Disaster Risk Assessment of the Silk Road

Peng Cui, Qiang Zou, Yu Lei, Zhengtao Zhang, and Shengnan Wu

Abstract

Disasters Risks, generated by the interaction of complex human and natural systems, are more significant, more complicated, and more difficult to foresee. Silk Road spans Asia, Europe, and Africa, involving more than 140 countries and nearly 66% of the world population. Relevant studies show that the countries along the Silk Road area suffered from the most frequent natural hazards and the most severe losses in the world. In order to promote social and economic development in Silk Road areas, it is urgent to carry out comprehensive research on disaster risk and disaster reduction. This compels new conceptual and analytical approaches to improve understanding of disaster risk at different scales. This paper presents the Silk Road disaster risk assessment at four scales, which could serve a different purpose. It is a robust response to one of the prioritized areas of Sendai Framework on Disaster Risk Reduction for people to understand disaster risk better.

P. Cui (✉) · Z. Zhang · S. Wu
Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, 100101, China
e-mail: pengcui@imde.ac.cn

Z. Zhang
e-mail: zhangzt@igsnrr.ac.cn

S. Wu
e-mail: wsn_zju@163.com

P. Cui · Q. Zou
The Centre for Excellence in Tibetan Plateau Earth Sciences (CETES) of the Chinese Academy of Sciences (CAS), University of Chinese Academy of Sciences, Beijing, China

Q. Zou · Y. Lei
Key Laboratory of Mountain Hazards and Earth Surface Process/Institute of Mountain Hazards and Environment (IMHE), Chinese Academy of Sciences (CAS), Chengdu, 610041, China
e-mail: zouqiang@imde.ac.cn

Y. Lei
e-mail: leiyu@imde.ac.cn

Keywords

Silk road • Disaster • Risk assessment • Sendai framework • Disaster risk reduction

Introduction

The Silk Road, beginning in the Han Dynasty, has been playing an essential role in connecting Asia, Europe, and Africa through the exchanges of the trades, sciences, technologies, and cultures for centuries. Meanwhile, overwhelming disasters, such as earthquakes, floods, droughts, landslides, and debris flows, frequently occur, and bring significant challenges to sustainable development in the Silk Road area. The statistic showed that the average economic loss due to disasters against GDP for the Silk Road countries is twice the world average, while the annual mortality risks in this area are much higher than that of the rest of the world (Lei et al. 2018). Therefore, for a better understanding of disaster risks and more solid support in risk-informed sustainable development in the Silk Road area, disaster risk assessment of the entire Silk Road area is indispensable.

Disasters Overview of the Silk Road

As presented in the Global Assessment Report 2019 (GAR 2019), extreme changes in planetary and socio-ecological systems are happening now. The risks generated by the interaction of complex human and natural systems are escalating and greatly hindering our development. With the complex geological setting and climatic coverage, the Silk Road area has been plagued by natural hazards for a long time.

Ž. Arbanas et al. (eds.), *Understanding and Reducing Landslide Disaster Risk*, ICL Contribution to Landslide Disaster Risk Reduction,
https://doi.org/10.1007/978-3-030-60713-5_31

Earthquake

The Silk Road Economic Belt stretches along the Eurasia seismic belt. In the history, mega earthquakes taking place in the Silk Road area included the 1906 Manas earthquake (Ms8.0), the 1911 Alma-Ata earthquake (Ms 8.0), the 1920 Haiyuan (Ms 8.5) and the 1948 Ashgabat earthquake (Ms 7.8). The Maritime Silk Road crosses the subduction zone of the India Plate and the Eurasian Plate, the collision zone of the Arabian Plate, the Eurasian Plate and the African Plate and other plate boundaries, where a 9.3-magnitude earthquake occurred in 2004 and induced tsunami in the Indian Ocean (Cui et al. 2017).

Meteorological disaster

Global warming and the change of extreme weather events (such as extreme rainfall) have attracted wide attention. According to the fifth assessment report of the intergovernmental panel on climate change (IPCC 2013), from 1880 to 2012, the global average sea and land surface temperature showed a linear upward trend, raised by 0.85°C. As a result, a variety of extreme weather and climate events occur more frequently. The world meteorological organization (WMO) estimates that in the 25 years from 1967 to 1991, drought has affected 2.8 billion people worldwide, of whom 1.3 million died direct or indirect of drought. On the other hand, the flood also caused a huge problem in some regions. On October 31, 2012, heavy rains hit near Chennai, India, affecting 60,000 people, flooded many villages.

Geological disaster

Under global warming, extreme temperature and precipitation in high mountain areas increase in frequency and intensity. With the fragile environment in the Silk Road area, geological disasters in mountainous areas (such as landslide, debris flow, GLOF, melting glaciers) have also increased in frequency and scale, often led to substantial property losses and casualties. Take China-Pakistan Economic Corridor as an example, the Karakoram Highway (from China Xinjiang Kashgar to northern Pakistan city), of which there are 56 rockfall, 155 landslides, 21 debris flows, 2 landslide dammed lakes (Atabad landslide lake and Su Bing moraine lake), and 10 large glaciers.

Maritime Disaster

Most countries in the Silk Road area are affected by Maritime disasters, including storm surge, tsunami, coastal erosion, ocean acidification, and red tide. From the northern part of the South China Sea to the northern Indian Ocean coast, tropical cyclones are the most common disasters. In 2004, an 8.7 magnitude earthquake struck off the coast of Sumatra island in northern Indonesia, triggering a strong tsunami that directly or indirectly killed about 240,000 people in Sri Lanka, India, Indonesia, Thailand, Malaysia, and other countries, injuring more than 500,000 people and causing an economic loss of more than us $10 billion. Besides, sea-level rise caused by climate change will exacerbate Marine disasters such as increased coastal storm surges, coastal erosion.

Disaster Chain

Disaster chain refers to a series of disasters events induced by a primary disaster. It expands its influence in time and space, amplifies its damage and increases the disaster loss, which often leads to catastrophe or even transboundary disaster, increasing the complexity of disaster risk reduction. A typical example is the Yigong landslide—dammed lake—outburst flood in 2000 in China (Delaney and Evans 2015). It caused massive damage to both China and India.

Methodology

The principle of Disaster Risk

Landslide, debris flow, earthquake, tsunami, storm surge, and flood are natural phenomena, and they become disasters only when they interact with human society. In this regard, the disaster risk can be symbolized as the possibility of a specific disaster event causing casualties and property loss (UNISDR 2009). Disaster risk is a consequence of the interaction between the disaster and human and the properties exposed to hazards. Therefore, disaster and disaster risk are contributed by both elements of nature and society of great variety. Nowadays, the disaster risk model (Peduzzi et al. 2002; Granger 2003; ISDR 2004) extensively accepted to disaster assessment can be formulated as:

$$\text{Disaster Risk (R)} = \text{Hazard(H)} \times \text{Vulnerability (V)} \quad (1)$$

where, the Hazard (H) describing the probability or magnitude of occurrence of the disaster of given type and scale and reflecting the potential impact; the Vulnerability (V) describing the degree of damage of a specific element at risk under the influence of the disaster event, and mainly reflecting the capacity to resist disaster and value of this element at risk. The vulnerability can also be evaluated by exposure and fragility.

Multi-scale disaster risk assessment

The disaster risk assessment in different scale requires specific assessment methods and data support. It is an essential step to define the scale of assessment so that its end-user could adopt the risk assessment result. In this paper, we presented four scales of assessment based on our pre-defined objectives (Table 1). The data supporting this study are all open accessed from varies sources, such as USGS, NOAA, EMDAT, etc.

(1) Global Scale
The disaster risk assessment at this scale is to analysze the disaster fostering conditions and identify the general distribution of disaster in the Silk Road to provide support to the international cooperation in disaster risk reduction in the Silk Road area.
(2) Regional Scale
Disaster risk assessment at the regional scale evaluates the hazard zonation to facilitate countries in the Silk Road in establishing the inter-country collaborative risk reduction mechanism in accordance with the dominated disasters affecting their countries. Regional risk assessment address the potential disaster intensity and their possible consequences in the assessment area based on the analysis of the environment, disaster conditioning factors, and elemental risk (Cui et al. 2015).
(3) Local Scale
At the local scale, the risk assessment can be conducted incorporating the dynamic process of the disaster. A numerical simulation is a useful tool in this analysis. For example, we simulated the full process of a debris flow event and proposed a quantitative method of debris flow hazard assessment, based on kinetic energy. Using the value of elements at risk to represent the vulnerability, we propose a systematic and quantitative method for risk analysis of debris flow on a local scale (Cui et al. 2013; Zou et al, 2016). The assessment result is capable of supporting the design of early warning systems, emergency management plans, and disaster relief.
4. Infrastructure-oriented
Assessment at this scale focuses on the risk of essential infrastructures such as transportation line and hydropower project, to improve the construction and operation safety, reduce the maintenance cost of the infrastructure projects in their life cycle. This assessment takes a particular interest in the vulnerability of the element at risk in this case, the infrastructure (Zou et al. 2018). The structure response to disaster impact and failure process must be studied in this assessment.

Economic loss assessment

The total economic loss caused by the disaster is divided into Direct Economic Loss (DEL) and Indirect Economic Loss (IEL). The assessment method for DEL along the Silk Road mainly combines the disaster intensity, frequency, and spatial distribution, as well as the corresponding casualties and economic value exposed. The economic value is evaluated by the types of structures and their loss rate (or GDP distribution if it is assessment at a global scale).

Besides, with the development of social economy, acceleration of the process of global economic integration, the IEL (losses caused by production suspension and reduction due to direct economic loss, and the imbalance between supply and demand in the industrial linkage) hidden behind trade links cannot be ignored. The IEL caused by a catastrophic disaster could affect all the countries around the world and exceed the direct economic loss. Therefore, the assessment method of IEL is to build a comprehensive model that combined with the disaster mechanism and economic mechanism (e.g., Input–Output model) (Zhang et al. 2019):

$$YA_i(t) = Dem_i^{local}(t) + Dem_i^{recons}(t) \quad (2)$$

$$IEL = \sum_{i=1}^{n} \int_{1}^{p} \frac{YA_i(t)}{YA_i(0)} dt \quad (3)$$

where YA refers to the supply capacity of the ith sector at timestep t (e.g., day, month, etc.) after a disaster, Dem_i^{local} means the intermediate demand (e.g., government or residents demands for regular operation). Dem_i^{recons} Indicates the reconstruction demand (houses or infrastructures repair, rescue people). There will always be IEL until the end at time p. The IEL equals the sum of the cumulative losses (compare to pre-disaster level $YA(0)$) of each sector over time.

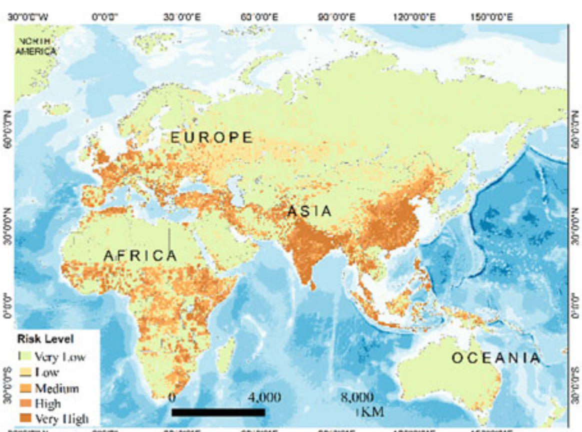
Table 1 Scales and objectives of disaster risk assessment

Assessment scale	Resolution	Objective
Global	1–10 km	Identify global disaster risk pattern, support international DRR
Regional	100 m	National disaster risk zonation, support the national strategy on collaborative disaster response
Local	1–5 m	Identify disaster influence and support urban plan
Infrastructure-oriented	Demand base, <1 m	Support Infrastructure design and safe operation

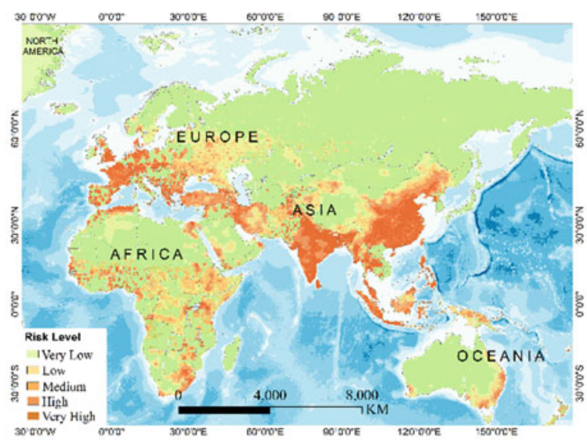
Assessment Results

Global scale

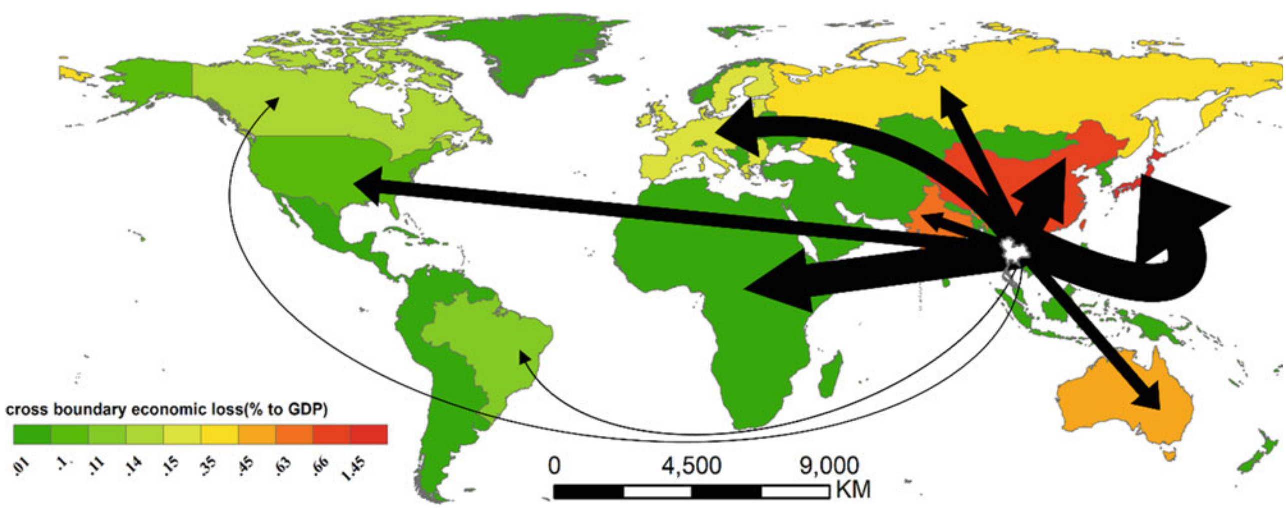
1. Risk Assessment of Mortality
   The risk of mortality is affected by the frequency of disasters and human vulnerability. Countries with a high-risk level include China and India, which is mainly caused by a high frequency of disaster and high population density. However, some other regions in Europe which have a low frequency but expose a medium or high risk since the population density is large or the capacity to resist disaster is weak (Fig. 1a).
2. Risk Assessment of Direct Economic Loss
   The risk of economic loss is mainly affected by the frequency and economic development level. Countries with high risk mainly locate in eastern Asia and Australia. These regions have more frequent disasters and high GDP, which leads to a high-risk level of economic loss. The regions with medium risk level distribute in central and western Europe and southwestern Asia(Fig. 1b).
3. Risk Assessment of Indirect Economic Loss
   Based on the statistics of the catastrophic flood in 2011, Thailand, the flood caused a DEL of 46,531 million USD (World Bank 2012), also an IEL of more than ten times larger than DEL in the next four years. Besides, many oversea invested factories built in Thailand (e.g., hard disk, automobile factories) were also damaged, resulting in large cross-boundary economic loss to other countries around the world through the trade network (Fig. 1c). The total cross-boundary economic loss has reached more than five times than its DEL. Japan suffers the most



(a) Spatial distribution of mortality risk



(b) Spatial distribution of economic loss risk



(c) Cross-boundary economic losses of the flood in 2011, Thailand (The width of arrows means the ranking of cross-boundary economic loss suffered by each country)

Fig. 1 Risk assessment results at globe scale

(178% of DEL), followed by China (86%), Europe (55%), USA(32%), Russia (12%), Australia (11%), India (10%), Brazil (5%), and Canada(5%). In addition, although the Europe suffers larger loss than Australia, it has the opposite effect on GDP, which shows that the actual cross-boundary economic loss suffered by different regions is closely related to the trade ties and their GDP. This analysis indicates that countries should not only pay attention to the DEL with the disaster area, but also the IEL and the cross-boundary loss of much wider region.

Regional scale: Tibet plateau disaster risk assessment

Base on the types of hazards (such as landslide, debris flow, flash flood, drought and snow calamity) at Qinghai-Tibet Plateau (Fig. 2)(Cui and Jia 2015), a hazardous and vulnerability analysis is carried out at this region and subsequently an integrated risk assessment is conducted. The assessment result shown in Fig. 3 indicates that the high-risk regions are mainly located at the fringe of western and southern Qinghai-Tibet Plateau while the moderate risk regions are in south-central, west-central and north-east area including southern Tibet, northern Qinghai and north-west of Sichuan. The low-risk regions are at the central of Qinghai-Tibet Plateau, including north-central of Tibet and south-west of Qinghai. The northern and north-west of Qinghai-Tibet plateau, including northern Tibet and southern Xinjiang, are under minimum risk (Cui et al. 2015).

Local scale: Dynamic Process-based Risk Assessment of Debris Flow

The proposed method on the local scale was applied to a case study of debris flow in Qipan gully, which caused severe damages for Duwen Highway and Qipan town of Sichuan Province in 2013 (Fig. 4a). Using debris flow simulation (Fig. 4b), remote sensing (RS), and GIS techniques, the proposed method studied the disaster movement and divided the debris flow areas into three zones as high-risk, medium-risk, and low-risk zone as shown in Fig. 4c. The result shows that the high-risk zone accounted for 54.2% of the total area (271,950 m^2), while the medium risk zone occupied 30.7% of the total area (154,070 m^2) and the low-risk zone contained 15.2% of total area (76,080 m^2). Comparing this result with the field survey data after the debris flow events, it showed that the calculated risk zones are very much consistent with the in-situ condition, which strongly suggests that this risk assessment method is able for debris-flow risk analysis and risk management of debris-flow alluvial fans.

Project-oriented risk assessment

In this case, we evaluated the potential hazard induced by debris flow in Ridi Gully (Zou et al. 2017). Considering the most damage from debris flow to the affected objects, we used the maximum simulated flow height to estimate the hazard of debris flow in Ridi Gully. By applying GIS spatial analysis techniques, we extracted the channel profile of Ridi Gully. Specifically, at the location where the Sichuan Tibet Railway crosses with a bridge. The depth of debris flow was 8.5 m with 100-year rainfall and 13.8 m with 200-year rainfall. Subsequently, we compared the simulated results with the 18 m headroom design of the Sichuan-Tibet Railway (Fig. 5a). It shows that half of the height of the designed headroom will be deposited by debris flow with a 100-year return period precipitation, and nearly two-thirds of the headroom will be taken by debris flow of a 200-year return

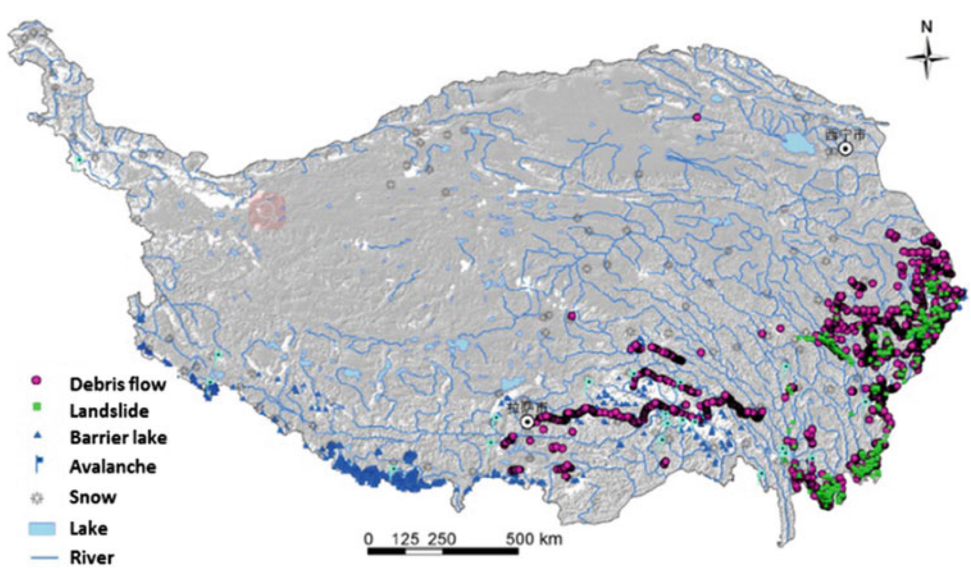


Fig. 2 Hazards distribution in the study area

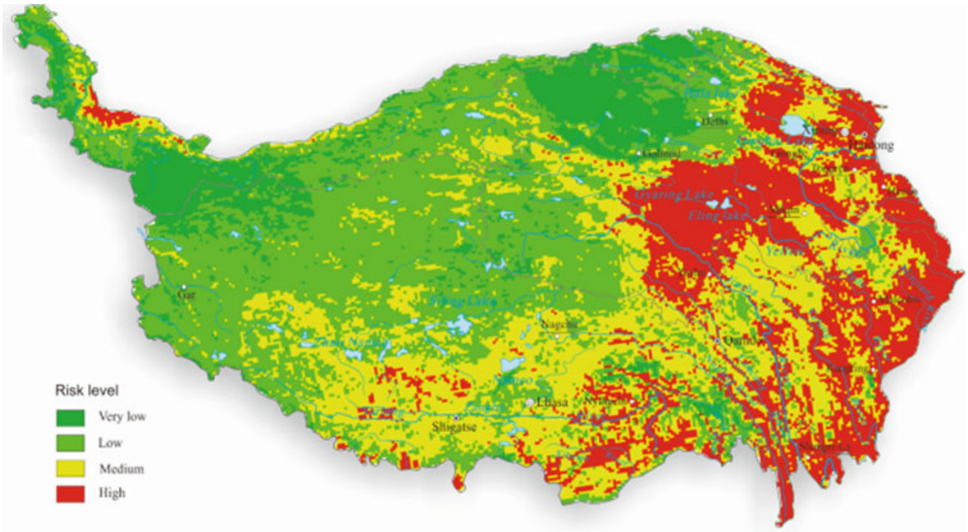
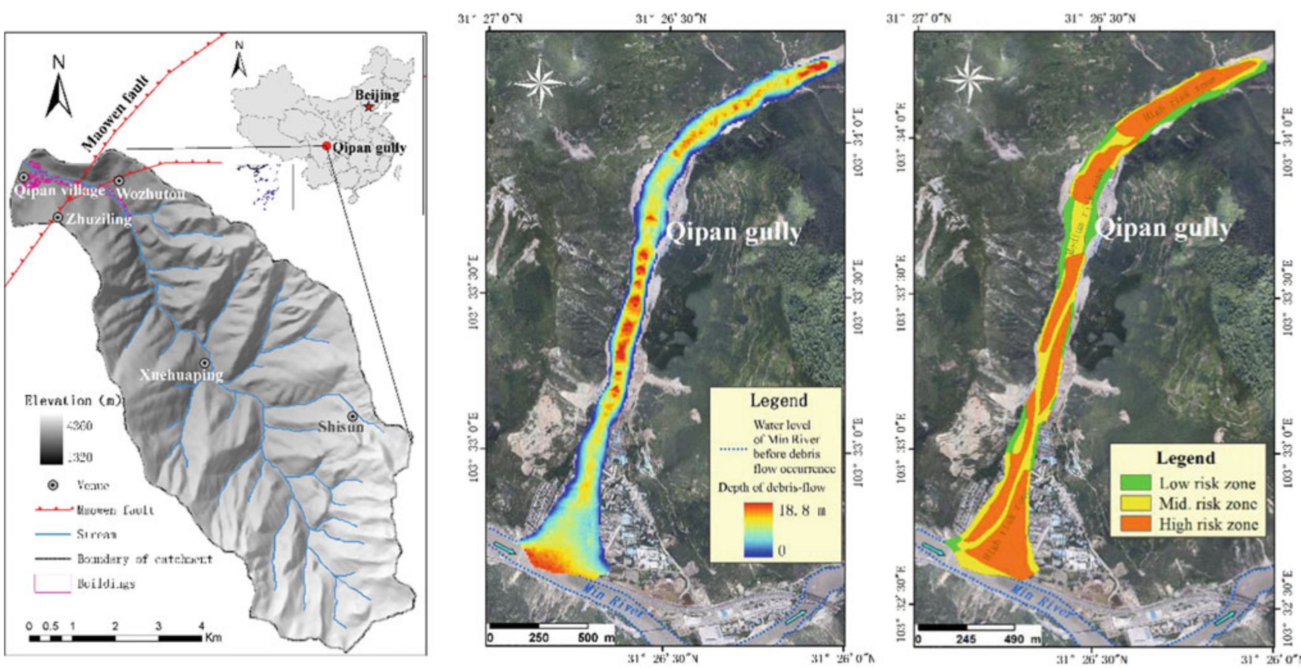


Fig. 3 Risk assessment of natural hazards



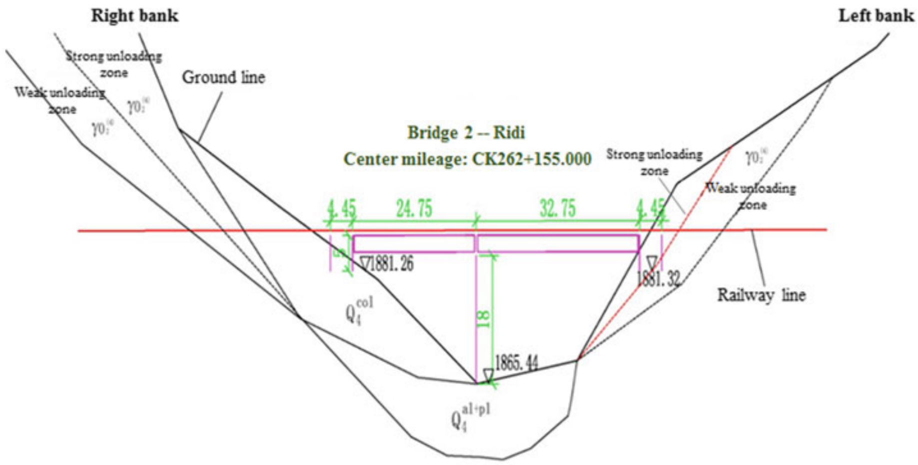
(a) Location of Qipan gully

(b) Flow depth in the debris-flow affected area

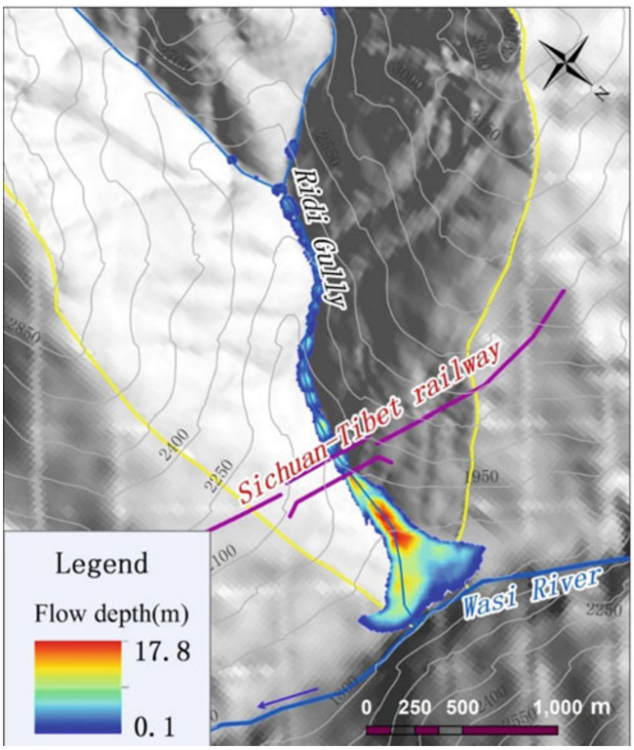
(c) Risk map of debris-flow in Qipan gully

Fig. 4 Risk assessment results in Qipan gully

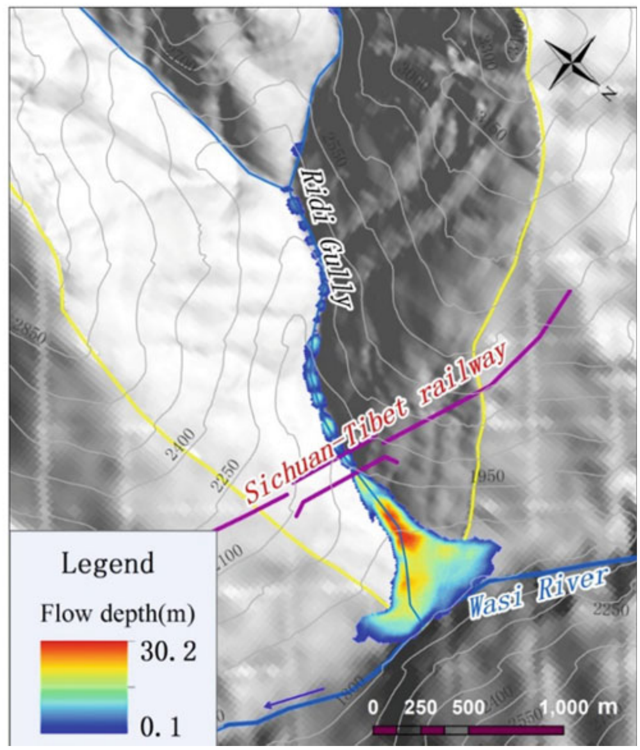
period precipitation (Fig. 5b, c). As a result, the G318 national highway and villages in the alluvial area of the Ridi Gully are subjected to a high risk of debris flow. Considering the composite effects of debris flow impact, burying, and erosion, the risk of debris flow is high to very high around the Ridi Gully. Therefore, to reduce the potential damages induced by the debris flow, engineering measures are required to control debris flow, and a real-time monitoring and warning system is necessary to ensure the safety of the railway.



(a) The section profile of Sichuan-Tibet Railway across Ridi gully



(b) Simulation of a 100-year return period precipitation



(c) Simulation of a 200-year return period precipitation

Fig. 5 Simulated results of the Sichuan-Tibet Railway section in Ridi Gully

Discussion and Conclusions

The Silk Road area has a complex geological setting with a widely distributed earthquake, drought and waterlogging disaster, meteorological disaster, and geological disaster. Especially, South Asia is dominated by earthquakes, geological disasters, and flood disasters; Southeast Asia mainly suffers from earthquakes, geological disasters, and ocean disasters; and the Mediterranean is mainly influenced by earthquakes, geological disasters and flood disasters.

The paper carries out the disaster risk assessment of different scales, and the assessment results play an essential role in identifying global risk law, drawing inter-regional disaster risk maps, determining disaster impact and community planning, service engineering construction, safe operation and maintenance. However, due to the wide distribution and prominent uncertainty of natural disasters in the Silk Road area, it is necessary to:

1. understand the regional distribution of disaster and their risk;
2. combining the needs of real-time disaster monitoring and data transmission, developing affordable technologies and instruments, identify new indicators to develop a refined disaster monitor system and carrying out dynamic based disaster monitoring.
3. develop key technologies for disaster prevention and control of major projects, reduce the impact of natural hazards and improve the construction and operation safety toward a whole life circle project design.
4. enhance the disaster resilience of countries along the Silk Road, promote international cooperation on disaster risk and comprehensive disaster reduction and establish a inter-country disaster risk reduction mechanism for transboundary disasters.

Acknowledgements This work is supported by the International Partnership Program (Grant No. 131551KYSB20160002), the NSFC Research Fund for Young Scientists (41807509) and the Strategic Priority Research Program of Chinese Academy of Sciences(Grant No. XDA20030301).

References

Cui P, Jia Y (2015) Mountain hazards in the Tibetan Plateau: research status and prospects. Natl Sci Rev 2(4):397–402

Cui P, Zou Q, Xiang LZ, Zeng C (2013) Risk assessment of simultaneous debris flows in mountain townships. Prog Phys Geogr 37(4):516–542

Cui P, Fenghuan Su, Zou Q et al (2015) Risk assessment and disaster reduction strategies for mountainous and meteorological hazards in Tibetan Plateau. Chin Sci Bull 60:3067–3077 (in Chinese)

Cui P, Deep Regmi A, Zou Q et al (2017) Natural hazards and disaster risk in one belt one road corridors. In: 4th world landslide forum, Ljubljana, Slovenia, EU

Delaney KB, Evans SG (2015) The 2000 Yigong landslide (Tibetan plateau), rockslide-dammed lake and outburst flood: review, remote sensing analysis, and process modelling. Geomorphology 246:377–393

IPCC (2013). Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

ISDR (Intentional Strategy for Disaster Reduction). (2004). Living with risk. A global review of disaster reduction initiatives. United Nations publication, New York and Geneva.

Granger K (2003) Quantifying storm tide risk in cairns. In: Natural Hazards, vol 30. Kluwer Academic Publishers, pp 165–185

Peduzzi P, Dao Q-H, Herold C et al (2002) Global Risk and Vulnerability Index Trends per Year (GRAVITY), Phase II: Development, analysis and results, scientific report UNDP/BCPR. Switzerland, Geneva

UNDRR (2019) Global assessment report. [online] Available at: https://gar.unisdr.org/report-2019. Assessed 2 Dec 2019

UNISDR (2009) Terminology on disaster risk reduction. [online] Available at: https://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf. Assessed 13 Sep 2019

World Bank (2012) Thai Flood 2011. Rapid assessment for resilient recovery and reconstruction planning. Bangkok: The World Bank

Yu L, Cui P, Regmi AD et al (2018) An international program on Silk Road Disaster Risk Reduction-a Belt and Road initiative (2016–2020). Journal of Mountain Science 015(007):1383–1396

Zou Q, Cui P, Zeng C et al (2016) Dynamic process-based risk assessment of debris flow on a local scale. Phys Geogr 37(2):132–152

Zou Q, Zhou G, Li S et al (2017) Dynamic-process analysis and hazard prediction of debris flow in eastern Qinghai-Tibet Plateau area—a case study at RiDi gully. Arct Antarct Alp Res 49(3):373–390

Zou Q, Cui P, Zhou G et al (2018) A new approach to assessing vulnerability of mountain highways subject to debris flows in China. Prog Phys Geogr 42(3):305–329

Zhang Z, Li N, Cui P et al (2019) How to Integrate Labor Disruption into an Economic Impact Evaluation Model for Postdisaster Recovery Periods. Risk Anal 39(11):2443–2456