Resilience for Landslide Geohazards and Promoting Strategies in the Three Gorges Reservoir Area

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Abstract Recently, resilience is increasingly used as a concept for understanding natural disaster systems. Landslide is one of the most frequent geohazards in the Three Gorges Reservoir Area (TGRA). However, it is difficult to measure local disaster resilience, because of special geographical location in the TGRA and the special disaster landslide. Current approaches to disaster resilience evaluation are usually limited either by the qualitative method or properties of different disaster. Therefore, practical evaluating methods for the disaster resilience are needed. In this study, we developed an indicator system to evaluate landslides’ disaster resilience in the TGRA at the county level. It includes two properties of inherent geological stress and external social response, which are summarized into physical stress (Ps) and social forces (Sf). The evaluated disaster resilience can be simulated for promoting strategies with fuzzy cognitive map (FCM). The results show that: (1) The strong resilience counties are: Fuling and Yunyang. The weak resilience counties are Wulong, Xingshan, Zhong, Zigui and Dudukou. (2) The resilience of the TGRA has spatial auto-correlation, that is, the areas with similar resilience are gathered in geographical location. (3) Proper policy guideline is essential to promote the disaster resilience. Policy promotes the system from all aspects in the TGRA.

Keywords: Geohazards; Landslide; Disaster Resilience; Evaluation indicator system; Three Gorges Reservoir Area; Promoting Strategies

1. Introduction

The Yangtze River TGAR refers to the area inundated and affected by the Three Gorges Project which is the largest hydropower station in the world and the largest project in China. TGRA is a typical ecologically fragile area that suffers from frequent environmental geological disasters and is characterized by steep topography, poor riparian stratum stability, and intense human activity (Ma et al., 2015). When disaster occurs, it is not only a geophysical and biophysical process, but also affects human
beings and their living environment (Burton, 1978). The impact of natural disasters and risks on cities can vary in population and economy gathering, as well as geographical locations among cities. Local resilience and safety have become an important issue in disaster prevention and mitigation plans. Since 2000, most “resilience” researches have adopted the term "social ecosystem (SES)" and its framework (Berkes & Ross, 2013). Current research on resilience can be divided into different fields, such as ecological resilience (Walker, 2006), community resilience (Frazier T G, 2013), urban resilience (Meerow, 2016), climate resilience (Vivekananda, 2014), system resilience (Hosseini, 2016), disaster resilience (Cutter, 2016). A massive research base has emerged for understanding resilience (Vale, 2010; Leichenko, 2011; Aldunce, 2014; Alshehri, 2015; Normandin, 2019). Various frameworks are proposed to evaluate resilience (City Resilience Framework, 2015; Yang, 2015; Kachi, 2016). These frameworks are based on the characteristics of cities and the indicators selected for evaluating resilience. The same disasters occur in cities with different resilience, and the losses are greatly different (Zhang, 2014). It is the resilience that determines the performance of cities confronted with disasters. The concept “disaster resilience” has emerged in recent years. Disaster resilience was seen as the ability to reduce disaster risk and loss, the ability to quickly return to normal conditions, and the ability to adapt to the changed/new environments (Wilson, 2016) before, during and after the disaster. The term “disaster resilience” is increasingly used in research journals, government documents, and the media, but work still remains on making resilience assessment usable (Hosseini, 2016), and the method of resilience quantification is still missing (Ingrisch & Bahn, 2018).

The difficulty when assessing the disaster resilience of different regions, lies in, it’s necessary to take the major disasters in the region and the impact of disasters into account. Since the study of Twigg (Manyena, 2006), many real cases of resilience assessment in developed countries have emerged. Studies explicitly used some disaster resilience evaluation indicators, and the specific evaluation indicator system is shown in Table 1.

| Indicator system | Specific indicators | Empirical research objects | Literature citation |
|------------------|---------------------|---------------------------|---------------------|
| Coastal RI       | Critical infrastructure, facilities, transportation, mitigation measures, business plan, social system | US-coastal counties, 2010 | (Sempier, 2010) |
| RCI              | Regional economic capacity, socio-demographic capacity, community connectivity capacity | US-Metropolitan areas, 2010 | (Pendall, 2010) |
| ResilUS          | Disaster recovery, system performance | USA-earthquake area, 2011 | (Mikes, 2011) |
| CART             | Connection and caring, resource, transformative potential, disaster management, information & communication | Individual communities, 2013 | (Pfefferbaum, 2013) |
| CoBRA            | Livelihood survival ability, Innovative potential | Ethiopia - 2013 | (Hughes, 2013) |
| PEOPLES          | Population, environment, government, infrastructure, community competencies, economic, social-cultural capital | USA-coastal area, 2014 | (Martinelli, 2014) |
| BRIC | Social, economic, community capital, policy, infrastructure, environment | US-counties, 2014 | (Cutter, 2016) |
|------|------------------------------------------------------------------------|-----------------|-------------|
| BRIC | Social, economic, policy, infrastructure, community capital, environmental | Mississippi-counties, 2015 | (Burton, 2015) |
| CRI  | Social capital, economic development                                   | US-counties, 2015 | (Bergstrøm, 2015) |
| CDRI | Human, social, economic, policy, physical, environmental              | Korea-municipalities, 2016 | (Yoon, 2016) |

Whereas, specific local indicators still need to be considered. In the existing literature, indicators in the framework of resilience assessment are in different shape. Therefore, the establishment of resilience assessment indicators needs to take into account the differences in urban disaster background, assessment time span (as a long-term process or short-term sustainability results), assessment subject (for individuals, special groups or cities for resilience evaluation). Another difficulty is that each resilience evaluation framework is not uniform, including data conversion (Asadzadeh, 2015), weight assignment (Cutter, 2010), visualization (Mayunga, 2009), and validation after evaluation (Birkmann, 2013; Bijan, 2018). Though theoretical and practical researches about disaster resilience have been conducted in China, China is still at the research and exploration stage (Sun, 2017; Cui, 2018). In addition, after the quantitative evaluation of local resilience, according to the particularity of the city, the proposed resilience enhancement strategy also has particularity (Wang, 2017).

Therefore, there is no universally applicable framework for local disaster resilience evaluation, which also provides research breadth and depth for resilience research methods, disaster background, data processing and resilience enhancement strategies. The point discussed here —the link between natural disaster and resilience is necessary to be addressed through quantitative evaluation. Since disaster resilience has the antecedent conditions interacting with the hazard event characteristics to produce immediate effects. Besides, the event characteristics including frequency, duration, intensity, magnitude, and rate of onset, vary depending on the type of hazard and the location of the study area. For this purpose, we attempt to establish the quantitative evaluation based on the DROP (Disaster Resilience of Place) model (Cutter, 2008a). The DROP presents resilience as both an inherent or antecedent condition and a process. Dimensions like ecological, social, economic, institutional, infrastructure, community competence are proposed as the measurement index (Cutter, 2008a). The measurement core for disaster resilience are further elaborated such as: economic, social, institutional, information/communication, infrastructure and environmental (Cutter, 2016). Disaster stress is concerned when evaluate the disaster resilience (Fang, 2018), which is the antecedent condition. This paper framed disaster resilience into two dimensions - physical stress and social forces. The antecedent condition measured by the loss of the hazard (Zhou, 2010) is called physical stress in this paper. Economic resilience, human resilience, infrastructure resilience, environmental resilience and institution resilience are closely related to human production and life, which can be regard as social forces.

Physical stress refers to the impact from landslide disasters, which can be measured by the number of potential landslides, loss and threatened population in
county area. Economic resilience refers to the post-disaster recovery and promotes the local reconstruction and recovery activities measured by economic diversity, resident saving and so on. Human resilience refers to the social action post and after disaster, such as employment, population density, education, and other factors. Infrastructure resilience refers to the infrastructure or services redundancy after disaster, such as emergency shelter and services. The environment resilience helps to resilient the landslide hazard such as rainfall and green coverage. The policy resilience is often related to the government decision-making.

The disaster resilience evaluation system involves many factors from various factors including consists of physical stress and economic, human, infrastructure, environment and policy. Therefore, promoting disaster resilience in the TGRA involves not only landslide geohazards, but also many social factors, which makes the problem more complex.

The disaster resilience evaluation system can be considered a complex system. The proposed method of disaster resilience discussions is based on fuzzy cognitive maps (FCM). FCM describes the causal and effect relationship among factors in a complex system. FCM is developed (Kosko, 1986; Groumpos, 2010) to model complex systems (Georgopoulos, 2014; Jamshidi, 2018) and to support making decisions (Markaki, 2019) in the social science area and extension areas include planning and urban management. A major advantage of FCM is that they can handle even incomplete or conflicting information (Georgopoulos, 2014)

The evaluation and discussion enable us to provide meaningful exploration for the study of geological hazards in the TGRA, identify major driving variables that relate resilience in this area.

2. Study Area

2.1 Research site

The TGRA refers to the area inundated and affected by the Three Gorges Project of the Yangtze River. The reservoir area is situated at the plain of the middle and lower reaches of the Yangtze River, involving 27 districts and counties in Hubei and Chongqing (see Fig. 1).
The TGRA along the main stream of the Yangtze River is about 650 km long, spanning different geomorphic units and geotectonic units. The reservoir area spans the western Hubei and Eastern Sichuan mountainous areas. The trend of the whole terrain is obvious high in the west, and low in the east (shown in Fig.2).
Based on the environmental and ecological monitoring bulletins of the Three Gorges area in 2018, there are 5386 hidden geological hazards (collapse, landslide, unstable reservoir bank) in this area (see Fig.3), most of them are landslides. All of them are monitored by collective measures and mass prevention, including 213 professional monitoring points. From Fig.2 and Fig.3, the number of landslides is positively correlated with the topographic altitude.

![Fig.3 The quantity of geohazards in each county in the TGRA](image)

At present, the main natural inducing factors of landslides in the TGRA, reservoir water level (hydrology), and rainfall (meteorology) (Gao, 2007; Lu, 2013). These are the inherent topographic and geomorphological characteristics of the TGRA and the induced factors of landslide geological hazards, which constitutes the current state of the tenacity of landslide geological hazards in the TGRA. However, the frequent occurrence of landslide geological hazards is also caused by the external factors besides the inherent topographic and geomorphological characteristics.

2.2. Data source

Due to availability of data, 530 potential landslides are considered as sample points. These sample points are selected for engineering management, monitoring and early warning, relocation and concession points (40%, 45%, 15%) which have implemented geological disaster prevention and control in the reservoir area. Based on the population and economic losses threatened by 530 survey sites in the corresponding areas, the resilience of the TGRA facing landslide geological hazards was evaluated.

The data of the resilience of landslide geological hazards come from the headquarters of geological hazards prevention and control in the TGRA in 2017; The data of human economy and social policy of districts and counties come from the statistical yearbook of Chongqing in 2016, Yichang in 2016, and the statistics of 2016
published by the people's governments of counties on their official websites. In particular, it is pointed out that the rainfall data of 17 districts and counties are derived from the ecological and Environmental Monitoring Bulletin of the Three Gorges of the Yangtze River from 2015 to 2017 on the official website of the Ministry of Environmental Protection, and some of the missing data are supplemented by the statistical bulletin of the counties in 2016. Chongqing Municipal Bulletin on Soil and Water Conservation 2015, provided by the official website of Chongqing Municipal Water Conservancy Bureau, supplements the expenditure of land, resources and meteorology under the expenditure of public finance budget from the statistics of Yichang City in 2016 due to the lack of data on the total assets of soil and water conservation in four districts and counties of Hubei Section.

3. Methodology

3.1 Research framework

This study is conducted using a combination of factor analysis and FCM. Fig.4 shows the research framework in evaluating disaster resilience. In order to develop an appropriate and meaningful indicator system, indicator definition lies in the first stage. Indicator definition helps to construct the subsystem contain physical stress (landslide stress), social forces (economic resilience, human resilience, infrastructure resilience, environment resilience and policy resilience). Factor analysis measures the weight of each subsystem, evaluation model is constructed for disaster resilience evaluation. The evaluation value can be visualized, Moran’s index(I) analyze the spatial autocorrelation. FCM has obvious advantage in describing causality of various factors in complex system. Scenario simulation by FCM can distinguish the obstacle and promoting factor, and contribute to promoting strategies.
3.2. Disaster resilience evaluation model

Both inherent social resilience should be considered as antecedent condition in an overlap relationship. The antecedent condition interacts with the hazard event characteristics and produces immediate effects. The event characteristics include frequency, duration, intensity, magnitude, and rate of onset, which varies depending on the type of hazard and the location of the study area. Models in analyzing vulnerability (Calderón, 2003; Yang, 2015) and resilience (Cutter, 2003; Gallopín, 2006; Bergstrand, 2015) can provide reference to some extent. Disaster resilience can be impacted by both external and internal influences, where the former is the disaster characteristics and the latter the inherent characteristic (Zhou, 2010). (Cutter, 2016) suggests that attempts to enhance resilience cannot be approached using a one-size-fits-most strategy given the variability in the primary drivers of disaster resilience at county scales. In this paper, we established an evaluation indicator system summarized into physical stress ($Ps$) and social forces ($Sf$) (as shown in Fig.5).
\[ DR = Ps \times Sf \]  

3.3. Disaster resilience indicator system

The objective of indicator selection is to ensure that the selected indicators are relevant, measurable and accessible, and most importantly, to accurately reflect the concept being measured (Hughes, 2013). Usually, the indicators of resilient cities are selected from the four perspectives of economy, population, infrastructure and environment (City Resilience Framework, 2015; Cutter, 2016). Reviews from the theoretical framework of resilience and the indicator system of resilience evaluation, it is found that environmental resilience is closely related to human life (Sempier, 2010; Schultz, 2016; Cutter, 2016). As the object of evaluation, considering that the city is disaster-oriented, it also synthesizes the influence factors of disasters (Bergstrand, 2015). Due to the differences between regions, disaster resilience evaluation system are required in the TGRA.

This paper reviews the existing literatures about landslide geohazards management and disaster resilience, gives careful consideration of all the relevant factors when evaluate the disaster resilience in the TGRA, then constructs a resilience evaluation indicator system of landslide geological hazards for the TGRA (shown in table 2), The consideration of indicator system selection: (1) is based on previous research and be relevant to disaster resilience; (2)reflects the local geographical characteristics;(3)have to selectively eliminate the relevant indicators if there was a
high degree of correlation between the factors (Cutter et al., 2010). Table 2 shows the basic research on the selection of index system. Based on these considerations and the data availability and elimination of the highly correlated variables, table 3 presents 3 external indicators and 20 internal indicators.

External indicators indicate the physical stress, smaller disaster stress means the smaller evaluated overall resilience score (Fang, 2018), which can be measured by frequency of disaster (Cutter, 2000), threat target of landslide monomer as negative index factor. In this paper, frequency of landslide is hard to acquire. After consulting experts’ experience, distribution density of hidden landslide in each county replaced it. And the threatening population and economic loss can measure the degree of landslide geohazards.

Internal indicators depict the social forces dominated by residents, which can be divided into five aspects: economic, human, infrastructure, environment and institute. These five aspects are the important elements of human residence in the region: (1) Human system resilience affects community comprehension, communication, and mobility, which relates to the demographics of a community and their physical and mental wellness (Cutter, 2014). It’s worth noting that, combining with the field survey, we found that all the communication equipment in the Three Gorges area are telephones or mobile phones, and in the face of disasters, peoples are unlikely informed of disaster news by watching TV or radio. Therefore, this paper directly considers the number of telephones as the index of measuring residents’ connectivity. (2) Economic system resilience is the capacity to reduce both direct and indirect disaster-related economic losses (Chang, 2004). (3) Infrastructure system resilience is the ability to predict, absorb, adapt, and/or quickly recover from a disruptive event (The National Infrastructure Advisory Council (NIAC), 2008). (4) Environment system resilience can be measured by impervious surfaces (cutter, 2016) and natural resources (Xiao, 2014). (5) Policy system resilience is the capability support for the whole system recovery process (Haddow, 2014).
| Indicators definition | Indicator Factors | Index description | Relation between Indicators and resilience |
|-----------------------|-------------------|------------------|--------------------------------------------|
| Physical stress (Pr)  | Frequency of Disasters in 5 Years (Cutter, 2000), Threat target of landslide monomer as negative index factor | The basic principle of recovery from landslides is to restore affected areas to their pre-disaster state (Kachi, 2016). Therefore, considering the threatening object of landslide, it can be regarded as a negative index. |
| Social forces (Sf)    | Social and demographic factors for prevention and recovery of landslide disasters connectiveness | Gender, age, disability, health, family size and structure, language, literacy, education and employment impact capacity to build resilience to disasters (Morrow, 1999) (Phillips, 2011). The connection of social capital can enhance the solution of collective action problems after natural disasters (Gill, 2014). Social networking helps cities recover after disasters (Akama, 2014). |
| Economic resilience   | Economic factors for prevention and recovery of investment in landslide disaster | Losses caused by natural disasters may increase with wealth, but the possibility of increasing losses may also be a mitigating factor. Economic capital usually provides sound social capital (Thomas, 2013). The location and planning of infrastructure is an important factor in disaster mitigation. Governments at all levels participated in the planning process (King, 2008) (Crompton, 2010). Planners can be agents of change in building resilience to disasters (Smith, 2009). |
| Infrastructure resilience | Preparedness for disaster risk mitigation or planning | Impervious surfaces (Cutter, 2016), natural resources (Pinho, 2010; Xiao, 2014) Climate (Peng, 2016) Long-term design work under public leadership can promote an effective response to natural disaster events. Regulatory System Related to Natural Disaster Management (O’Neill, 2012). |
| Environment resilience | Soft location factors include high-quality living environment | |
| Policy resilience     | Policy and leadership within government institutions | Behavior change social and cultural background (Dake KM, 1992) (Eiser JR, 2012). Emergency capability support for the whole system recovery process (Haddow GD, 2011). |
3.4. Data processing of indicator system

In view of the Three Gorges area with frequent landslide disasters, this paper adopts factor analysis to evaluate the disaster resilience. Factor analysis aims to find independent latent variables. For the problem studied, we can try to describe every component of the original observation with the sum of the linear function as few unmeasurable common factors as possible and the special factor. The factor load matrix of each index variable after orthogonal rotation can be computed by SPSS. Before that, different evaluation indicators have different dimensions; therefore, it is necessary to standardize the evaluation indicators. Considering the application scope and research purpose of different standardization methods, this paper chooses the extremum method (i.e. standardization method) to transform the original matrix linearly, and obtains the new standardized data matrix. The bigger the original standard, the better the index, that is, the treatment formula of the positive index is as follows:

\[
Y_{ij} = \frac{X_{ij} - \text{Min}(X_{ij})}{\text{Max}(X_{ij}) - \text{Min}(X_{ij})}
\]  

(2)

The smaller the original index, the better the result, that is, the treatment formula of the reverse index is as follows:

\[
Y_{ij} = \frac{\text{Max}(X_{ij}) - X_{ij}}{\text{Max}(X_{ij}) - \text{Min}(X_{ij})}
\]  

(3)

\(X_{ij}\) is the original data for evaluation index, \(Y_{ij}\) is the normalized data. \(\text{Max}(X_{ij})\) is the maximum value in the original data, \(\text{Min}(X_{ij})\) is the minimum value in the original data.
### Table 3
Selection of indicators and data sources for evaluation of resilience of TGRA

| First level index | Second level index | Third level index | Index unit | Direction of Indicators |
|-------------------|--------------------|-------------------|------------|-------------------------|
| Physical stress   | Stress of landslide geohazards | Distribution density of hidden landslide | Landslides / 10000 cubic meters | - |
|                   |                    | Threatening Population per unit volume of county landslide* | Per 10000 cubic meters | - |
|                   |                    | Economic loss caused by unit volume of county landslide* | Per 10000 cubic meters | - |
| Economic factor   | GDP**              | Ten thousand yuan | + |
|                   | Per Capita GDP**   | Ten thousand yuan | + |
|                   | Proportion of tertiary industry ** | % | + |
|                   | agricultural acreage** | Hectare | + |
|                   | Resident Savings Balance* | Billion yuan | + |
| Human factor      | Proportion of population above secondary school level ** | % | + |
|                   | Population density ** | per square kilometer | + |
|                   | Proportion of the lowest life guarantee population** | % | + |
|                   | Obtain employment ** | ten thousand people | + |
|                   | Per capita telephone equipment ownership ** | /person | + |
| Social forces     | Quantity of schools ** | + |
|                   | Quantity of medical institution ** | + |
|                   | Quantity of hospital beds** | + |
|                   | Per capita road length ** | Km/person | + |
| Infrastructure factor | Green Coverage Ratio of Built-up Area ** | % | + |
|                   | Annual rainfall * | Mm/year | - |
| Environmental factor | The proportion of unemployment insurance population ** | % | - |
|                   | Medical insurance coverage** | % | + |
|                   | Total Assets of Soil and Water Conservation* | ten thousand yuan | + |
|                   | Investment Completion of Urban Fixed Assets*v | ten thousand yuan | + |

**NOTE:** "*" indicate: The data are from the headquarters of geological hazard prevention and control in the TGRA 2017; "**" indicate: the data are from 2016 Statistical Yearbook of Counties and Municipalities; "***" Indicate: the data are from the 16 year EPS database; "^" indicate: the data are from the 2016 Water Resources Bureau Soil Conservation Bulletin."+" means positive, "-" means negative.
3.5. Analysis the relationship of subsystem for evaluation of resilience of TGRA

FCM is a computational modeling method with the ability to simulate a complicated system that involves a fuzzy or uncertain situation and is viewed as a directed graph that consists of nodes and weighted arcs, as shown in Fig. 6. Detailed description about this method can be found in reference (Ma, 2019).

![Fig. 6 The basic fuzzy cognitive map.](image)

The disaster aspect is difficult to be changed, but the social forces is highly correlated with every single person which can be handled by human. FCM spot the critical factors in the complex system (Bakhtavar, 2018). This paper adopted FCM to analyze the influence between the social forces (i.e., economic, human, infrastructure, environment, policy aspects) and the evaluated disaster resilience. Although, FCM is depend on expert experience to set the weight of subsystems, while the evaluated disaster resilience can provide the weight of subsystems by linear regression. First, we assume that the social forces subsystems influence each other. Then, linear regression is adopted to calculate the interact between subsystems and evaluated disaster resilience. In this way, FCM can support the strategy promotion for the landslide disaster resilience in the TGRA.

4. Results

4.1 disaster resilience evaluation

Table 4 shows the results of the evaluated disaster resilience of 17 districts and counties in the TGRA ranges from high to low. After obtaining the evaluation values of the TGRA for landslide geological hazards, in order to clearly display the evaluation results, the evaluation values of the 17 districts and counties are standardized and classified into four grades: 0-0.25, 0.26-0.5, 0.51-0.75 and 0.76-1.0 by using the method of equal interval segmenting. Respectively mean: lowest resilience, lower resilience, high resilience, highest resilience (as shown in Table 4). Five counties with lowest resilience are Dadukou, Zigui, Zhongxian, Xingshan and Wulong; Lower resilience counties are Fengdu, Shizhu County, Changshou District, Yiling District and Kaixian
County; Counties with higher resilience are Fengjie County, Wuxi County, Wushan County and Wanzhou District. Badong County; The two highest counties are, Fuling District and Yunyang County. Among them, the number of cities with lowest resilience and lower resilience accounted for 58.9% of the total evaluation districts and counties, and the number of districts and counties with higher resilience and highest resilience accounted for 41.1% of the total evaluation districts and counties. We can see that the overall resilience of the TGRA still needs to be improved.

Table 4
Disaster resilience Evaluation Value of 17 Districts and Counties in the TGRA

| NO. | County    | Resilience score |
|-----|-----------|------------------|
| 1   | Fuling    | 24.23            |
| 2   | Yunyang   | 15.80            |
| 3   | Badong    | 13.43            |
| 4   | Wanzhou   | 12.35            |
| 5   | Wushan    | 10.35            |
| 6   | Wuxi      | 5.00             |
| 7   | Fengjie   | 3.86             |
| 8   | Kai       | -0.15            |
| 9   | Yiling    | -2.30            |
| 10  | Changshou | -4.18            |
| 11  | Shizhu    | -6.13            |
| 12  | Fengdu    | -6.52            |
| 13  | Wulong    | -8.13            |
| 14  | Xingshan  | -11.65           |
| 15  | Zhong     | -11.79           |
| 16  | Zigui     | -13.84           |
| 17  | Dudukou   | -17.32           |
ArcGIS has the function of spatial geographic analysis. In order to display the resilience state of each district and county more intuitively, this paper uses ArcGIS to map and express the resilience evaluation values of 17 districts and counties, as shown in Fig.7.

In order to determine the potential dependence of resilience in the TGRA, the Moran's index (I) of spatial autocorrelation analysis is used to explore the spatial aggregation characteristics of the TGRA facing landslide geological hazards.

Combining with the hot spot analysis function of spatial correlation analysis in ArcGIS software (shown in Fig.8), the spatial correlation characteristics of the TGRA resilience of landslide geological hazards can be more intuitively reflected.
Disasters is hard to be prevented but their impacts can be mitigated through adapted disaster management strategies (Alshehri, 2015). This study also focuses on promotion of disaster management strategies and their effectiveness in improving disaster resilience. The evaluation results were depicted in our study area. To achieve the goal of mitigating the stress caused by landslide geological hazards, disaster reduction is the primary consideration. Engineering measures for disaster reduction, such as soil and water conservation planning, drainage engineering, slope cutting engineering, support engineering and other measures to change the physical movement characteristics of disaster-causing bodies. Non-engineering measures usually refer to restricting and regulating human social behavior through legal constraints, policy propaganda, education, medical planning and other methods. For example, the study of site selection can avoid more disaster losses artificially after considering the local disaster resilience. Relocation and evasion, engineering management and monitoring and early warning are three kinds of landslide disaster prevention and control projects. The research on the prevention and control project means the losses that the disaster may cause to human society can be reduced as many as possible by scientific means, thus enhancing the resilience of the reservoir area to landslide geological disasters. In other words, non-engineering measures help promoting social response influenced by human daily life. Non-engineering measures can be applied flexibly among human.

FCM is proposed to examine the relationship of the factors in social response and the resilience. Fig.9 depicts the fuzzy cognitive map of disaster resilience, economic, policy, human, infrastructure and environment in study area.
We assume factors in the fuzzy cognitive map affect each other, and the crisp value of the connection matrix is shown in table 5. The crisp value can be calculated by regression analysis in SPSS. Table 5 shows the extent of each social force factor affects other factors. For example, for disaster resilience, the influence factor of economic is 0.41, the policy aspect’s influence factor is 0.39, the human aspect’s influence factor is 0.46, the infrastructure aspect’s influence factor is 0.37, the environment aspect’s influence factor is 0.39. We can learn from table 5, economic resilience is the weightiest factor to promote local disaster resilience, policy resilience and economic resilience enhances each other, infrastructure resilience benefits for human resilience, disaster resilience helps infrastructure resilience the most, economic resilience makes a significant contribution to environment resilience.

Table 5

The crisp value of the connection matrix.

|                  | Disaster resilience | Economic | Policy | Human | Infrastructure | Environment |
|------------------|---------------------|----------|--------|-------|----------------|-------------|
| Disaster resilience | 0                   | -0.2     | 0.301  | 0.04  | 0.66           | 0.53        |
| Economic         | 0.41                | 0        | 0.61   | 0.24  | -0.12          | 0.55        |
| Policy           | 0.39                | 0.79     | 0      | 0.39  | 0.05           | -0.37       |
| Human            | 0.46                | 0.17     | 0.73   | 0     | 0.3            | -0.08       |
| Infrastructure  | 0.37                | -0.01    | 0.032  | 0.35  | 0              | -0.28       |
| Environment     | 0.39                | 0.3      | -0.15  | -0.07 | -0.19          | 0           |

FCM calculates the steady state: 0.92002 in disaster resilience, 0.82949 in economic, 0.7724 in policy, 0.62911 in human, 0.8009 in infrastructure, 0.75794 in environment.

5. Discussion and Promoting strategies

Results present that the disaster resilience scores are not completely random in the spatial distribution, but the spatial aggregation between the similar values. At the same
time, these districts and counties have positively affected the social forces of geological disasters in the surrounding areas, thus become a "diffusion center". Moreover, the districts and counties in this region are in the inactive zone of geological disasters, and thus the social development level is relatively good, which makes the region have a strong ability to respond to and recover from geological disasters. According to the growth pole theory, the social forces of geological hazards in these areas are relatively high, and the regional economic and social factors will affect the surrounding areas, thus driving the whole regional geological hazards to improve the social forces and narrowing the overall difference.

For further analysis of the results, we separately set one of the factors in the complex system to 0.1, 0.25, 0.75, 0.9, 1(Ma,2019), and get the new state compares to the steady state. 0.1 means the worst circumstance in the subsystem, 1 means the best. This comparation helps simulating relationship of each subsystem in the disaster resilience evaluation complex system (shown in Fig.10).

The simulation result reveals that disaster resilience has a significant influence on both the infrastructure and environment aspect. Under the worst condition, when serious landslide disasters happen, compared to the steady state, the infrastructure resilience has a decrease of more than 15%, and the environment resilience more than 7%. However, notably, with the increase of the disaster resilience, the economic resilience decreased. Since economic factors may mainly contribute to constructing the considerable disaster resilience. And the increment of infrastructure resilience is the greatest when disaster resilience is the best (shown in Fig.10-a).
Fig. 10 The simulation results of subsystems by FCM.
In Fig. 10-b, economic resilience is set from 0.1 to 1. When the economic resilience is set to 0.1, which means the economic resilience is the worst. We can find that the environment resilience and policy resilience have significant influences on economic, where the deviations range from -8.46% to 1.25% and -6.62% to 0.94% respectively. The result shows that economic resilience’s increasing is beneficial to environment resilience, human resilience and policy resilience. Besides, the infrastructure resilience helps increasing economic resilience. Thus, the development of urban economy has a direct impact on the investment of urban infrastructure construction, the development of government disaster prevention and response, environmental quality and human security. Therefore, economic development plays an extremely important role in improving economic resilience and further enhancing the resilience of other indicators. According to actual investigation, the TGRA is a kind of underdeveloped area, where people living in the county area live on agriculture, forestry tourism and fruit industry. The economy of this area is relatively weak, and the gap between the rich and the poor is obvious. Therefore, narrowing the regional development gap can effectively narrow the regional resilience index difference. To sum up, while not affecting the economic development of Chongqing's main urban areas, the government should increase its support for the economic development of the central part of the reservoir area. The specific measures are as follows. First, the government may increase the proportion of tertiary industry, optimize the industrial structure of the reservoir area's immigrant areas, coordinate the regional economy and actively promote the economic restructuring. Second, we should increase technological innovation and upgrade traditional industries. The old industrial system has been formed in the TGRA, but due to its long history, it is necessary to intensify technological innovation to further activate the autonomous economic capacity of the area. Thirdly, we should vigorously develop the peculiar forestry, fruit and medicine industries in the rural areas of the reservoir area, intensify the construction of multi-functional shelter forests, and create an eco-economic model of harmonious economic and ecological development. Fourthly, we should develop labor-intensive small and medium-sized enterprises, promote economic production in poor areas and narrow the gap between rich and poor.

Fig.10-c depicts the policy circumstance, where “economic resilience” is the most influenced range from 14.6% to 1.27%. “Human resilience” and “environment resilience” also have significant deviations. Besides, when “policy resilience” is the best, indicating that the government has its full support to improve the disaster resilience, other aspects increase compared to steady state. The result reveals the importance of “policy resilience”, it has significant impacts on the system and government policy influences all other aspects. It’s not difficult to see that the above five resilience promotions are inseparable from the guidance and support of policy resilience, which includes two aspects of government management and social security. In response to natural disasters, social security can reduce disaster losses, provide security barriers for urban residents, and people's livelihood security in education, health care, employment and other aspects, which can effectively help residents recover after disasters. Specific implementation methods are as follows. First,
improve the investment efficiency of disaster prevention in the TGRA, improve the reservoir area security system, enhance the disaster prevention capacity of the reservoir area, thereby improve the reservoir area resilience. We should gradually improve the social system, strengthen the innovation of the security system, explore the security system in line with regional characteristics, narrow the regional gap and improve the ability of different regions to cope with disasters. Secondly, we should vigorously develop the ecological circular economy in the reservoir area, promote the harmonious development of economy and ecological environment, and establish a sustainable ecological economic system in the reservoir area. Thirdly, we should deepen the reform of the reservoir system and improve the utilization rate of social resources. Fourth, we should strengthen ecological protection and environmental construction, transform arable land, return farmland to forestry, develop ecological economy, develop agronomy and prevent soil erosion. Fifth, we should learn from Japan's policy of strengthening and toughening its territory, establish all levels of policy for the cause of resilient cities, clarify responsibilities and obligations, and coordinate the allocation of resources. Sixth, we should pay attention to disaster prevention education, compile disaster prevention textbooks for primary and secondary schools, add the concepts of "resilient city planning" and cultivate each student's "resilient land" consciousness.

Fig.10-d explains the impact of human resilience on other aspects. Under the impact of the change of human resilience, the “policy resilience” varies from -8.14% to 1.24%, is the most significant affected aspect. The second affected aspect is “infrastructure resilience” with a fluctuation from -6.03 to 1.12. It’s worth noting that when “human resilience” is in its best circumstance, the “environment resilience” decreases from the steady state. This result show environment makes certain sacrifices for “human resilience”. Human resilience refers to people's awareness of disasters, disaster prevention and population density concentration in dangerous areas. On the other hand, it includes employment ability and economic ability in terms of the ability to recover from disasters. To enhance the resilience of the human, specific measures are as follows: first, popularize ecological knowledge to the masses in the reservoir area, strengthen the ecological concept of the masses, disaster knowledge education and propaganda, and increase the awareness of self-protection of the masses. Secondly, we should strengthen the support of rural education, carry out various vocational and technical training, popularize scientific and technological knowledge and disaster prevention knowledge in rural areas, further improve the comprehensive quality of rural population, and then improve the living standards of the people in the reservoir area. Thirdly, we should encourage the masses of the reservoir area to innovate and start businesses, increase their financial investment and technical support for innovation and entrepreneurship, so that the masses of the reservoir area can enhance the comprehensive resilience of the region through self-development and accumulation. Fourthly, policy supporting and assisting policies to the poor and low-income people should be proposed. Through the above measures, we will gradually realize the development from blindly coping with disasters and passive adaptation to conscious and conscious transformation of our own living conditions.
Fig. 10-e reflects the “infrastructure resilience” condition, where “human resilience” is most significant influenced with deviation from -5.26% to 1.2%. The “environment resilience” changes from -0.78% to 2.61%, while “economic resilience” have less obvious change from -0.04% to 0.08%. With the increasing of “infrastructure resilience”, “economic resilience” and “environment resilience” both have a decrease, which illustrates economic and environment have negative contributions to promote “infrastructure resilience”. The local economic development and per capita income have a great relationship with the construction of infrastructure. The local post-disaster recovery mainly depends on the stock of infrastructure. The construction of infrastructure is the material basis of disaster prevention construction in the reservoir area. The specific measures to improve the resilience of infrastructure are as follows. First, learn from Japan's territorial strengthening and resilience planning. We should strictly control the ability of infrastructure construction to withstand disasters. Second, develop scientific and rational planning of reservoir construction projects, especially post-disaster relief facilities, such as schools, roads, hospitals and other infrastructure, to provide effective protective walls for residents. Thirdly, establish a "bottom-up" decision-making mode, focusing on the needs of the people, to improve the quality and quantity of public infrastructure such as schools and hospitals, promote the sharing of educational resources and medical and health collaboration, and provide basic educational resources and medical security for residents. Fourth, improve the capacity of transportation, schools, medical facilities to deal with disaster interference. Fifthly, in line with regional economic development ideas, promote rural economy and urbanization by assisting agriculture with industry, strengthen infrastructure construction and further improve infrastructure resilience.

Fig. 10-f depicts other aspects’ change influenced by “environment resilience” change. “Economic resilience” is the most influenced aspect with deviation from -3.98 to 0.61. The result shows that “policy resilience”, “human resilience” and “infrastructure resilience” may be devoted to elevating “environment resilience”. On the one hand, increasing the coverage of green space can greatly reduce soil erosion. On the other hand, reduce and resolve the geological hazards of the Three Gorges Project and control the pollution of the cut-off zone after the completion of the Three Gorges Project. Specific implementation methods are as follows. First, implement the greening project around the reservoir area, and strengthen the protection and maintenance of the original natural forest vegetation. Secondly, make policy proposal protecting the diversity of local species in the reservoir area, intensify the efforts of forest construction, implement the policy of closing hills and afforestation projects, increase forest and grass vegetation, reduce the proportion of steep slopes in cultivated land, control soil erosion, and promote agricultural development on the basis of ensuring ecological harmony and the self-recovery of forests. Thirdly, strictly control unreasonable human-induced land development in the reservoir area to ensure the protection of forest land for regional ecological resilience. Fourth, increase investment in environmental protection funds and technologies, and promote the development of resource-saving and environment-friendly society.
It’s worth noting that, “resilience” in the Three Gorges Area is most affected by “human resilience”. It reveals the importance of “human resilience” when promoting the disaster resilience. Since society relates closely to human, the indicators of “human resilience” reflect the response to disaster before, during and after the disaster. At the same time, the introduction of human resources, the popularization of policies, the development of education science and technology, the continuous improvement of transportation and communication, and the building of a high-efficiency agriculture-based, highlighting the tertiary industry of high-tech innovation-oriented areas play a vital role in improving the overall resilience of the TGRA. Besides, in terms of three basic factors of production, infrastructure and industry, the coordinated development of economic, human and environment, the integration and application of various social resources are the necessary conditions for the resilient area.

6. Conclusions

The evaluation and promotion of disaster resilience may contribute to people's livelihood in the Three Gorges Area, especially in rural areas. It may also have considerable significance for the local development and disaster prevention and mitigation at the county level from the perspective of government. However, the research confronts many obstacles, because the promotion of disaster resilience in this area involves several factors, including the geological conditions, and the social aspects. The geological conditions are complicated but the social aspects can be regulated. Consequently, promoting the disaster resilience involves many social elements, which suggests that the solution of this problem turns out to be more complicated. This study aims to evaluate disaster resilience for the Three Gorges Area, analyze the spatial distribution characteristics of disaster resilience, explain the interrelationship among the social aspects, and illustrate the influence mechanism among them, which may be a new insight and way for studying the disaster resilience.

First and foremost, based on spatial autocorrelation analysis, we found that the distribution pattern of regional resilience evaluation value is characterized by aggregation of disaster resilience in space, which shows significantly positive spatial correlation of landslide geological hazards stress, and negative correlation with regional economic level. According to the hot spot analysis, Fengjie County, Yunyang County, Kai County and Wuxi County show a high clustering, and the level of resilience is negatively correlated with the regional economic level. The disaster resilience of economically developed areas is relatively high. What is more, the government is an important factor for positive impact. As all other resilience aspects improved in good condition of the “policy resilience”, it is evident that the proper policy guideline is essential to the promotion of disaster resilience due to its crucial role in economic construction and human security. “Human resilience” has the greatest impact to “policy resilience” and “disaster resilience”. This shows once again that human beings are the core of social system. At present, in the process of coordinating the prevention and control of geological hazards in China, it is necessary to coordinate the management and allocation of human, material and financial...
resources in the corresponding regional disaster prevention and control management according to the level of resilience of different regions. For regions with high resilience, we should strengthen the investment of resources to reduce the impact of geological disasters; for regions with low resilience, we should strengthen the resilience of economy and population, consolidate policy resilience and promote regional resilience.

In conclusion, this study is to build the ability of geological disaster prevention and mitigation in the TGRA. We attempt to measure the performance of the TGRA facing with landslide geological hazards from the perspective of combining qualitative and quantitative analysis. A majority of resilience enhancement strategies are proposed based on FCM. However, there are some shortcomings in our study, since it is in the exploratory stage and the data are limited, this paper only studies this topic from the static point of view. The next step is to dynamically analyze the resilience of this area from the perspective of time span.

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