International Journal of Disaster Risk Science (2023) 14:1044–1053
https://doi.org/10.1007/s13753-023-00533-7

www.ijdrs.com
www.springer.com/13753

PERSPECTIVES

The 2023 Earthquake in Türkiye and Implications for China's Response to Catastrophe

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Accepted: 14 December 2023 / Published online: 3 January 2024

Abstract
On 6 February 2023, two 7.8 magnitude earthquakes consecutively hit south-central Türkiye, causing great concern from all governments, the United Nations, academia, and all sectors of society. Analyses indicate that there is also a high possibility of strong earthquakes with a magnitude of 7.8 or above occurring in the western region of China in the coming years. China is a country that is highly susceptible to catastrophic disasters such as earthquakes, floods, and other natural calamities, which can cause significant damages to both human life and property, as well as widespread impacts on the society. Currently, China's capacity for disaster prevention and control is still limited. In order to effectively reduce the impact of catastrophic disasters, ensure the safety of people's lives and property to the greatest extent possible, maintain social stability in high-risk areas, and ensure high-quality and sustainable regional development, it is urgent to improve the seismic resistance level of houses and critical infrastructure in high earthquake risk zones and increase the earthquake-resistant design level of houses in high-risk fault areas with frequent seismic activities; significantly enhance the ability to defend against extreme weather and ocean disasters in economically developed areas along the southeastern coast, as well as the level of fortification in response to extreme meteorological and hydrological disasters of coastal towns/cities and key infrastructure; vigorously enhance the emergency response capacity and disaster risk prevention level in western and ethnic minority regions; comprehensively improve the defense level of residential areas and major infrastructure in high geological hazard risk zones with flash floods, landslides, and mudslides; systematically promote national disaster prevention and mitigation education; and greatly enhance the societal disaster risk reduction ability, including catastrophic insurance.

Keywords China · Disaster impact · Disaster response · Earthquake in Türkiye

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1 The 2023 Earthquake in Türkiye and Disruptive Earthquake Risk in China

According to the China Earthquake Networks Center, a 7.8 magnitude earthquake struck the Kahramanmaras Province in central-southern Türkiye on 6 February 2023 at 4:28 a.m. local time, with the epicenter located at 38.00°N and 37.15°E and a depth of 20 km, and numerous aftershocks followed. On the same day, another 7.8 magnitude earthquake struck near the northern part of the previous one (38.10°N and 37.11°E) at 1:28 p.m. local time, approximately 96 km away, creating a rare and typical double earthquake sequence. The earthquake sequence has drawn high attention from governments, the United Nations, academia, and other institutions worldwide. This study analyzed the possible impacts of Türkiye's twin earthquakes on China and the implications for coping with catastrophic disasters.

1.1 Earthquakes in the Tibetan Plateau Seismic Zone

The danger of earthquakes in the Tibetan Plateau seismic zone with the principal part located in China is significantly higher than that in the Central Asian seismic belt where the Türkiye earthquakes occurred. The Eurasian seismic belt, one of the most intensely deformed regions with frequent strong earthquakes, is divided into four secondary seismic belts: the Mediterranean seismic belt, the Central Asian seismic belt, the Himalayan seismic belt, and the Indonesian seismic belt (Zhu et al. 2022). The recent earthquakes in Türkiye occurred in the Central Asian seismic belt (Fig. 1). According to data from the U.S. Geological Survey (USGS 2023), earthquakes with a magnitude of 6.0 or higher in the Central Asian seismic belt mainly occurred in the western segment of the Zagros Mountains and the eastern Iranian plateau since 1900. Meanwhile, the frequency of earthquakes showed a fluctuating increasing trend. During the last 123 years, there were 38 earthquakes with a magnitude of 6.0–6.9, 15 earthquakes with a magnitude of 7.0–7.9 (about once every 5 years), and one earthquake with a magnitude of 8.0 or higher (about once every 100 years) in the Central Asian seismic belt. We used the formula $\lg E = 1.5MS + 11.8$ to calculate the seismic energy (Gutenberg and Richter 1955). It is clear that the release of seismic energy showed a periodic increase in pace with the increasing earthquake activities (Figs. 2 and 5).

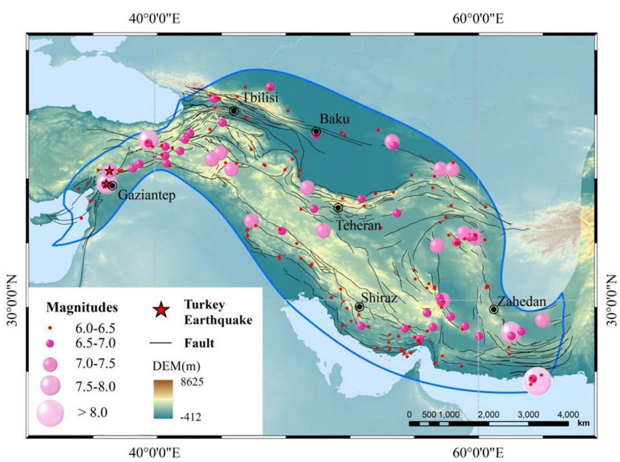


Fig. 1 Distribution of earthquakes with magnitudes of 6.0 or higher from 1900–2022 in the Central Asian seismic belt. *Data source* U.S. Geological Survey (USGS 2023)

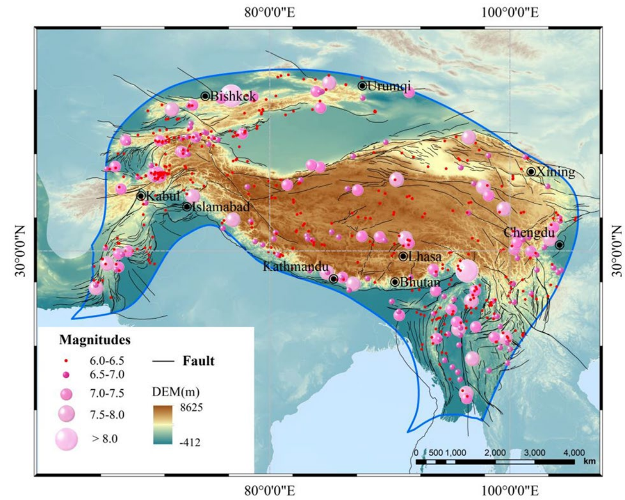
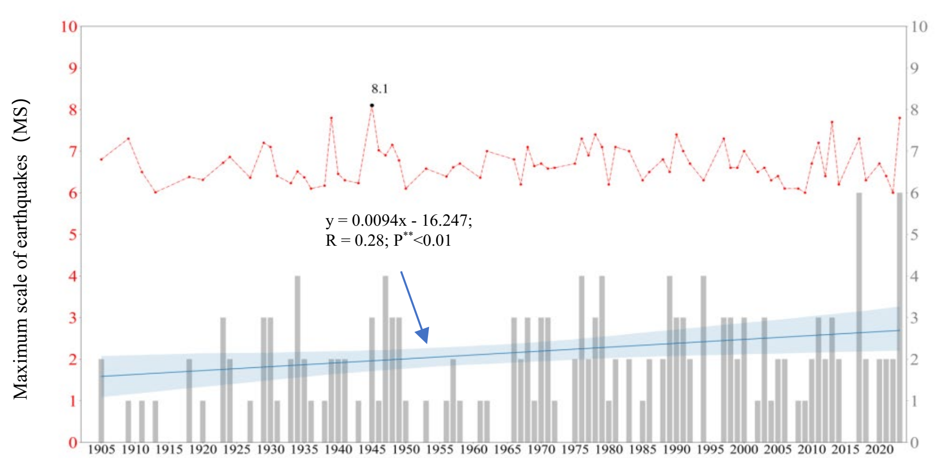


Fig. 3 Distribution of earthquakes with magnitudes of 6.0 or higher from 1900–2022 in the Tibetan Plateau earthquake zone. *Data source* U.S. Geological Survey (USGS 2023)

The Tibetan Plateau seismic zone is primarily located in the Himalayan seismic belt and its surroundings, and its western part is adjacent to the Central Asian seismic belt (Fig. 3). Since 1900, earthquakes with a magnitude of 6.0 or higher in the Tibetan Plateau seismic zone have mainly occurred in the surrounding areas of the Himalayas, Karakoram Mountains, Kunlun Mountains, Tianshan Mountains, Hengduan Mountains, Qilian Mountains, and

Fig. 2 Changes in seismic activities in the Central Asian seismic belt. *Data source* U.S. Geological Survey (USGS 2023)



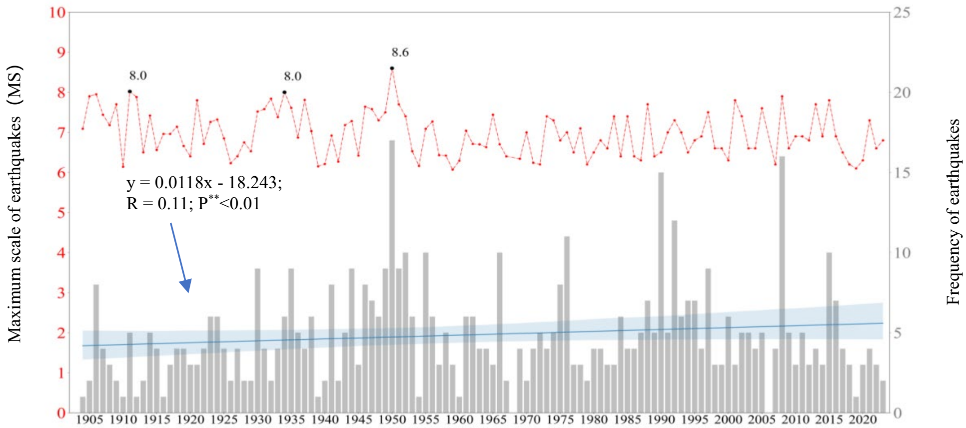


Fig. 4 Changes in seismic activities in the Tibetan Plateau earthquake zone *Data source* U.S. Geological Survey (USGS 2023)

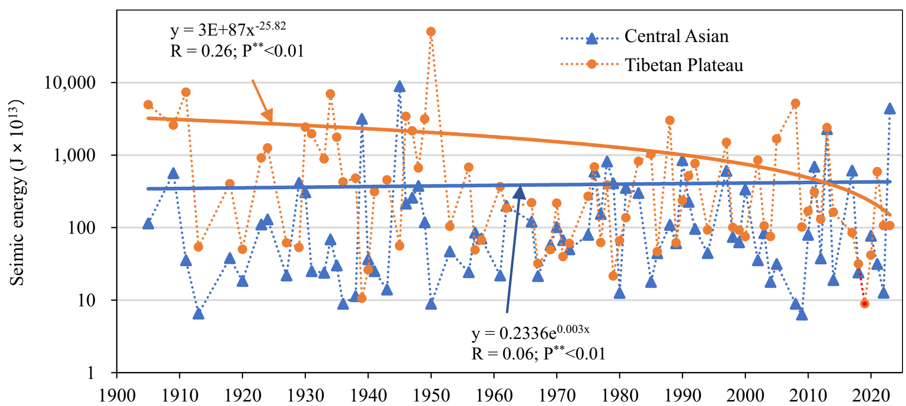


Fig. 5 Comparison of seismic energy release and trends in the Central Asian seismic belt and Tibetan Plateau earthquake zone. *Data source* U.S. Geological Survey (USGS 2023)

Nyenchen Tanglha Mountains, with a slightly fluctuating increase in earthquake frequency (see Fig. 4). In the last 123 years, this region has experienced 31 earthquakes with a magnitude of 6.0 to 6.9, 21 earthquakes with a magnitude of 7.0 to 7.9, and two earthquakes with a magnitude of 8.0 or higher (approximately once every 50 years). Among them, the 8.6 magnitude earthquake in Zayü, Tibet in 1950 was the strongest earthquake in the last century, and the release of earthquake energy showed a periodic decrease of 10 years. The Zayü earthquake in 1950, the Damxung earthquake with a magnitude of 8.0 in 1951, the Kunlun Mountains earthquake with a magnitude of 8.1 in 2001, and the Wenchuan earthquake with a magnitude of 8.0 in 2008 (Yang et al. 2011), indicate there was a south-to-north and west-to-east shift of large earthquake activities in the Tibetan Plateau seismic zone.

1.2 Risk of Earthquakes with a Magnitude of 7.8 or Higher in Western China

Analyses of the association between earthquake characteristics of the Central Asian seismic belt and the Tibetan Plateau earthquake zone showed that the risk of earthquakes with a magnitude of 7.8 or higher is expected to increase in western China in the coming years.

1.2.1 Relationship Between Seismic Activities in the Central Asian Seismic Belt and the Tibetan Plateau Earthquake Zone

The recent earthquakes in Türkiye occurred in the Central Asian seismic belt, which is adjacent to the west of the Tibetan Plateau earthquake zone. The annual frequency of earthquakes in the Tibetan Plateau earthquake zone is 2.4 times of that in the Central Asian seismic belt (Figs. 2 and 4). The annual mean energy release and single earthquake energy release in the Tibetan Plateau earthquake zone are 4 times and 1.7 times of those in the Central Asian seismic belt, respectively (Fig. 5). The area of the Central Asian seismic belt is about 40% smaller than the Tibetan Plateau earthquake zone, thus when comparing the earthquake frequency and seismic energy release of the two seismic belts, we need to consider this difference.

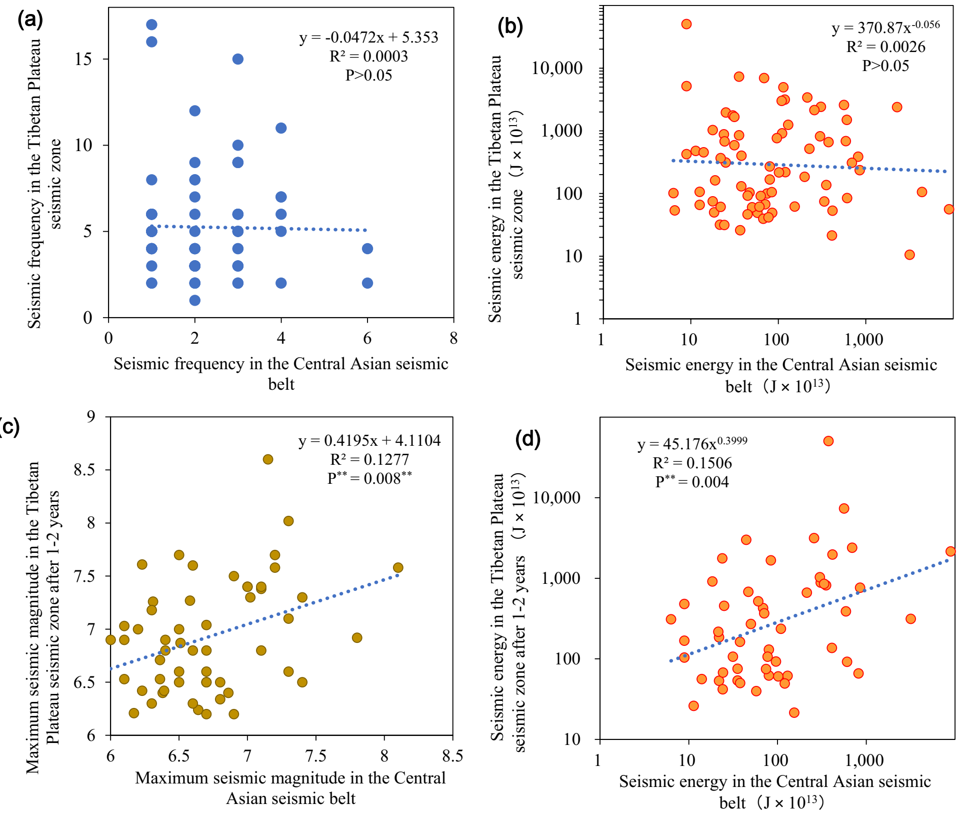


Fig. 6 Correlations between seismic frequency/magnitude and energy release in the Central Asian and Tibetan Plateau seismic zones. **a**, **b** Correlations between earthquake frequency and seismic energy release in the Central Asian seismic belt and the Tibetan Plateau earthquake zone in the same year. **c**, **d** Correlations between the maximum seismic magnitude and seismic energy release in the Central Asian seismic belt and in the following 1–2 years in the Tibetan Plateau earthquake zone. ** Indicates significant at $p < 0.01$ level

1.2.2 Prospective Consequences of the Türkiye Earthquakes on China

Earthquake frequency and seismic energy release in the Central Asian seismic belt poorly correlate to those in the Tibetan Plateau earthquake zone in the same year (Fig. 6a and b), but earthquake magnitude and seismic energy release in the Central Asian seismic belt significantly correlate to those in the Tibetan Plateau earthquake zone in the following 1–2 years (Fig. 6c and d). This implies that the impact of the Türkiye earthquakes in the Central Asian seismic belt on the Tibetan Plateau and its surroundings in China might not be immediate but delayed.

The Eurasian seismic belt is one of the world's seismic belts with the strongest seismic activity, the widest range of seismic impacts, and the largest disaster losses (Li and Zhang 1994). Despite that each seismic belt in the Eurasian seismic belt has its own relatively independent plate movements, tectonic activities, and seismic mechanisms, the recent earthquakes in Türkiye may have subsequent effects on the adjacent Tibetan Plateau earthquake zone in the next 1–2 years. In addition, the Tibetan Plateau earthquake zone had a high release of earthquake energy from 1900 to 1950. After the 8.6 magnitude earthquake in Zayü in 1950, the fluctuating increase of seismic energy had been maintained for more than 70 years. The seismic energy in the Tibetan Plateau earthquake zone gradually dropped to its lowest value of the last century in 2019. However, the seismic energy has kept rising since 2019 (Fig. 5), therefore the risk of strong and destructive earthquakes with 7.8 magnitude or above in western China in the next few years needs to be highly concerned.

2 Risk of Major Natural Hazard-Related Disasters Globally and in China

This section discusses the threats to the world and China from great earthquakes, strong tropical cyclones, big floods, and so on.

2.1 Global Great Earthquakes, Typhoons, and Floods

The threat of great earthquakes with a magnitude of 8.0 or above looms over the entire world. The Eurasian and circum-Pacific seismic belts are the two seismic belts with the most intense seismic activity, widest impact range, and largest disaster losses in the world. About 85% of deadly earthquakes in the world occur in the Alpine/Himalayan collision zone, spanning from Europe to Indonesia, while 12% occur in the Pacific Rim including the Americas, Japan, and New Zealand (Bilham 2013). Due to the movement of tectonic plates, it is inevitable that major earthquake disasters will occur again in the future in the Alpine/Himalayan collision zone and the circum-Pacific seismic belt (Tucker 2004; Deng et al. 2014; Bilham 2019; Wesnousky 2020). The 8.0 magnitude Wenchuan Earthquake in 2008, the 9.0 magnitude Great East Japan Earthquake in 2011, the 8.1 magnitude Nepal earthquake in 2015, and the double 7.8 magnitude earthquakes in Türkiye in 2023 all reflect the active period of global geological activity (Dal Zilio et al. 2021).

Coastal regions are suffering from the threats of strong tropical cyclones (TCs). The increasing trend of TC in terms of quantity and proportion (Kossin et al. 2020; Bloemendaal et al. 2022), their migration towards the poles and land (Kossin et al. 2014; Kossin et al. 2016), longer durations on terrene, and higher precipitation intensity (Liu and Wang 2020; Guzman and Jiang 2021) due to climate change has altered the impact of TCs on coastal areas (Kossin et al. 2016). In 2019, Typhoon Lekima was stranded on land in China for 44 hours. When looking at the typhoon frequency and intensity, it is clear that the frequency and proportion of strong typhoons have increased significantly (Elsner et al. 2008), with the greatest increase in the North Pacific, Indian Ocean, and Southwest Pacific, and the smallest increase in the North Atlantic (Webster et al. 2005). Meanwhile, tropical cyclones are becoming stronger and occurring at higher latitudes (Studholme et al. 2022). Since 1982, the maximum intensity point of cyclones has also been moving closer to land. As the paths of cyclones shift towards the poles and westward, the distance between the maximum intensity point of cyclones and land decreases by about 30 km every decade (Wang and Toumi 2021). This change could increase the danger of tropical cyclones to coastal populations.

The increased extreme precipitation will lead to higher flood risks. In a warming climate, global population exposed to floods is increasing, with the most significant increases in Asia and Africa. Given current protection levels and vulnerability, under the moderate emissions scenario (RCP4.5-SSP2), the annual global flood-related deaths in the mid-century is projected to be 1.9 times higher than that of the historical period (1986–2005) (Zhang et al. 2021). The annual GDP loss caused by floods globally may also increase by 4.8 times compared to the historical period (Zhang, Li et al. 2022; Zhang, Liao et al. 2022).

2.2 Great Earthquakes, Floods, Tropical Cyclones, Landslides, and Other Hazards in China

There is an increased possibility of great earthquake disasters occurring in China. Previous studies show that in addition to the increased probability of strong and destructive earthquakes in the western region of China in the coming years (Xu et al. 2017; Li et al. 2021), seismic activities in many other parts of China may also enter an active phase (Han et al. 2022). In the coming years, there is a possibility of earthquakes with a magnitude of 7.0 or above occurring in the northern Hainan fault zone of the north-south seismic belt and southern Tianshan, northern Tianshan, and eastern central Altai seismic belts (Chai and Chen 2017). There is also a possibility of earthquakes with a magnitude of 6.0 or above occurring in the junction of Shanxi, Hebei, and Inner Mongolia, the surrounding areas of the Bohai Sea, and the northern margin of the Ordos block (Cao et al. 2015; Zhu 2017).

The frequency and intensity of meteorological and hydrological hazards may increase under climate change. Simulation studies show that by around 2050, flood intensity in China is expected to increase by 33–66% and the flooded area is expected to increase by 50% compared to the baseline (historical) period (1986–2005) (Arnell and Gosling 2016). By around 2030, the proportion of flooded areas with high risk is expected to increase by 2.1–8.0% compared to the baseline period (Xu et al. 2014), and meanwhile, the flooded area on the coastal zone is expected to increase by 500 km^2, with the length of China's coastline flooded increasing by 50% compared to the historical period (Yin et al. 2020). By around 2050, area inundated by torrential flood in some regions is expected to increase by 17.6–22% compared to the historical period (Zhang et al. 2019). The number of low-intensity tropical cyclones in China is expected to decrease, while the number of high-intensity tropical cyclones is expected to increase significantly, with a northward shift in their trajectory and an earlier first landing month (Liu et al. 2020). By around 2050, due to climate fluctuations, the intensity of Pacific tropical cyclones affecting China is expected to increase by about 20% compared to the historical period (Chand et al. 2017).

The susceptibility to geological disasters is expected to significantly increase, due to the effects of global climate change, including the rise of extreme precipitation, thawing of permafrost in some regions, and an increase in loose surface materials. Specifically, during 2031 and 2060, the probability of landslides occurring in China will be notably higher compared to the historical period of 1986–2005. In the moderate (RCP4.5) and high (RCP8.5) emission scenarios, the number of landslides may increase by 19.9% and 33.2% respectively, due to the changes in extreme precipitation and air temperature (Lin et al. 2020).

3 Losses Caused by Major Natural Hazard-Related Disasters Globally and in China

The frequent occurrence of major natural hazard-related disasters in the future may bring huge losses to China and globally. By analyzing the impacts of recent catastrophic disasters worldwide, comparing losses due to catastrophic events in China to the rest of the world, and accounting the contribution of catastrophic events to the total natural hazard-related disaster losses of China, this section calls for attention to reduce the risk of huge losses due to major disasters in China.

3.1 Catastrophic Losses from Major Natural Hazard-Related Disasters

Human casualties and property losses of major disasters around the world are increasing. In 2004, the Indian Ocean earthquake and tsunami swept across several countries, killing about 250,000 people; in 2011, the earthquake in Japan caused more than USD 100 billion in property damage; and in 2005, Hurricane Katrina caused USD 125 billion in property damage and social disruption in the United States. Currently, 65% of the world's big cities are at risk of seismic disaster risk, and earthquakes with more than 100,000 deaths will continue to increase as the number and size of big cities increase (Bilham 2009).

Indirect economic losses caused by major global disasters such as earthquakes will become greater and greater. At present, the global industrial chain and trade chain network is becoming increasingly complex, and the disaster chain triggered by major earthquake disasters will cause the world industrial chain to shake. The 2008 Wenchuan earthquake-geological hazard-flash flood disaster chain caused serious damage to the Dongfang Steam Turbine Plant, resulting in a loss of output value of billions of yuan; the 2011 East Japan earthquake-tsunami-nuclear leakage accident affected the global industrial chain, and the Great East Japan Earthquake and Thailand flood caused the global loss of USD 385.61 billion, which is 2.3 times the direct loss of the two catastrophes, with Malaysia, China, Indonesia, South Korea, and the United States suffering the largest economic losses (Zhang, Li et al. 2022; Zhang, Liao et al. 2022). In 2023, the damage to important energy infrastructure caused by the double strong earthquakes in Türkiye may have an impact on the international oil and gas energy pattern and the layout of oil and gas pipelines (Alam and Ali 2023).

3.2 China's Disaster-Related Losses

China's disaster-related losses rank among the most substantial globally. In terms of the risk of deaths caused by various major natural hazard-related disasters, China ranks the 8th in the world and is a high-risk country, with eastern China being one of the worst regions in the world, surpassing some countries in Southeast Asia and South Asia. From 1991 to 2021, China accounted for five of the top 50 natural hazard-related disasters that caused the most deaths in the world, and the total number of deaths in the five major disasters was 99,139, accounting for 7.74% of the total number of deaths in the top 50 disasters in the world (ADREM et al. 2022). Combining the proportion of direct economic losses in GDP caused by various major natural hazard-related disasters, China ranks the 11th in the world and is among the high-risk countries. With regard to the five major categories of natural hazard-related disasters that caused severe property losses, China ranks among the top three globally. Between 1991 and 2021, 10 of the world's top 50 natural hazard-related disasters causing the most direct economic losses are in China, resulting in total direct economic losses of USD 2.12875 trillion (comparable prices in 2021), which accounts for 15.7% of the total direct economic losses of the top 50 globally (Shi et al. 2014; Shi and Kasperson 2015; Shi et al. 2016; Shi 2022). Catastrophic disasters posed great threats and caused huge losses to people's lives and property in China—the 2008 Wenchuan Earthquake killed a total of 69,220 people and caused 17,923 missing, with a direct economic loss of 845.14 billion yuan (Zeng and Wang 2013), and the July 20 heavy rain in Zhengzhou City, Henan Province in 2020 caused a direct economic loss of 120.06 billion yuan (Ministry of Emergency Management of the People's Republic of China 2022).

4 Challenges in China's Natural Hazard-Related Disaster Prevention and Control

This section summarizes the achievements of disaster reduction of China and discusses the challenges that China faces to improve its capacity to reduce risk from major disasters.

4.1 China's Ability of Emergency Response and Post-Disaster Relief to Natural Hazard-Related Disasters

China's ability to deal with natural hazard-related disasters has improved significantly. Since 1949, China has attached great importance to the prevention and control of natural hazards and disasters, one major disaster risk after another has been effectively addressed, and the country created many miracles of emergency rescue and disaster relief work and emergency response. China's disaster prevention and emergency management system has fully demonstrated in practice the advantages of the Chinese socialist system in concentrating its efforts on major events, and its ability to deal with natural hazards and disasters has been significantly improved, with the decreasing overall rate of casualties and economic losses from natural hazard-related disasters. According to the preliminary results of the First National

Natural Disaster Census,[1] the period from 2011 to 2020 has seen the lowest number of natural hazard-related disasters in 43 years (1978–2020). The national average annual death number decreased from 6.75 thousand in 1978–1990 to 1.25 thousand in 2011–2020, and the national average annual death rate per million people decreased from 6.47 in 1978–1990 to 0.91 in 2011–2020. The proportion of annual direct economic losses in GDP decreased from 4.07% in 1978–1990 to 0.52% in 2011–2020. With the gradual implementation of China's nine major projects for the prevention and control of natural hazard-related disasters, China's ability to respond to such disasters will be more significantly improved.

4.2 The Ability to Resist Major Natural Hazard-Related Disasters

There has been no significant improvement in the ability to resist major natural hazard-related disasters. Despite the steady decline in the overall loss rate of natural hazard-related disasters, China's capability to resist major natural hazards and disasters has not improved significantly. The situation of "high risk in cities and no defenses in rural areas" has not been fundamentally changed. The loss caused by the 2008 Wenchuan Earthquake and the 2008 snow and frozen rain disaster in southern China were equivalent to roughly 3.4% of the preceding year's national GDP, higher than the damage caused by the Tangshan Earthquake in 1976, which was 0.1% of the national GDP of the previous year (National Development and Reform Commission 2008; Xinhua News Agency 2008; China Earthquake Administration 2009). Against the backdrop of the increasing risk of catastrophes such as global earthquakes and global climate change, China faces a severe situation of major natural hazard-related disasters, and significant challenges in modernizing its disaster prevention and control capabilities.

The substandard or low fortification level of housing construction and infrastructure is a decisive factor for the formation of catastrophe. In 2010, the magnitude 7.0 earthquake in Haiti caused the death of about 220,000 people, while the magnitude 9.1 earthquake in Chile in the same year only caused 500 deaths and a relatively slight impact on the national economy (USAID (2010a), USAID (2010b)). This comparison shows that the improvement of seismic fortification of buildings in Chile has significantly reduced the loss of a high-magnitude earthquake. The World Bank estimated that the 2023 Türkiye earthquakes have caused more than USD 34 billion in direct property damage, with an estimated 1.25 million people temporarily homeless due to damaged houses or complete building collapse, and the total cost of reconstruction and economic recovery may reach USD 100 billion, which is closely related to the substandard seismic fortification of houses (GFDRR 2023).

Nearly 18 billion m^2 of old houses in China's cities have not yet been seismically reinforced, involving a population of about 300 million people, while nearly 19 billion m^2 of rural houses have not yet met the seismic fortification requirements, involving a population of about 500 million people, a significant portion of which live in high earthquake intensity and earthquake-prone areas (Meng 2019). We can learn many lessons from the Türkiye earthquake disaster, but the most important one might be the heavy casualties by building collapses, so it is urgent to improve the seismic resistance level of houses in rural and urban China.

Second, there is a high vulnerability of infrastructure to major disasters. For instance, China's oil and gas pipelines have a total length of more than 166,000 km. Some of these pipelines were inadequately seismically defended in their early construction, and others straddle seismic fault zones, which pose a significant risk (National Energy Administration 2023). China has built 98,000 reservoirs and dams of various types, with a total storage capacity of more than 930 billion m^3. Large dams and reservoirs are mainly distributed in seismically active areas such as the southwest and northwest of China (CPC Central Committee and State Council 2023). There are 179 cities and 285 counties with hydropower stations, accounting for 25.4% of China's cities and 16.7% of the country's counties respectively (China Society for Hydropower Engineering 2021). Under the threat of major earthquakes, typhoons, floods, and other catastrophes, the lack of safety and resilience of China's infrastructure has become increasingly prominent, and there is an urgent need to strengthen the infrastructure in the high-risk area of seismically active fault zones and improve the fortification level to resist earthquakes, typhoons, and floods.

Third, the monitoring, forecasting, and early warning capabilities of major disasters are still deficient. While the capabilities of forecasting and early warning of meteorological disasters such as TCs have been significantly improved, those for geological hazards, earthquakes, floods, and other hazards are still difficult to meet the needs of emergency management and risk prevention. Existing disaster monitoring, forecasting, and early warning systems lack refined monitoring, prediction, early warning, and risk assessment capabilities for important elements at risk, such as population gathering areas, major engineering facilities, and key areas with major risk of hazards. Disaster warnings are mostly focused on earthquake magnitude, wind speed, wave height, water level, and so on, and lack risk assessment for the consequences of disasters such as house collapse and dike breach, and provide less operable prevention and control suggestions

[1] Unpublished data.

than desired, making it difficult to carry out actual emergency response work such as evacuation and risk avoidance based on these warnings.

5 Countermeasures and Recommendations for Ensuring China's Safe, High-Quality, and Sustainable Development

In order to ensure China's safe, high-quality, and sustainable development, the first priority is to improve the seismic fortification level of buildings in high-risk areas of seismic active fault zones as soon as possible. At present, there is an urgent need to put forward targeted reinforcement measures such as adding ring beams, constructional columns, and pulling steel bars for buildings of different structural types in the high-risk areas of seismic active fault zones. The reinforcement of houses in high-risk areas will be incorporated into urban renewal and "new urban construction" planning to promote the overall improvement of seismic resilience and drive local economic and social development.

The second is to significantly improve the fortification level of coastal cities and towns and important infrastructure to deal with extreme meteorological and hydrological disasters. In view of important coastal towns/cities and key projects, accurate monitoring, prediction, and early warning of meteorological and marine disasters, as well as the construction of urban infrastructure and coastal protection engineering work should be strengthened to enhance the ability to withstand super typhoons, storm surges, tsunamis, and other giant disasters, and ensure high-quality and sustainable economic and social development in coastal areas.

The third is to vigorously enhance the disaster risk prevention capacity of the western and border areas. Infrastructure such as those related to energy, transportation, and information in western China is becoming increasingly more important in the national economy. The latest research showed that there is a possibility of earthquakes of magnitude 7.0 or above in western China (Xu et al. 2017; Li et al. 2021). Geological disasters in northwest and southwest China will also maintain a high incidence, with a relatively high probability of catastrophes in the western region. When extreme disasters strike the western region, high priority should be given to the possible superimposed effects of disasters and political, economic, and social insecurity, and we should quickly adjust the level of emergency response according to the development of the disaster, upgrade the response if necessary, and make targeted preparation for the delivery of emergency relief resources and emergency response forces.

The fourth is to comprehensively raise the fortification level of concentrated residential areas and major infrastructure in high-risk areas of hazards such as flash floods and debris flows. It is necessary to speed up the detailed survey and dynamic investigation and evaluation of the potential geological hazard points, identify those that have not been discovered, and improve the grading and differentiated governance system of geological hazards. For the identified major geological hazard points, 24-hour automatic monitoring should be established, universal intelligent monitoring equipment should be popularized, and early warning of small-scale and short-duration extreme disasters at the city and county levels should be strengthened to ensure that the frontline posts and threatened people are immediately informed so that disaster prevention and risk avoidance actions can be effectively organized.

The fifth is to systematically promote education for all on disaster prevention and mitigation. The majority of the rescue operations during the golden rescue period after major disasters rely on the public to save themselves and each other. Therefore, it is particularly important to improve the public's safety knowledge and skills of self-help and mutual rescue in response to disasters. China has established the "5.12" Disaster Prevention and Reduction Day, but it is still necessary to enhance the knowledge on disaster prevention and mitigation for the general public, and promote knowledge of disasters and their coping skills in the classroom, incorporating it into the important content of basic education. Safety skills are the most basic skills, which should be strengthened in communities, organizations, and work units. Grassroots organizations and work units should regularly organize disaster prevention and mitigation drills, and build a number of safety education experience museums to make people feel the disasters and acquire skills with an aim to form the soft power of safety culture with Chinese characteristics.

The sixth is to greatly enhance the societal disaster mitigation capacity including catastrophe insurance. China should improve the comprehensive prevention capability of the whole society to resist natural hazard-related disasters and shift away from the sole reliance on the government for disaster relief. In the face of the threat of catastrophe, we should concentrate the efforts of the government, industry, and society, and coordinate legal, administrative, scientific, technological, and economic means to facilitate disaster risk identification, control, and reduction. Compulsory insurance for high-risk regions should be fully implemented to effectively meet catastrophe insurance needs. The insurance coverage of housing for urban residents should also be increased. Mandatory insurance policy for enterprises and institutions in high-risk areas of natural hazards and disasters should be implemented and catastrophe insurance should be taken as an important basis for financing and credit. The country should adopt policies to guide and encourage the accelerated research and implementation of catastrophe insurances for typhoons and floods, and select key areas for catastrophe insurance pilot programs.

Acknowledgments This work is founded by the Sixth Task of the Second Tibetan Plateau Scientific Expedition and Research Program (STEP), "Integrated Disaster Risk Prevention" (Grant No. 2019QZKK0906). We would like to acknowledge the following individuals from various institutions who have contributed to the writing and discussion of this article: Shanping Song and Wen Li from the National Institute of Education Policy and Social Governance, Beijing Normal University; Chunyang He, Wei Xu, Ying Wang, and Ming Wang from the Academy of Disaster Reduction and Emergency Management, Beijing Normal University; Guofeng Su from the Institute for National Governance and Global Governance, Tsinghua University; Weicheng Fan, Hongyong Yuan, Bing Huang, Wenzhong Mi, Zhang Wei, Dianzhu Liu, Shuai Liu, and Kongzheng Liang from the School of Public Security, Tsinghua University; and Tao Chen, Jianguo Chen, and Rui Zhou from the Hefei Institute of Public Safety Research, Tsinghua University.

References

ADREM (Academy of Disaster Reduction and Emergency Management, Ministry of Emergency Management & Ministry of Education), School of National Safety and Emergency Management, Beijing Normal University, NDRCC (National Disaster Reduction Center of China, Ministry of Emergency Management), and IFRC (International Federation of Red Cross and Red Crescent Societies). 2022. 2021 Global disaster assessment report. https://www.preventionweb.net/publication/2021-global-disaster-assessment-report. Accessed 20 Sept 2023.

Alam, I., and Y. Ali. 2023. Studying the effects of Türkiye earthquake disaster and its impact on real estate industry: A risk analysis based on input-output & non-linear optimization models. *International Journal of Disaster Risk Reduction* 96: Article 103920.

Arnell, N.W., and S.N. Gosling. 2016. The impacts of climate change on river flood risk at the global scale. *Climatic Change* 134(3): 387–401.

Bilham, R. 2009. The seismic future of cities. *Bulletin of Earthquake Engineering* 7: 839–887.

Bilham, R. 2013. Earthquake tectonics and hazards on the continents. International Centre for Theoretical Physics Trieste course notes.

Bilham, R. 2019. Himalayan earthquakes: A review of historical seismicity and early 21st century slip potential. *Geological Society Special Publication* 483: 423–482.

Bloemendaal, N., H. de Moel, A.B. Martinez, S. Muis, I.D. Haigh, K. van der Wiel, R.J. Haarsma, P.J. Ward, et al. 2022. A globally consistent local-scale assessment of future tropical cyclone risk. *Science Advances* 8: Article eabm8438.

Cao, F.J., L. Wang, J. Li, X. Wang, M. Yang, and B. Zhang. 2015. Relevant migration characteristics of strong earthquakes between the north-south seismic belt and North China block. *Acta Seismologica Sinica* 37(4): 554–564; 711 (in Chinese).

Chai, R.J., and D.Q. Chen. 2017. Preliminary study on characteristics of strong earthquake's migration in main block of China, based on projection line of strong earthquakes migration. *South China Journal of Seismology* 37(S1): 41–47 (in Chinese).

Chand, S., K. Tory, H. Ye, and K. Walsh. 2017. Projected increase in El Niño-driven tropical cyclone frequency in the Pacific. *Nature Climate Change* 7: 123–127.

China Earthquake Administration. 2009. A review of the losses from the seismic disaster in China's mainland in 2008. https://www.gov.cn/gzdt/2009-02/16/content_1232718.htm. Accessed 21 Dec 2023 (in Chinese).

China Society for Hydropower Engineering. 2021. China hydropower report 2021. http://www.hydropower.org.cn/showNewsDetail.asp?nsId=31467. Accessed 21 Dec 2023 (in Chinese).

CPC Central Committee and State Council. 2023. The outline of the national water network construction plan. https://www.gov.cn/zhengce/202305/content_6876215.htm. Accessed 21 Dec 2023 (in Chinese).

Dal Zilio, L., G. Hetényi, J. Hubbard, and L. Bollinger. 2021. Building the Himalaya from tectonic to earthquake scales. *Nature Reviews Earth and Environment* 2: 251–268.

Deng, Q.D., S.P. Cheng, J. Ma, and P. Du. 2014. Seismic activities and earthquake potential in the Tibetan Plateau. *Chinese Journal of Geophysics* 57(5): 678–697.

Elsner, J.B., J.P. Kossin, and Y.H. Jagger. 2008. The increasing intensity of the strongest tropical cyclones. *Nature* 455: 92–95.

GFDRR (Global Facility for Disaster Reduction and Recovery). 2023. Global rapid post-disaster damage estimation (GRADE) report: February 6, 2023 Kahramanmaraş Earthquakes – Türkiye report. Washington, DC: World Bank Group. http://documents.worldbank.org/curated/en/099022723021250141/P1788430aeb62f08009b2302bd4074030fb. Accessed 14 Dec 2023.

Gutenberg, B., and C.F. Richter. 1955. Magnitude and energy of earthquakes. *Nature* 176(4486): Article 795.

Guzman, O., and H. Jiang. 2021. Global increase in tropical cyclone rain rate. *Nature Communication* 12: Article 5344.

Han, Y., Y. Zang, L. Meng, Y. Wang, S. Deng, Y. Ma, and M. Xie. 2022. A summary of seismic activities in and around China in 2021. *Earthquake Research Advances* 2(3): Article 100157.

Kossin, J.P., K.A. Emanuel, and G.A. Vecchi. 2014. The poleward migration of the location of tropical cyclone maximum intensity. *Nature* 509: 349–352.

Kossin, J.P., K.A. Emanuel, and S.J. Camargo. 2016. Past and projected changes in western North Pacific tropical cyclone exposure. *Journal of Climate* 29: 5725–5739.

Kossin, J.P., K.R. Knapp, T.L. Olander, and C.S. Velden. 2020. Global increase in major tropical cyclone exceedance probability over the past four decades. *Proceedings of the National Academy of Sciences of the United States of America* 117: 11975–11980.

Li, X.Z., and G.M. Zhang. 1994. Study on the relation between the seismicities in Eurasian seismic belt and in China continent. *Seismology and Geology* 16(4): 300–304.

Li, H.B., J.W. Pan, Z.M. Sun, J.L. Si, J.L. Pei, D.L. Pei, M.-L. Chevalier, and H. Wang et al. 2021. Continental tectonic deformation and seismic activity: A case study from the Tibetan Plateau. *Acta Geologica Sinica* 95(1): 194–213 (in Chinese).

Lin, Q., Y. Wang, T. Glade, J. Zhang, and Y. Zhang. 2020. Assessing the spatiotemporal impact of climate change on event rainfall

characteristics influencing landslide occurrences based on multiple GCM projections in China. *Climatic Change* 162(2): 761–779.
Liu, L., and Y. Wang. 2020. Trends in landfalling tropical cyclone-induced precipitation over China. *Journal of Climate* 33: 2223–2235.
Liu, L., Y. Wang, R. Zhan, J. Xu, and Y. Duan. 2020. Increasing destructive potential of landfalling tropical cyclones over China. *Journal of Climate* 33: 3731–3743.
Meng, X. 2019. Earthquake chain and earthquake risk management. https://jjxy.cidp.edu.cn/2019guangxi.pdf. Accessed 21 Dec 2023 (in Chinese).
Ministry of Emergency Management of the People's Republic of China. 2022. Top 10 natural disasters in the country in 2021. https://www.mem.gov.cn/xw/yjglbgzdt/202201/t20220123_407199.shtml. Accessed 21 Dec 2023.
National Development and Reform Commission. 2008. The combined direct economic losses from low-temperature, rain, snow, and ice disasters amounted to 151.65 billion yuan. https://www.gov.cn/jrzg/2008-04/22/content_951622.htm. Accessed 21 Dec 2023 (in Chinese).
National Energy Administration. 2023. The oil and gas pipeline network will achieve comprehensive interconnection. https://www.nea.gov.cn/2023-04/07/c_1310709027.htm. Accessed 21 Dec 2023 (in Chinese).
Shi, P. 2022. *Atlas of global change risk of population and economic systems*. Berlin: Springer.
Shi, P.J., and R. Kasperson. 2015. *World atlas of natural disaster risk*. Berlin: Springer.
Shi, P., X. Yang, J. Fang, J. Wang, W. Xu, and G. Han. 2014. Mapping and ranking global mortality, affected population and GDP loss risks for multiple climatic hazards. *Journal of Geographical Sciences* 26(7): 353–358.
Shi, P., X. Yang, and W. Xu. 2016. Mapping global mortality and affected population risks for multiple natural hazards. *International Journal of Disaster Risk Science* 7(1): 54–62.
Studholme, J., A.V. Fedorov, S.K. Gulev, K. Emanuel, and K. Hodges. 2022. Poleward expansion of tropical cyclone latitudes in warming climates. *Nature Geoscience* 15: 14–28.
Tucker, B.E. 2004. Trends in global urban earthquake risk: A call to the international earth science and earthquake engineering communities. *Seismological Research Letters* 75(6): 695–700.
USAID (United States Agency for International Development). 2010. *USAID Haiti – Earthquake Fact Sheet #47, Fiscal Year (FY) 2010, 26 March 2010*. Washington, DC: USAID.
USAID (United States Agency for International Development). 2010. *USAID Chile – Earthquake Fact Sheet #14, Fiscal Year (FY) 2010, 18 March 2010*. Washington, DC: USAID.
USGS (U.S. Geological Survey). 2023. PAGER. https://earthquake.usgs.gov/data/pager/. Accessed 25 Feb 2023.
Wang, S., and R. Toumi. 2021. Recent migration of tropical cyclones toward coasts. *Science* 371: 514–517.
Webster, P.J., G.J. Holland, J.A. Curry, and H.-R. Chang. 2005. Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science* 309: 1844–1846.
Wesnousky, S.G. 2020. Great pending Himalaya earthquakes. *Seismological Research Letters* 91(6): 3334–3342.
Xinhua News Agency. 2008. Major earthquakes of magnitude 6 and above in China since 1976. https://www.gov.cn/jrzg/2008-05/13/content_970378.htm. Accessed 21 Dec 2023 (in Chinese).
Xu, Y., B. Zhang, B.T. Zhou, S.Y. Dong, L. Yu, and R.K. Li. 2014. Projected flood risks in China based on CMIP5. *Advances in Climate Change Research* 5(2): 57–65.
Xu, X.W., X.Y. Wu, G.H. Yu, X.B. Tan, and K. Li. 2017. Seismo-geological signatures for identifying M≥7.0 earthquake risk areas and their preliminary application in mainland China. *Seismology and Geology* 39(2): 219–275 (in Chinese).
Yang, G.G., Y.Z. Yang, Z. You, and X.Y. Zhang. 2011. The spatiotemporal distribution pattern of land seismic disasters in China. *Advance in Earth Science* 26(5): 548–555 (in Chinese).
Yin, J., S. Guo, L. Gu, S. He, H. Ba, J. Tian, Q. Li, and J. Chen. 2020. Projected changes of bivariate flood quantiles and estimation uncertainty based on multi-model ensembles over China. *Journal of Hydrology* 585: Article 124760.
Zeng, Z., and C. Wang. 2013. Wenchuan, China (2008 Earthquake). In *Encyclopedia of natural hazards*, ed. P.T. Bobrowsky, 1097–1102. Dordrecht: Springer.
Zhang, Y., Y. Wang, Y. Chen, F. Liang, and H. Liu. 2019. Assessment of future flash flood inundations in coastal regions under climate change scenarios – A case study of Hadahe River Basin in northeastern China. *Science of the Total Environment* 693: Article 133550.
Zhang, J., W. Xu, X. Liao, S. Zong, and B. Liu. 2021. Global mortality risk assessment from river flooding under climate change. *Environmental Research Letters* 16(6): Article 064036.
Zhang, Z., N. Li, M. Wang, K. Liu, C. Huang, L. Zhuang, and F. Liu. 2022. Economic ripple effects of individual disasters and disaster clusters. *International Journal of Disaster Risk Science* 13: 948–961.
Zhang, J., X. Liao, and W. Xu. 2022. Mapping global risk of GDP loss to river floods. In *Atlas of global change risk of population and economic systems*, ed. P. Shi, 195–202. Singapore: Springer Nature Singapore.
Zhu, H. 2017. Strong earthquake risk evaluations on major fault subzones in northern section of the north-south seismic belt based on the time and magnitude-predictable model. *Earthquake Research in China* 33(3): 374–384 (in Chinese).
Zhu, R.X., P. Zhao, and L. Zhao. 2022. Evolution and dynamic processes of the Neo-Tethys Ocean. *Science China: Earth Science* 52(1): 1–25 (in Chinese).