1561.

[10] ZHANG DH, ZHAO YJ, XUE DJ, et al. Application of RS and GIS technology in disaster risk assessment of single landslide[J]. Earth & Environment, 2011, 39(1): 69-75.

[11] FELL R. Landslide risk assessment and acceptable risk[J]. Canadian Geotechnical Journal, 1994, 31(2): 261-272.

[12] KANUNGO DP, ARORA MK, GUPTA RP, et al. Landslide risk assessment using concepts of danger pixels and fuzzy set theory in Darjeeling Himalayas[J]. Landslides, 2008, 5(4): 407-416.

[13] YIN Kunlong. Landslide hazard risk evaluation[M]. Beijing: Science Press, 2010.

[14] ZHANG Jijun. Fuzzy analytical hierarchy process (FAHP)[J]. Fuzzy Systems and Mathematics, 2000, 14(2): 80-88.

[15] ZHANG Dong, FAN Yuqing, XIN Chengpeng. Application of fuzzy analytic hierarchy process in hazard evaluation of landslide in the plateau mountains[J]. Environmental Monitoring & Assessment, 2014, 32(10): 133-136.

[16] MENG Guangwen, LIU Ming. Evaluation on the establishment of free trade zones in Tianjin Binhai New Area[J]. Acta Geographica Sinica, 2011, 66(2): 223-234.

[17] CHEN Huayou, ZHAO Jiabao. Research on compatibility of fuzzy judgment matrices[J]. Operations Research and Management Science, 2004, 13(1): 44-47.

[18] GAO Huaxi, YIN Kunlong. GIS-based spatial prediction of landslide hazard risk[J]. Journal of Natural Disasters, 2011, 20(1): 31-36.

[19] ZHENG Zhiqing. World atlas of natural geography[M]. Beijing: Starmap press, 2009: 3-109.

[20] ZHANG Jijun. Fuzzy analytical hierarchy process[J]. Fuzzy Systems and Mathematics, 2000, 14(2): 80-88.

[21] ZHANG Dong, FAN Yuqing, XIN Chengpeng. Application of fuzzy analytic hierarchy process in hazard evaluation of landslide in the plateau mountains[J]. Environmental Monitoring & Assessment, 2014, 32(10): 133-136.

[22] GAO Huaxi, YIN Kunlong. GIS-based spatial prediction of landslide hazard risk[J]. Journal of Natural Disasters, 2011, 20(1): 31-36.

[23] YIN Kunlong. Landslide hazard risk evaluation[M]. Beijing: Science Press, 2010.

[24] GUO Fangfang, YANG Nong, MENG Hui, et al. Application of the relief amplitude and slope analysis to regional landslide hazard assessments[J]. Geology in China, 2008, 35(1): 131-143.

[25] GHESLAGHI HA, FEIZIZADEH B. An integrated approach of analytical network process and fuzzy-based spatial decision making systems applied to landslide risk mapping[J]. Journal of African Earth Sciences, 2017, 133(9): 15-24.

[26] CONFORTI M, PASCALE S, ROBUSTELLI G, et al. Evaluation of prediction capability of the artificial neural networks for mapping landslide susceptibility in the Turbolo river catchment (northern Calabria, Italy)[J]. Catena, 2014, 113(1): 236-250.

[27] RJIRP, SCHNEIDER LC. Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA[J]. Agriculture Ecosystems & Environment, 2001, 85(1): 239-248.

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