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Poverty control policy may affect the transition of geological disaster risk in China

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The Chinese government has implemented measures to reduce poverty in the country. Specifically, the Targeted Poverty Alleviation (2013–2020) policy is a set of unique, large-scale and precise poverty control measures undertaken by China in an effort to eliminate absolute poverty. Deeply impoverished areas in the mountainous regions of Southwest China are also particularly prone to geological disasters. A poverty control policy might reduce risk from natural disasters in this region by changing human behaviour. However, it is unclear how the risk might change under the government's poverty control measures. This paper uses power-law relations and negative binomial regression to analyse primary economic losses from geological disasters in Yunnan Province between 2009 and 2017. The results of the analysis show that the relation between the level of economic development and disaster losses in Yunnan Province changed from an inverted-U shape to a U shape in this period. While direct economic losses from geological disasters are falling, we find that losses in wealthy counties Yunnan Province have not decreased significantly and might even be increasing. In impoverished areas, poverty alleviation policies reduce the economic losses of geological disasters by reducing the vulnerability and exposure, and increasing the resilience. On the contrary, poverty reduction measures promote a concentration of population and wealth in non-poor areas, increasing the vulnerability and exposure, which in turn lead to an increase in direct economic losses from geological disasters. Therefore, in order to consolidate the achievements of poverty alleviation projects, the government needs to pay attention to the transfer of geological disaster risk caused by the policy-driven transformation of human social behaviour.

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Introduction

For historical and environmental reasons, a large number of impoverished people live in mountainous areas of China, and these areas are subject to frequent natural disasters, including floods, landslides and earthquakes (Jiang et al., 2016; Zhou et al., 2020). Over the past several decades, the Chinese government has addressed this issue by implementing poverty reduction policies (State Council of the People’s Republic of China, 2001, 2011; Fang and Zhang, 2021; Tang, 2019a; Zhang, 2019). In particular, the Targeted Poverty Alleviation (TPA) policy initiated in 2013 requires the causes of poverty for each poor household to be identified and addressed through targeted poverty reduction measures (State Council of the People’s Republic of China et al., 2014; Liu et al. 2016, 2017). This programme has been a success—the standard of living of poor Chinese citizens was raised to and above the poverty level by the end of 2020. However, the effect of the measures on risks from natural disasters is unclear. To this end, the relationship over time between the level of economic development and disaster losses may help shape government policies.

In general, the relationship between the level of economic development and losses from natural disasters follows a monotonically decreasing (Kahn, 2005; Toya and Skidmore, 2007), inverted U-shaped (Kellenberg and Mobarak, 2008; Zhou et al., 2014) or U-shaped (Raschky, 2008; Schumacher and Strobl, 2011) pattern (Fig. 1). Different relationships may indicate a need to implement distinct and different policies to mitigate the risk of natural disasters (Kellenberg and Mobarak, 2008; Schumacher and Strobl, 2011). For example, an inverted U-shaped relationship might suggest that risk mitigation measures should be focused on moderately poor regions that have higher losses from natural disasters compared with extremely poor or rich ones. Previous studies, however, have not examined the possibility that risk-reduction policies could have unexpected effects on the relationship between natural disaster risk and economic development level.

Human behaviour is thought to be a major contributor to the relationship between the level of economic development and losses from natural disasters (Kellenberg and Mobarak, 2008; Raschky, 2008; Choi, 2016). Additionally, government policy is one of the most important forces leading to changes in human behaviour (Fischer et al., 2012; Shove, 2010). Accordingly, China’s poverty reduction policies could be expected to have an effect on the relationship between natural disaster risk and economic development level.

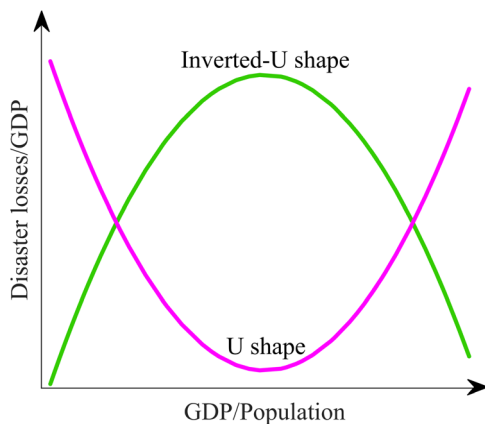


Fig. 1 Conceptual graph of nonlinear relationship between GDP/population and disaster losses/GDP. Green line represents inverted U-shape relationship, and pink line represents U-shape relationship between GDP/population and disaster losses/GDP.

This paper uses data from Yunnan Province, which is a poor mountainous region in Southwest China, to explore the issues raised above. Areas with high levels of poverty in Yunnan Province are mostly located in remote mountainous valleys with harsh natural environments and frequent natural disasters (Fig. 2). Over time, economic losses in this region have changed due to economic development, which in turn has been affected by changes in human behaviour. We explore the relationship between economic development level and economic losses using a dataset of geological disasters from 2009 to 2017. We examine this relationship using power law relation and negative binomial regression analyses, and then discuss the effects of China’s poverty reduction measures on these changes.

Results

Power-law relationship between geological disaster losses and economic development level. We normalized GDP per capita to [0, 1] to clarify the relationship between geological disaster losses and economic development. Figure 3 shows the power law fit showing the relation between direct economic losses/GDP and GDP per capita between 2009 and 2017. It is evident from Fig. 3 that poorer counties suffered more economic losses from geological disasters than wealthier ones. We infer from this relation that targeted poverty reduction measures reduce losses from disasters, which is in accord with suggestions by other researchers that economic growth can mitigate the risk of natural disasters (Kahn, 2005; Toya and Skidmore, 2007). However, the trend line for the period 2013–2016 has a generally higher tail and lower head compared with the 2009–2012 trend line (Fig. 3). This implies that direct economic losses from geological disasters in wealthier counties increased as losses in impoverished counties decreased. This may cause changes in the nonlinear relationship between GDP/population and direct economic losses/GDP

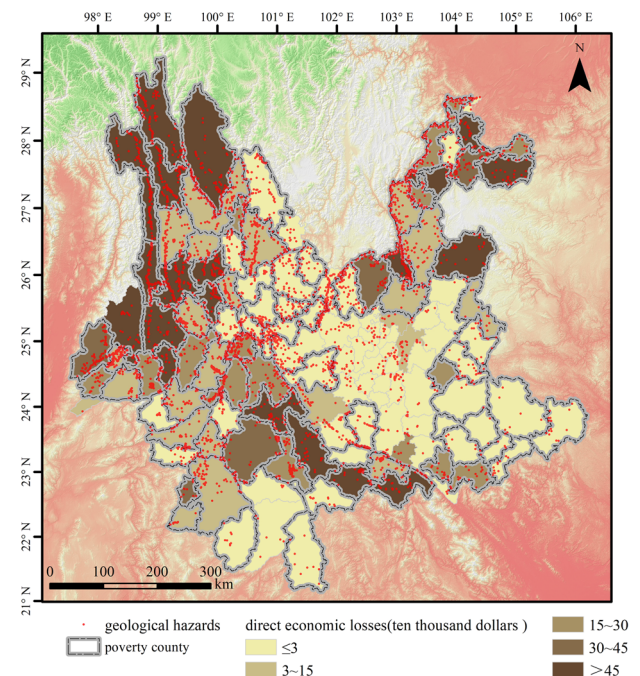


Fig. 2 Distribution of geological hazards, and related direct economic losses (average values in 2009–2017) in Yunnan Province. There were 88 poverty-stricken counties in Yunnan Province in 2015 Annual per capita income of RMB 4000.00 is regarded as the poverty household. A county with a percentage of poor households >3% is considered a poor county. Most of these poor counties are in areas with frequent geological hazards.

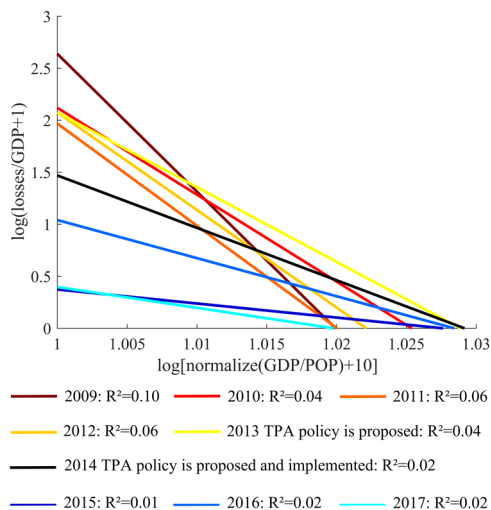


Fig. 3 Power-law relationships between geological disaster economic losses and economic development in different years in Yunnan Province, China. The negative relations shown in this figure imply that poor counties suffered greater direct economic losses from geological disasters than more wealthy ones. A counterclockwise rotational displacement of trend lines is also apparent.

(Kellenberg and Mobarak, 2008; Raschky, 2008; Schumacher and Strobl, 2011). However, power-law analysis is not good at non-linear analysis with multiple factors.

Negative binomial relationship between losses from geological disasters and economic development level. In this section, we used negative binomial regression to explore the characteristics of the nonlinear relationship between GDP/population and direct economic losses/GDP. We selected $[\log(\text{GDP}_{it}/\text{POP}_{it})]^2$ as a variable to explore the nonlinear relationship between GDP/population and direct economic losses. Other variables include: POP_{it} is the population, Aff_{it} is the population affected by geological disasters, PD_{it} is the ratio of population to the total area of low and moderate geological hazard susceptibility areas, and PORP_{it} is the proportion of the rural population per thousand people. Table 1 presents the negative binomial estimation results. Columns 2–10 record the regression analysis results from 2009 to 2017. Pseudo- R^2 values range from 0.24 to 0.64 (Table 1).

Row 3 of Table 1 shows regression results for the relation between $[\log(\text{GDP}_{it}/\text{POP}_{it})]^2$ and $\log(\text{losses}/\text{GDP} + 1)$. The sign of the coefficient is negative from 2009 to 2012, but becomes positive in 2013. Nonlinear relationships between GDP/population and direct economic losses/GDP shown in Fig. 4 were obtained from the values in Table 1. The results show that the relationship changed from an inverted U-shape during 2009–2012 to a U-shape during 2013–2017.

Discussion

Socio-economic significance of the nonlinear relationship. A change in the relationship between direct economic losses from geological disasters/GDP and GDP/population in Yunnan Province occurred in 2013. The inverted U-shaped relationship (Fig. 4a) shows that direct economic losses first increase slightly and then decrease with economic development. Although the hazard is extremely high in impoverished counties, the level of economic development is low, thus economic losses from natural disasters are low. In contrast, counties with high hazard levels and relatively high economic development and those with moderate hazard levels and high economic development have experienced

Table 1 Negative binomial regression results.

Variable	Year	2009	2010	2011	2012	2013	2014	2015	2016	2017
$\log(\text{GDP}_{it}/\text{POP}_{it})$		3.18 (7.51)	2.99 (9.57)	6.60 (13.94)	1.70 (13.37)	-10.12 (7.34)	-25.07* (12.94)	-71.46 (44.87)	-46.49** (21.36)	-131.74** (63.44)
$[\log(\text{GDP}_{it}/\text{POP}_{it})]^2$		-0.70 (1.21)	-0.56 (1.50)	-1.23 (2.13)	-0.56 (1.99)	1.39 (1.05)	3.59* (1.85)	9.74 (6.43)	6.39** (3.03)	17.51* (9.10)
$\log(\text{POP}_{it})$		0.36 (0.28)	-0.01 (0.32)	0.49 (0.44)	0.11 (0.40)	0.10 (0.37)	-0.34 (0.60)	-1.80 (2.07)	0.01 (0.92)	-1.18 (1.12)
$\log(\text{Aff}_{it})$		0.64*** (0.07)	0.87*** (0.09)	0.82*** (0.10)	0.85*** (0.09)	0.83*** (0.09)	1.23*** (0.15)	2.14*** (0.47)	1.57*** (0.27)	1.57*** (0.27)
$\log(\text{PORP}_{it})$		-0.75 (0.85)	0.70 (1.24)	-0.36 (1.50)	-1.17 (1.02)	1.32* (0.79)	7.20** (2.95)	-0.22 (4.38)	2.73 (2.95)	9.81 (14.02)
$\log(\text{PD}_{it})$		-0.42* (0.24)	0.39 (0.26)	-0.18 (0.35)	-0.18 (0.32)	-0.26 (0.28)	0.42 (0.42)	-0.82 (1.59)	-0.28 (0.68)	-4.83** (2.45)
const		-2.53 (11.46)	-7.98 (14.58)	-10.75 (21.83)	2.79 (21.84)	13.50 (13.22)	21.60 (23.05)	138.04* (78.47)	74.38** (37.76)	228.90*** (87.34)
Observation		129	129	129	129	129	129	129	129	129
Log-likelihood		-176.08	-134.73	-135.85	-152.52	-147.72	-107.81	-27.91	-84.77	-15.08
Pseudo- R^2		0.24	0.36	0.28	0.24	0.29	0.32	0.46	0.29	0.64
U or IU shape		IU	IU	IU	IU	U	U	U	U	U

Standard errors in parentheses.
 *Significant at the 10% level.
 **Significant at the 5% level.
 ***Significant at the 1% level.

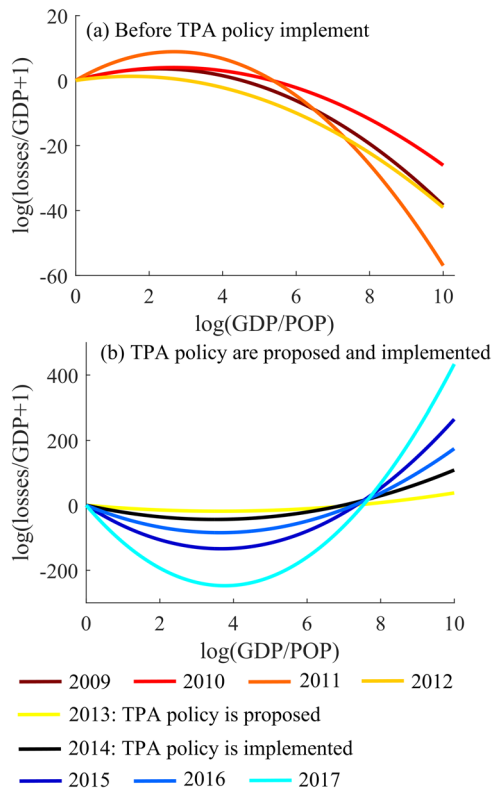


Fig. 4 Nonlinear relationships between losses from geological disasters and economic development level between 2009 and 2017 in Yunnan Province. The coefficients of $\log(\text{GDP}_{it}/\text{POP}_{it})$ and $[\log(\text{GDP}_{it}/\text{POP}_{it})]^2$ are derived from negative binomial regressions in Table 1. **a** Inverted U-shaped relationships are obtained for the years 2009–2012. **b** U-shaped relationships are obtained for the years 2013–2017.

high losses from natural disasters. Finally, counties with low hazard levels and high economic development have low losses.

A U-shaped relationship (Fig. 4b) indicates that direct economic losses from natural disasters first decrease, but then increase as economic development proceeds. In the early stages of economic development, residents of areas with high hazard and poor economic conditions might be willing to suffer economic losses from disasters to obtain future economic benefits (Kellenberg and Mobarak, 2008). People living in high-risk areas that have reached a certain level of economic development are both willing and able to reduce economic losses through investment in disaster prevention and mitigation (Schumacher and Strobl, 2011). Highly developed, low-hazard areas will accept increased economic losses due to sustained population and infrastructure growth (Raschky, 2008; Zhou et al., 2014).

Explanations for the transition of the nonlinear relationship.

We propose that the reason for the change from the inverted U-shaped relationship to the U-shaped relationship seen in Fig. 4 is that the risk to impoverished counties decreases significantly with economic progress, whereas the risk to developing counties does not significantly decrease and may even increase. The change in risk with economic development is related to the change in human social behaviour, which itself is strongly influenced by government policy. As a result of Chinese government policies, most Chinese citizens are not now impoverished. We argue that the change in human behaviour influenced by these measures altered the relationship between GDP/population and economic losses/GDP. We argue that the change in human behaviour influenced by poverty control policy (State

Council of the People's Republic of China, 2001, 2011; Fang and Zhang, 2021; Tang, 2019a; Zhang, 2019) over decades promotes changes in the relationship between GDP/population and direct economic losses/GDP.

Population migrations are an important strategy for reducing poverty (National Development and Reform Commission of China, 2012, 2014, 2018; Yang et al., 2020; Liu et al., 2018). It refers to the voluntary relocation of poor people living in areas lacking suitable living conditions so as to increase income and mitigate poverty by improving the production and living conditions in the new environment (Lo et al., 2016; Lo and Wang, 2018; Yan, 2016a). However, it is difficult for poor people whose main source of income is agriculture to move to safer and wealthier areas rely on their economic strength (Tang, 2019a). In addition, intergenerational memory, place attachment, place identity, and worry about sustainable livelihoods hinder population migration (Xu et al., 2017; Peng et al., 2020; Swapan and Sadeque, 2021; Xu et al., 2021; Feng and Zhu, 2021). The Chinese government has implemented a series of measures, including housing subsidies, land security, schooling, low-interest loans, preferential taxation, improved communication, supporting infrastructure and better medical facilities, to encourage poor people to relocate (National Development and Reform Commission of China, 2012, 2014, 2016, 2018; People's Government of Yunnan Province, 2016; Ministry of Finance of the People's Republic of China, 2018; Tang, 2019c). The government also provides job training and entrepreneurship guidance to relocated citizens to increase their ability to improve their lives (People's Government of Yunnan Province, 2014; Liu et al., 2018; Leng et al., 2021; Tang, 2019b). Relocation can directly reduce the exposure and vulnerability. Meanwhile these measures enhance the resilience of people to natural disasters.

Transfer of employment is an important means of poverty alleviation in China. The Chinese government has implemented measures to encourage the impoverished surplus rural labour force to move away from agricultural production and to engage in work or business activities that improve their livelihoods (Yan, 2016a; People's Government of Yunnan Province, 2014). It has provided skill training, employment guidance and financial subsidies for those wishing to change their employment. Economic benefits obtained by transferring employment increase peoples' willingness and ability to relocate.

Knowledge is an important factor affecting social behaviour and can reduce individual vulnerability and exposure to natural disasters (Toya and Skidmore, 2007; Muttarak and Lutz, 2014; Hoffmann and Blecha, 2020; Righi et al., 2021; Frankenberg et al., 2013). The general low level of knowledge and skills possessed by people living in poverty is mainly the result of their low level of education. Education provides skills and opportunities for people to escape poverty (Yan, 2016a). Although alleviating poverty through education is arguably a slow process, it is fundamental to solving the problem of intergenerational poverty. China has improved educational funding programmes for poor students, promoted the full coverage of basic public services for education of the poor, and guaranteed their right to education (Tang, 2019c; Yan, 2016a, 2016b; Ministry of Education of the People's Republic of China et al., 2016; Xue and Zhou, 2018). In summary, poverty alleviation policies have accelerated the migration of impoverished people from hazardous areas, thus effectively reducing the risk in those areas. The policies also reduce risk by strengthening the resilience of the population to natural disasters.

Development of mountain areas commonly increases the risk of natural disasters due to increased population and concentrations of property in hazardous areas (Li, Lei et al., 2017; Cui et al., 2019). China's poverty control policy has resulted in the movement of large numbers of people from impoverished

hazardous areas to wealthier and safer ones (Wang and Cai, 2006; Jia et al., 2017). This, in turn, has resulted in rapid urban expansion. However, these urban environments are not perfectly safe: flooding, earthquakes, and engineered slopes contribute risks to people living in the mountainous towns in China, and, urban sprawl and asset concentration may increase hazard, exposure and vulnerability (Lan et al., 2021; Raschky, 2008; Cui et al., 2019; Gencer, 2013).

Suggestions on policies for risk reduction. The poverty control policies of the Chinese government have played an important and positive role in controlling losses from geological disasters. To consolidate and further improve the results achieved through the country’s poverty control policies, we make the following recommendations: continue to implement poverty control policies; and pay attention to the increased risk of natural disasters that may occur due to the increased population and concentration of wealth in large urban environments.

Conclusion

To explore the changing characteristics of natural disaster risk accompanying economic development and poverty reduction, we analysed direct economic losses from geological disasters in Yunnan Province between 2009 and 2017. When poverty control policies were implemented around 2013, economic losses from natural disasters throughout the province, but especially in its impoverished counties, declined steeply. The nonlinear relationship between GDP/population and primary economic losses/GDP changed from an inverted-U shape to a U shape. An important reason for this change is that, even as the risk to impoverished counties decreases, the risk to developing counties does not because of policy-induced changes in human behaviour. Relocation, employment transfer, and improved educational and medical services have accelerated the recent large-scale movement of people from dangerous impoverished areas to safer and more wealthy ones, sharply decreasing exposure and vulnerability in the former. Moreover, poverty alleviation policies also strengthen the resilience of people in the face of natural disasters. Although government poverty control measures have led to large-scale relocations of people into safer regions, concentrations of people and assets increase the vulnerability and exposure of large urban populations to rare disasters. Accordingly, to consolidate the achievements of China’s poverty reduction programme, the government should expand those measures while paying attention to risk reduction in all areas of the country.

Methods

Power-law relation analysis. We explored the characteristics of the power-law relationships between economic development and natural disaster losses in Yunnan Province, China. The power-law formula can be expressed as follows:

$$R = K \times I^{-\beta} \tag{1}$$

where R is risk, represented by “direct economic losses/GDP” (dollars/100 million dollars), I is the “GDP/population” (GDP per capita), and K and $-\beta$ are power-law coefficients. The data satisfy the power-law distribution and plot as a straight line on a log–log plot. We take the log of both sides of Eq. (1) to establish the following formula:

$$\text{Log}(\text{LOSSES}/\text{GDP} + 1) = \text{Log}(K) - \beta \text{Log}[\text{Normalize}(\text{GDP}/\text{POP}) + 10] \tag{2}$$

Negative binomial regression. We created an empirical model to explain the direct economic losses due to natural disasters in

county i at time t :

$$H(\text{LSI}, E_i) = \text{POP}_{it}/\text{LHA}_i \tag{3}$$

where LSI is geological hazard susceptibility index, E_i is geography or physical exposure component, $H(\text{LSI}, E_i)$ is natural hazard function, POP_{it} is the population of county i at time t , and LHA_i is the area of low and moderate hazard susceptibility in the county. LHA_i was calculated using the ALSA model (Li, Lan et al., 2017) and is based on geological hazards spatial data and geological hazard influence factors. The relationship between disaster losses and their components, which we used in our negative binomial regression model is expressed as

$$\begin{aligned} \log(\text{Losses}_{it}/\text{GDP}_{it} + 1) = & \beta_0 + \beta_1 \log(\text{GDP}_{it}/\text{POP}_{it}) + \\ & \beta_2 [\log(\text{GDP}_{it}/\text{POP}_{it})]^2 + \beta_3 \log(\text{POP}_{it}) + \\ & \beta_4 \log(\text{Aff}_{it}) + \beta_5 \log(\text{PORP}_{it}) + \beta_6 \log(\text{PD}_{it}) + \varepsilon_{it} \end{aligned} \tag{4}$$

where β_0 – β_6 are regression coefficients, Losses_{it} is direct economic losses from geological disasters in county i during period t , GDP_{it} represents GDP in county i during period t , POP_{it} is the population in county i during period t , Aff_{it} is the population affected by geological disasters in county i during period t , PORP_{it} is the proportion of the rural population in county i during period t , PD_{it} is calculated by Eq. (3), and ε_{it} is an error term.

Data

The data used in this paper mainly are of three types: geological disaster losses data, socioeconomic data, and geological hazard susceptibility analysis data.

Geological disaster losses data were obtained from the Department of Emergency Management of Yunnan Province. The data include direct economic losses and populations affected by geological disasters in each county from 2009 to 2017.

Socioeconomic data include GDP, GDP per capita, population, and rural population. These data come from the Bureau of Statistics of Yunnan Province and “China County Statistical Yearbook”.

Geological hazard susceptibility analysis data include geological hazards (slides, falls, flows) inventory data (Fig. 2), and geological hazard influence factors. Geological hazards inventory data were obtained from the Yunnan Institute of Geography. Seven categories of factors were selected for this study: topographic data, geological data, major river data, rainfall data, road network data, earthquake data, and vegetation data. Topographic data include elevation, slope, relief, aspect, plan curvature, profile curvature, and standard curvature, and were derived from the Shuttle Radar Topography Mission digital elevation model (SRTM DEM) dataset with a 90×90 m spatial resolution. NDVI data used in this study are the mean values of annual NDVI spatial distribution data from 1998 to 2018. Rainfall data are mean values of spatial interpolated annual precipitation from 1980 to 2015. NDVI and rainfall data were obtained from the Resource and Environment Science and Data Center, IGSNRR (Resource and Environment Science and Data Center; Xu, 2018). The spatial resolution of NDVI and rainfall data is 1×1 km. Geological data include lithologic and fault data and were derived from a 1:500,000 geological map. Our earthquake data are PGA values. Road network data were obtained from Open Street Map. Distances to faults, rivers and roads were derived using the ArcGIS toolkit. Geological hazard susceptibility was calculated using the ALSA model. We used the natural break classification method to divide the LSI into four classes: low, moderate, high, and extremely high susceptibility levels.

Data availability

Data sets are restricted and not publicly available.

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Author contributions

All authors have contributed substantially to the completion of this study and preparation of the manuscript. In particular, HL led in the initiative recognizing the need for the research

and interpretation of results and conclusions. NT led in the data collection, analysing, interpretation, and draft preparation. JJC led in revising the manuscript. All authors participated in data analysing, result interpretation, and manuscript revision.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not applicable.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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