

Assessment of Earthquake Prevention and Disaster Reduction Capability of County-Level Administrative Units in Gansu Province*

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Abstract

Firstly, this paper establishes the assessment indicator system for the earthquake prevention and disaster reduction capability of county-level administrative units in Gansu, and formulates three criteria, ten indicators and fifteen variables centered on one target. Then, the analytic hierarchy process is applied to determine the indicator weights, and the environmental supporting capability, infrastructure supporting capability and resource supporting capability of different counties in Gansu in the handling of earthquake disasters are calculated to obtain the assessment figure for the earthquake prevention and disaster reduction capability of county-level administrative units in Gansu. The research results indicate that Anning District of Lanzhou has the strongest earthquake prevention and disaster reduction capability while Zhouqu County possesses the weakest earthquake prevention and disaster reduction capability; the overall earthquake prevention and disaster reduction capability of northwestern and northeastern regions in Gansu is higher, in which the earthquake prevention and disaster reduction capability of Aksay-Subei District, Jinchuan District, Xifeng District, Linxia City District and Lanzhou City District is particularly prominent; the earthquake prevention and disaster reduction capability of Sunan-Tianzhu District and Gannan-Longnan District is relatively weaker; the geographical environment has a great impact on the earthquake prevention and disaster reduction capability, which is demonstrated as that the earthquake prevention and disaster reduction capability of regions with violent tectonic activities and dramatic topographic inequality tend to be weak; the whole province should improve the construction of infrastructure and fundamental resources in order to compensate for the insufficiency in environmental supporting capability. In addition, the expert scoring method is adopted in the determination of indicator weights, which is subject to high subjectivity; considering that some data are missing and the influential indicators are not considered comprehensively, the assessment indicator system requires further improvement.

Keywords: Gansu, county-level administrative units, earthquake prevention and disaster reduction capability, analytic hierarchy process

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1. Introduction

As one of the few Chinese provinces with frequency earthquake activities, Gansu tops the ranking of regional earthquake activity level. On its history, many destructive earthquakes have occurred, which led to severe personal casualties and economic loss in Gansu (Pei Huijuan, 2015). Inside Gansu, there are Qilian Mountains Earthquake Belt, Tianshui Earthquake Belt and Alkin Earthquake Belt, where the multiple destructive earthquakes are concentrated, including Ms8.5 Haiyuan Earthquake in 1920, Ms8.0 Gulang Earthquake in 1927 and Ms7.25 Shandan Earthquake in 1954, etc. In recent years, the occurrence frequency of earthquakes in Gansu and its surrounding regions has increased obviously (including Ms8.0 Wenchuan Earthquake in 2008, Ms6.6 Minxian-Zhangxian Earthquake in 2013, Ms6.4 Menyuan Earthquake in 2015 and Ms7.0 Jiuzhaigou Earthquake in 2017). In addition, with the quantum leaps in regional economy, the impacts of earthquake disasters on Gansu society and economy will be further aggravated (Nie Gaozhong, 2002).

Earthquake prevention and disaster reduction capability is the ability of a region to reduce earthquake damage and loss in the face of an earthquake disaster. The higher the capability of earthquake prevention and disaster reduction is, the less damage the earthquake will cause to the local social and economic development. In the 1990s, all countries in the world started to carry out scientific research on earthquake prevention and disaster reduction one after another, and established various indicator systems for earthquake prevention and disaster reduction capability assessment (Liu Xiaojing, 2012; Guo Yan, 2013; Deng Yan, 2013; Liu Li, 2008; Li Zhi, 2011; Davidson Rachel, 1997; Kunihiro A, 2000). The most representative overseas result is the earthquake disaster risk indicator EDRI (Davidson Rachel, 1997) in while the most representative domestic result is the system put forward by Academician Xie Lili to assess the capacity of urban earthquake prevention and disaster reduction based on the triple criteria (Liu Li, 2008). Targeted at Gansu Province, this paper establishes an assessment indicator system for earthquake prevention and disaster reduction capability based on the county-level administrative unit and to assess the earthquake prevention and disaster

reduction capability of all districts and counties in Gansu Province so as to correctly understand the distribution characteristics of earthquake prevention and disaster reduction capability in all districts and counties of Gansu Province and to provide scientific basis for the realization of the scientific configuration of earthquake prevention and disaster reduction resources.

2. Data and method

2.1. Data source and processing

The accuracy of the assessment indicators directly affects the reliability of the assessment result. Therefore, this paper uses the statistical data released by the state authority to conduct the calculation and analysis. The data of population, economy, health care, financial savings, traffic and communications are from the Statistical Yearbook of Gansu Province in 2016 (the deadline for statistics is December 2015) and the Statistical Yearbook of China County (the volume of cities and counties) 2016; the topographic data are from Japan ASEM satellite DEM data (spatial resolution of 30m); administrative divisions and active fault data are from Gansu Province earthquake emergency basic database. The spatialization of each indicator in this paper is done in the ArcGIS software platform. The coordinate system adopts WGS-1984.

2.2. Analysis method

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The analytic method adopted in this paper is AHP (analytic hierarchy process), which is a multi-criteria decision-making method proposed by Saaty (Saaty TL, 1980) et al. in the early 1970s. In the decision-making process, the factors are classified to form a hierarchical analysis model. After that, the factors are mutually compared on different hierarchies, and then the discriminant matrix is established, and then the weight on the importance of each factor is finally determined to provide a comparative quantitative basis for the development analysis and prediction (Saaty TL, 1994). The method used in the processing of statistical data in

this paper is linear dimensionless method to eliminate the impacts of the indicator dimension on the result.

The first step of AHP is to set up the Hierarchical Model. Based on profound analysis of practical problems, the relevant factors are decomposed into several hierarchies from top to bottom according to different attributes. The factors on the same hierarchy are subordinated to or have an impact on the factors on the above hierarchy, and dominate or are under the influence of the factors on the lower hierarchy. The top hierarchy is the target hierarchy, usually with only one factor, and the bottom hierarchy is usually a factor hierarchy. In the middle, there can be one or several hierarchies, usually the criteria hierarchy and indicator hierarchy.

The second step is to construct the comparison matrix. Starting from the second hierarchy of the hierarchical model, pairwise comparison method and 1-9 comparison scale are used to construct the comparison matrix for the factors on the same hierarchy subordinate to factors on the above hierarchy until the bottom. For n factors, we can get pair comparison judgment matrix $C = (C_{ij})_{n \times n}$, whose general form is expressed as:

B_k	C_1	C_2	...	C_n
C_1	C_{11}	C_{12}	...	C_{1n}
C_2	C_{21}	C_{22}	...	C_{2n}
...
C_n	C_{n1}	C_{n2}	...	C_{nn}

Matrix C possesses following properties: (1) $C_{ij} > 0$; (2) $C_{ij} = 1 / C_{ji} (i \neq j)$; (3) $C_{ii} = 1 (i = 1, 2, \dots, n)$.

1-9 comparison scale method is illustrated in following Table 1:

Table 1 Definition of comparison scale

No.	Importance level	Value of C_{ij}
1	i and j are equally important	1
2	i is slightly more important than j	3
3	i is obviously more important than j	5
4	i is highly more important than j	7
5	i is extremely more important than j	9
6	i is slightly less important than j	1/3
7	i is obviously less important than j	1/5
8	i is highly less important than j	1/7
9	i is extremely less important than j	1/9

Other relative importance levels can be assigned as 2, 4, 6, 8, 10, 1/2, 1/4, 1/6, 1/8, 1/10, and the important

level can be determined in comparison with the 1-9 scale.

The third step is to calculate the weight vector and does the consistency test. For each paired comparison matrix, the largest eigenvalue and the corresponding eigenvector are calculated, and the consistency test is performed by using consistency indicator, random consistency and consistency ratio.

The calculation process of the largest matrix eigenvalue λ_{max} is as follows:

(1) Calculate the product of each row element of the judgment matrix C .

$$M_i = \prod_{j=1}^n C_{ij}, i = 1, 2, \dots, n$$

(2) Calculate the n th power root of M_i

$$\bar{W}_i = \sqrt[n]{M_i}$$

(3) If the normalized

$$W_i = \frac{\bar{W}_i}{\sum_{j=1}^n \bar{W}_j}$$

then W_i is the sought eigenvector.

(4) Calculate the largest eigenvalue

$$\lambda_{max} \approx \sum_{i=1}^n \frac{CW_i}{nW_i}$$

CW_i denotes the negative average value of the other eigenvalues except for the largest eigenvalue of the judgment matrix after the i th component of the vector CW has been calculated to serve as a measure on the deviation of the judgment matrix from the consistency indicator, which means:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

The larger the CI is, the greater the deviation of the judgment matrix from the complete consistency will be. A smaller CI value indicate a better consistency of the judgment matrix; when the matrix has satisfactory consistency, λ_{max} is slightly larger than n and the other eigenvalues are close to 0. Hereunder, a measure of satisfactory consistency is proposed. When the order of the matrix is greater than 2, the ratio of consistency indicator CI of the judgment matrix to the same-order mean coincidence index RI is called the random consistency ratio and is denoted as CR . when

$$CR = \frac{CI}{RI} < 0.10$$

it is assumed that the judgment matrix has satisfactory consistency. Otherwise, the judgment matrix needs to be adjusted to a satisfactory consistency. The value of RI changes with the change of matrix dimension n, as shown in Table 2:

Table 2 Values of random consistency indicator

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

3. Assessment and earthquake prevention and disaster reduction capability

3.1. Assessment process

In this paper, the earthquake prevention and disaster reduction capability assessment is conducted on county-level administrative unit in Gansu, and the overall assessment process is shown in Figure 1. The target hierarchy is the calculated earthquake prevention and disaster reduction capability of the counties (districts).

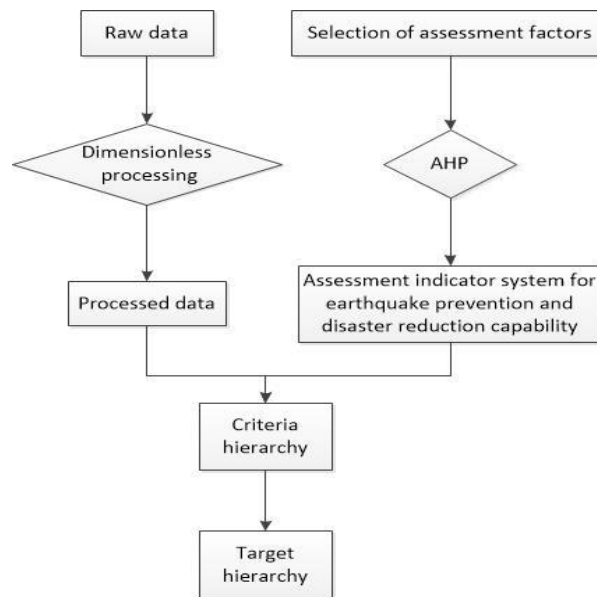


Figure 1 Assessment process

3.2. Assessment indicator system for earthquake prevention and disaster reduction capability

This paper selects the assessment indicators and factors from three aspects of environmental supporting

capability, infrastructure supporting capability and resource supporting capability, and establishes the assessment indicator system for earthquake prevention and disaster reduction capability of county-level administrative units in Gansu Province (Table 3).

Environmental supporting capability includes the distribution of topographic relief and active faults. It is more difficult to carry out disaster relief and rescue work in places where the topography fluctuates greatly. There is also a relatively higher risk of earthquakes in areas with more active faults. Infrastructure supporting capability includes building quality, traffic conditions, medical conditions, communication conditions and shelter premises. The finally-determined factor hierarchy includes topographic relief, active fault distribution, building seismic capacity, average resident GDP, road density, medical beds, fixed telephone density, satellite telephone density, average personal refuge, number of young males, emergency rescue forces, fiscal revenue density, average resident savings material reserves, population density above high school and others, making 15 factors in total. Among them, the

building quality depends first and foremost on the overall structure of the local buildings. The data of the building structures in all districts and counties in Gansu Province are used. Then, the seismic damage indicator of buildings in all districts and counties is calculated

Table 3 The assessment indicator system for earthquake prevention and disaster reduction capability of county-level administrative units in Gansu province.

Target hierarchy	Criteria hierarchy	Indicator hierarchy	Factory hierarchy	
Earthquake prevention and disaster reduction capability	Environmental supporting capability (0.547)	Topographic relief (0.182)	Topographic relief (0.182)	
		Active fault (0.365)	Active fault distribution (0.365)	
		Building quality (0.168)	Building seismic capacity (0.112)	
	Infrastructure supporting capability (0.345)	Traffic conditions (0.078)	Average resident GDP (0.056)	Average resident GDP (0.056)
		Medical conditions (0.049)	Road density (/km2) (0.078)	Road density (/km2) (0.078)
		Communication conditions (0.03)	Medical beds (/10000 persons) (0.049)	Medical beds (/10000 persons) (0.049)
			Fixed telephone density (/km2) (0.01)	Fixed telephone density (/km2) (0.01)
		Satellite telephone density (/km2) (0.02)	Satellite telephone density (/km2) (0.02)	
	Shelter premises (0.02)	Average personal refuge (/10000 persons) (0.02)	Average personal refuge (/10000 persons) (0.02)	
	Resource supporting capability (0.108)	Labor resources (0.035)	Number of young males (/km2) (0.007)	Number of young males (/km2) (0.007)
		Property resources (0.045)	Emergency rescue forces (/km2) (0.028)	Emergency rescue forces (/km2) (0.028)
			Fiscal revenue density (/km2) (0.013)	Fiscal revenue density (/km2) (0.013)
Cognitive level (0.028)		Average resident savings (0.008)	Average resident savings (0.008)	
		Material reserves (/10000 persons) (0.024)	Material reserves (/10000 persons) (0.024)	
		Population density above high school (/km2) (0.028)	Population density above high school (/km2) (0.028)	

based on the earthquake damage indicator of each structural building to represent the seismic capacity of buildings (Wang Xianghao, 2008). In addition, the building quality is closely linked with the local economy and people's living standard. The higher the local economy and people's living standard are, the higher the overall quality of living buildings is. Resource supporting capability includes labor resources, property resources and cognitive level. After the earthquake, more human and financial resources that can be mobilized for rescue provides better disaster relief effect. Besides, the knowledge level of local residents also exerts some influence on the implementation of earthquake prevention and disaster reduction policies.

The weights of assessment indicators are determined by AHP. According to the relative importance of each indicator, the factors on different hierarchies are mutually compared to establish the judgment matrices, and the consistency test of each judgment matrix is carried out. Combined with the scoring of experts in the field of earthquake, there are 8 final judgment matrices,

1 on the criteria hierarchy, 3 on the indicator hierarchy and 4 on the factor hierarchy.

The judgement matrix of environmental supporting capability, infrastructure supporting capability and resource supporting capability is determined as:

$$A_1 = \begin{bmatrix} 1 & 2 & 4 \\ 1/2 & 1 & 4 \\ 1/4 & 1/4 & 1 \end{bmatrix}$$

Through calculation, the weight coefficient of A_1 is $W_1 = (0.547, 0.345, 0.108)^T$.

The judgment matrix of topographic relief and active fault is determined as:

$$A_2 = \begin{bmatrix} 1 & 1/2 \\ 2 & 1 \end{bmatrix}$$

Through calculation, the weight coefficient of A_2 is $W_2 = (0.333, 0.667)^T$.

The judgment matrix of building quality, traffic conditions, medical conditions, communication conditions and shelter premises is determined as:

$$A_3 = \begin{bmatrix} 1 & 3 & 4 & 5 & 6 \\ 1/3 & 1 & 2 & 3 & 4 \\ 1/4 & 1/2 & 1 & 2 & 3 \\ 1/5 & 1/3 & 1/2 & 1 & 2 \\ 1/6 & 1/4 & 1/3 & 1/2 & 1 \end{bmatrix}$$

Through calculation, the weight coefficient of A_3 is $W_3 = (0.487, 0.228, 0.142, 0.087, 0.056)^T$.

The judgment matrix of labor resources, property resources and cognitive level is determined as:

$$A_4 = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 2 \\ 1 & 1/2 & 1 \end{bmatrix}$$

Through calculation, the weight coefficient of A_4 is $W_4 = (0.327, 0.413, 0.26)^T$.

The judgment matrix of building seismic capacity and average resident GDP is determined as:

$$A_5 = \begin{bmatrix} 1 & 2 \\ 1/2 & 1 \end{bmatrix}$$

Through calculation, the weight coefficient of A_5 is $W_5 = (0.667, 0.333)^T$.

The judgment matrix of fixed telephone density and satellite telephone density is determined as:

$$A_6 = \begin{bmatrix} 1 & 1/2 \\ 2 & 1 \end{bmatrix}$$

Through calculation, the weight coefficient of A_6 is $W_6 = (0.333, 0.667)^T$.

The judgment matrix of number of young males and emergency rescue forces is determined as:

$$A_7 = \begin{bmatrix} 1 & 1/4 \\ 4 & 1 \end{bmatrix}$$

Through calculation, the weight coefficient of A_7 is $W_7 = (0.2, 0.8)^T$.

The judgment matrix of fiscal revenue density, average resident savings and material reserves is determined as:

$$A_8 = \begin{bmatrix} 1 & 2 & 1/2 \\ 1/2 & 1 & 1/3 \\ 2 & 3 & 1 \end{bmatrix}$$

Through calculation, the weight coefficient of A_8 is $W_8 = (0.297, 0.163, 0.540)^T$.

It is tested that the random consistency ratios of all the judgment matrices are lower than 0.1, which means that the judgment matrices possess satisfactory consistency. As shown in Table (from up to bottom), the calculated criteria weights on the criteria hierarchy are respectively (0.547, 0.345, 0.108), and the calculated indicator weights on the indicator hierarchy are respectively (0.182, 0.365, 0.112, 0.056, 0.078, 0.049, 0.01, 0.02, 0.02, 0.007, 0.028, 0.013, 0.008, 0.024, 0.028).

The calculation formula of the final criteria hierarchy is given as:

$$C = \sum_{i=1}^n \delta_i \times I_i$$

Where

$$I = \sum_{j=1}^m \sigma_j \times F_j$$

The calculation formula of the target hierarchy is given as:

$$T = \sum_{k=1}^h \mu_k \times C_k$$

T represents the target hierarchy, C represents the criteria hierarchy, I represents the indicator hierarchy, F represents the factor hierarchy, δ represents the weight of each indicator hierarchy, σ represents the weight of each factor hierarchy, μ represents the weight of each criteria hierarchy, n represents the number of factors on the indicator hierarchy which is contained in the corresponding criteria hierarchy C, m is the number of factors on the factor hierarchy which is contained in the corresponding indicator hierarchy, and h is the number of factors on the criteria hierarchy which is contained in the corresponding target hierarchy.

The final value the above-calculated criteria hierarchy C and target hierarchy T ranges from 0 to 1, which is because the dimensionless method is adopted for all the factors in the calculation process to eliminate the influence of different dimensions on the result. The final calculation results have also been normalized to facilitate the follow-up classification analysis.

3.3. Result and analysis

(1) Environmental supporting capability

In combination of the topographic relief and active fault, the distribution figure of environmental supporting capability of counties and districts in Gansu Province is obtained. The capability is divided into five levels, respectively strong (0-0.09), relatively strong (0.09-0.21), medium (0.21-0.33), relatively weak (0.33-0.53) and weak (0.53-1). Hereunder, the classification is done in the ArcGIS software platform, and the method used is Natural Breaks (Jenks) (natural breakpoint classification, the same for below). The principle of classification is to put the similar individuals together and divide them into several classes. Statistics can be measured by the variance, which refers to calculating the variance of each class, and then calculating the sum of these variances and the size of the variance to compare the classification quality. The classification

with the minimum variance is the optimal method. Natural Breaks classification can well classify things alike together with obvious differences among classes but small differences within one class.

It can be seen from Figure 2 that the districts with strong environmental supporting capability are mainly located in the four regions of Dunhuang-Guazhou District, Jinchang-Minqin District, Dingxi-Pingliang-Qingyang District and Lanzhou City District. The topographic relief in these districts is relatively small, with Dunhuang-Guazhou District, Jinchang-Minqin District and Lanzhou City District relatively flat. The district with weak environmental supporting capability are mainly Gannan-Longnan District and Sunan-Tianzhu District. Sunan-Tianzhu District is located on the edge of the Qilian Mountains with a great topographic relief, while Gannan-Longnan District is located in the main active fault in the province, Kunlun fault zone with strong tectonic activity.

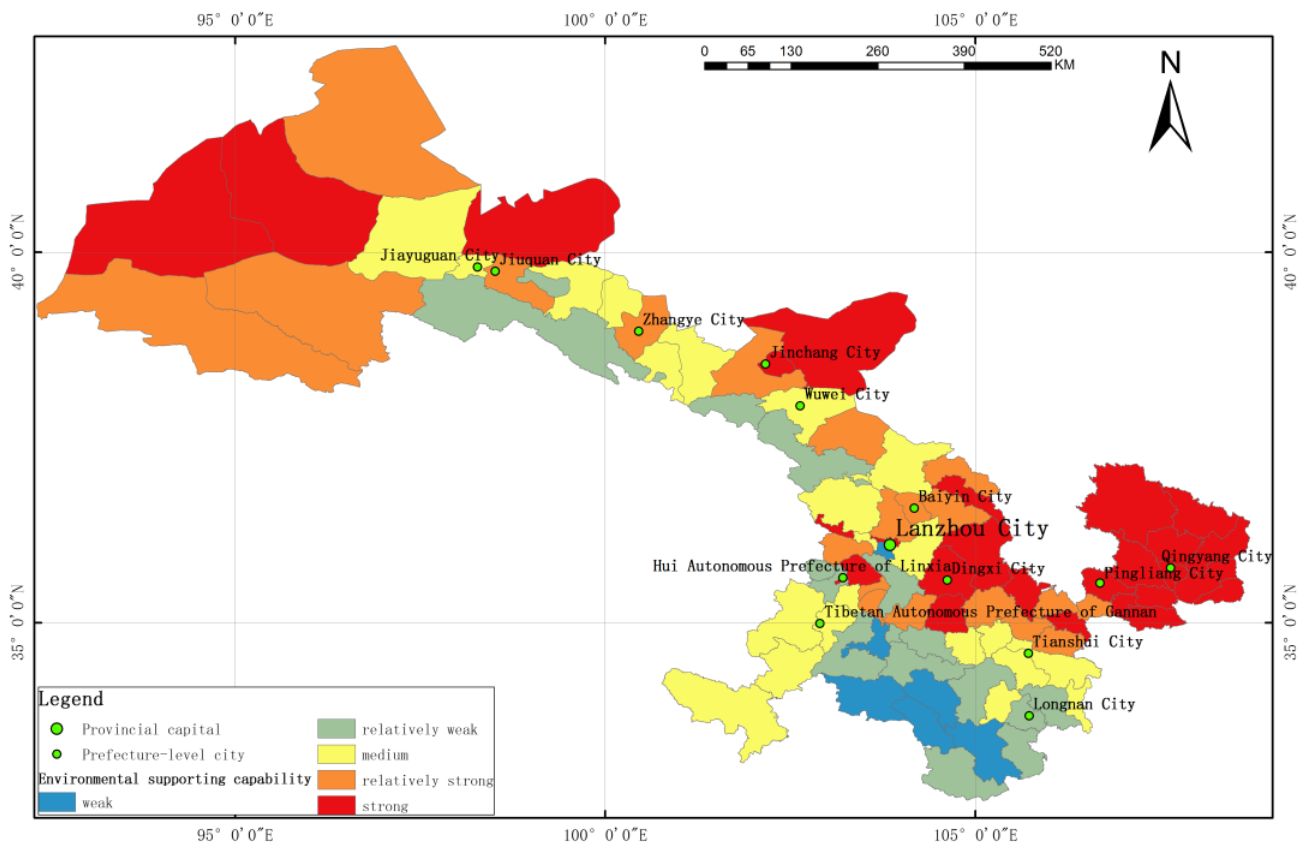


Figure 2 The distribution of environmental supporting capability of various districts and counties in Gansu Province.

(2) Infrastructure supporting capability

In combination of the building quality, traffic conditions, medical conditions and communication conditions, the distribution figure of infrastructure supporting capability of districts and counties in Gansu Province is obtained (Figure 3). The capability is divided into five levels, respectively strong (0.51-1), relatively strong (0.32-0.51), medium (0.23-0.32), relatively weak (0.13-0.23) and weak (0-0.13). As shown in Fig.3, the districts with strong infrastructure supporting capability mainly includes Aksay-Subei District, Jiayuguan City, Jinchang City District, Baiyin City District and Lanzhou City District. Among them, the Aksay-Subei District is sparsely populated with rich mineral resources. Its average GDP is in the forefront among the province, and it maintains a good overall building quality. Population is densely distributed throughout central and eastern Gansu Province, which pulls down the average GDP. The infrastructure supporting capability cannot meet the demand of excessive population. The Gannan-Linxia-Dingxi

District has a weak overall infrastructure supporting capability.

(3) Resource supporting capability

Through the labor resources, property resources and cognitive level, the distribution figure of resource supporting capability of districts and counties in Gansu Province is obtained (Figure 4). The capability is divided into five levels, respectively strong (0.66-1), relatively strong (0.25-0.66) medium (0.11-0.25), relatively weak (0.05-0.11) and weak (0-0.05). Fig.4 shows that the overall resource supporting capability of Gansu Province is weak, with only relatively strong capability of Anning District of Lanzhou, Linxia City District, Subei County and Qinzhou District. The appearance of this phenomenon is due to the backward economic development of Gansu Province, and the government revenue and the average resident savings are less. In addition, the provincial education is underdeveloped, resulting in a low cognitive level of the people.

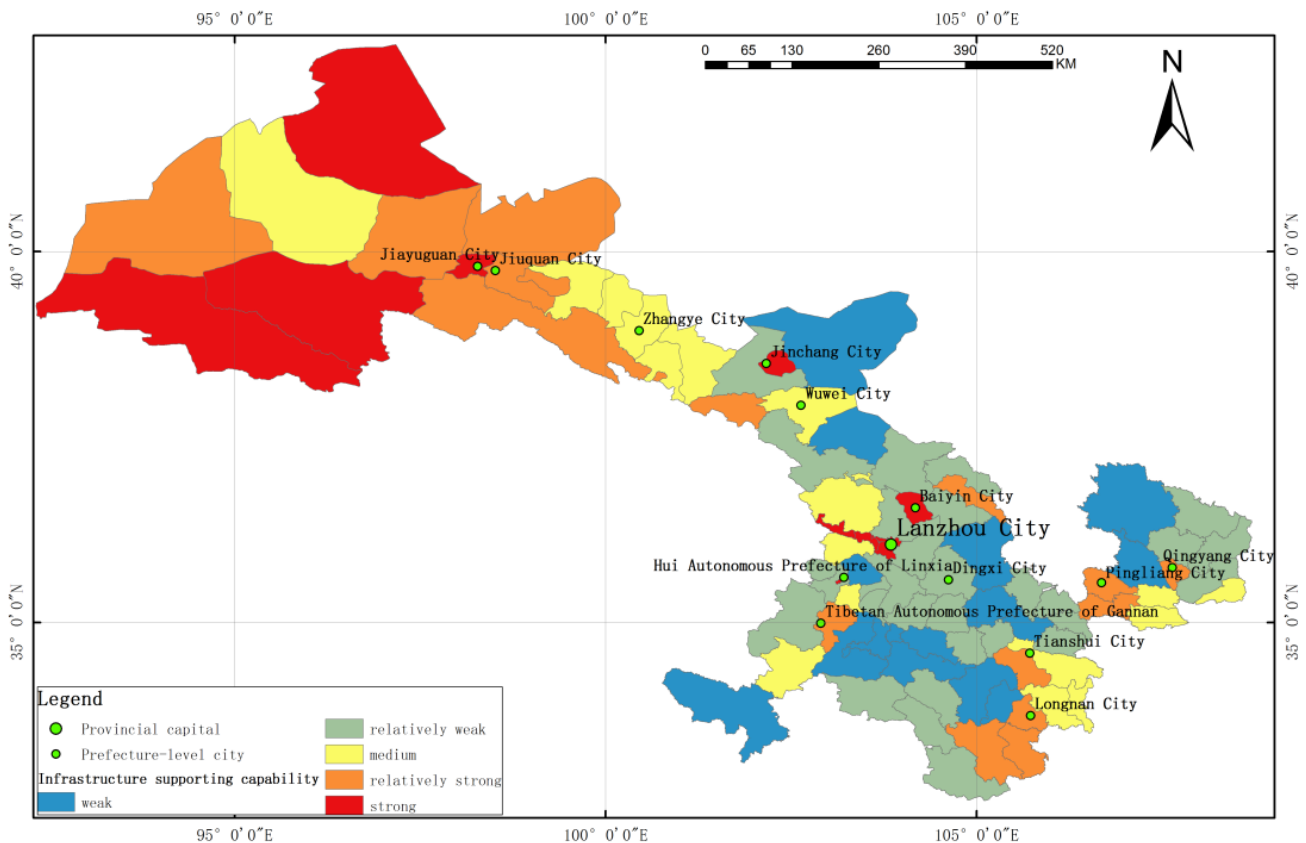


Figure 3 The distribution of infrastructure supporting capability of various districts and counties in Gansu Province.

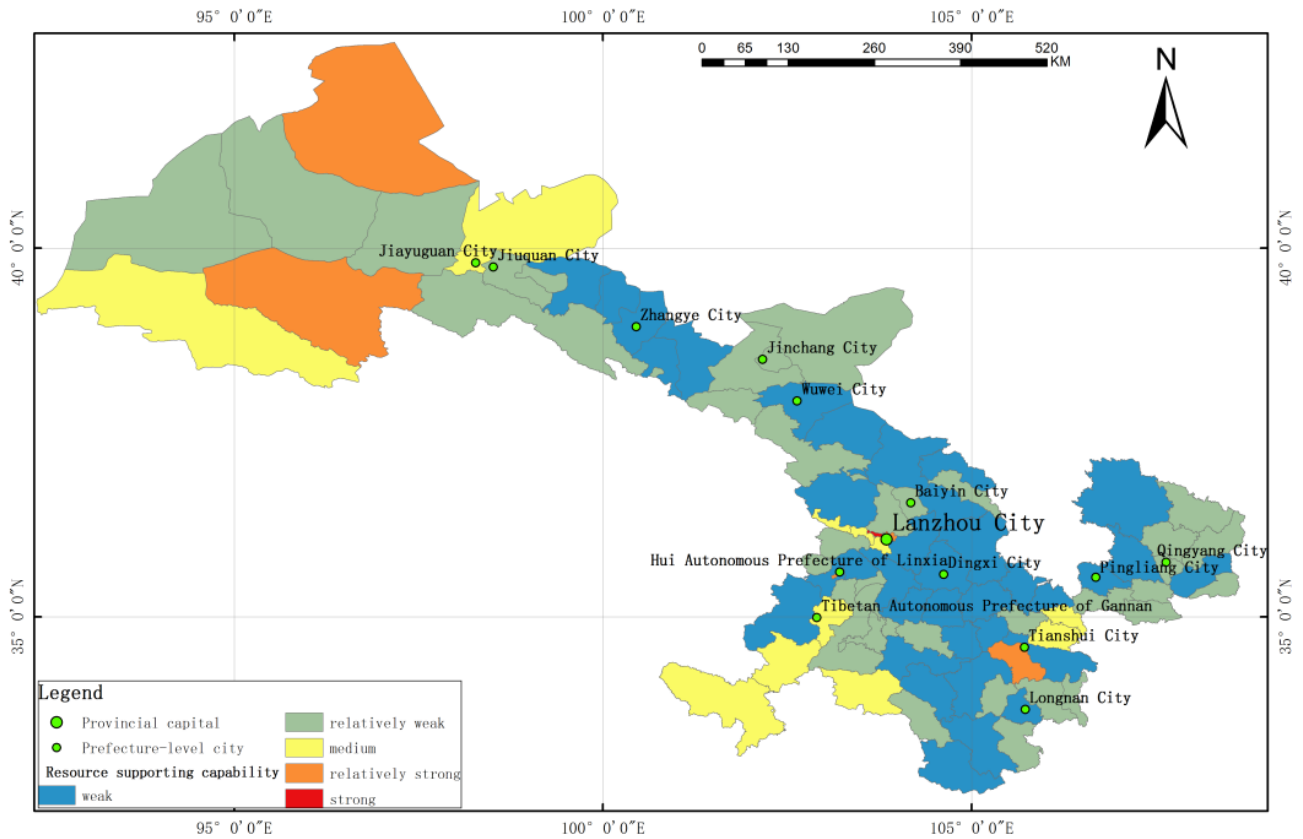


Figure 4 The distribution of resource supporting capability of various districts and counties in Gansu Province.

(4) Earthquake prevention and disaster reduction capability

In combination of the environmental supporting capability, infrastructure supporting capability and resource supporting capability, the distribution figure of earthquake prevention and disaster reduction capability of various districts and counties in Gansu Province is finally calculated. The capability is divided into five levels, respectively strong (0.76-1), relatively strong (0.63-0.76), medium (0.50-0.63), relatively weak (0.26-0.50) and weak (0-0.26). As shown in Fig.5, the earthquake prevention and disaster reduction capability of west section and mid-east section of Hexi, Longdong District and Lanzhou in Gansu Province is relatively strong, where the earthquake prevention and disaster reduction capability of Anning District of Lanzhou is the strongest, followed by Aksay District, Jinchuan District, Xifeng District and Linxia City District. Then, the earthquake prevention and disaster reduction capability of Sunan-Tianzhu District and Gannan-

Longnan District is relatively weak, and Zhouqu County has the weakest earthquake prevention and disaster reduction capability in all the counties and districts in Gansu Province.

4. Conclusion

In this paper, the assessment indicator system of earthquake prevention and disaster reduction capability of county-level administrative units in Gansu Province is established. The analytic hierarchy process is used to determine the weight of each indicator factor. The ArcGIS software platform is used to calculate the environmental supporting capability, infrastructure supporting capability and resource supporting capability of all districts and counties in Gansu Province. On this basis, the assessment figure of earthquake prevention and disaster reduction capability is obtained. The research results indicate that Anning District of Lanzhou has the strongest earthquake prevention and

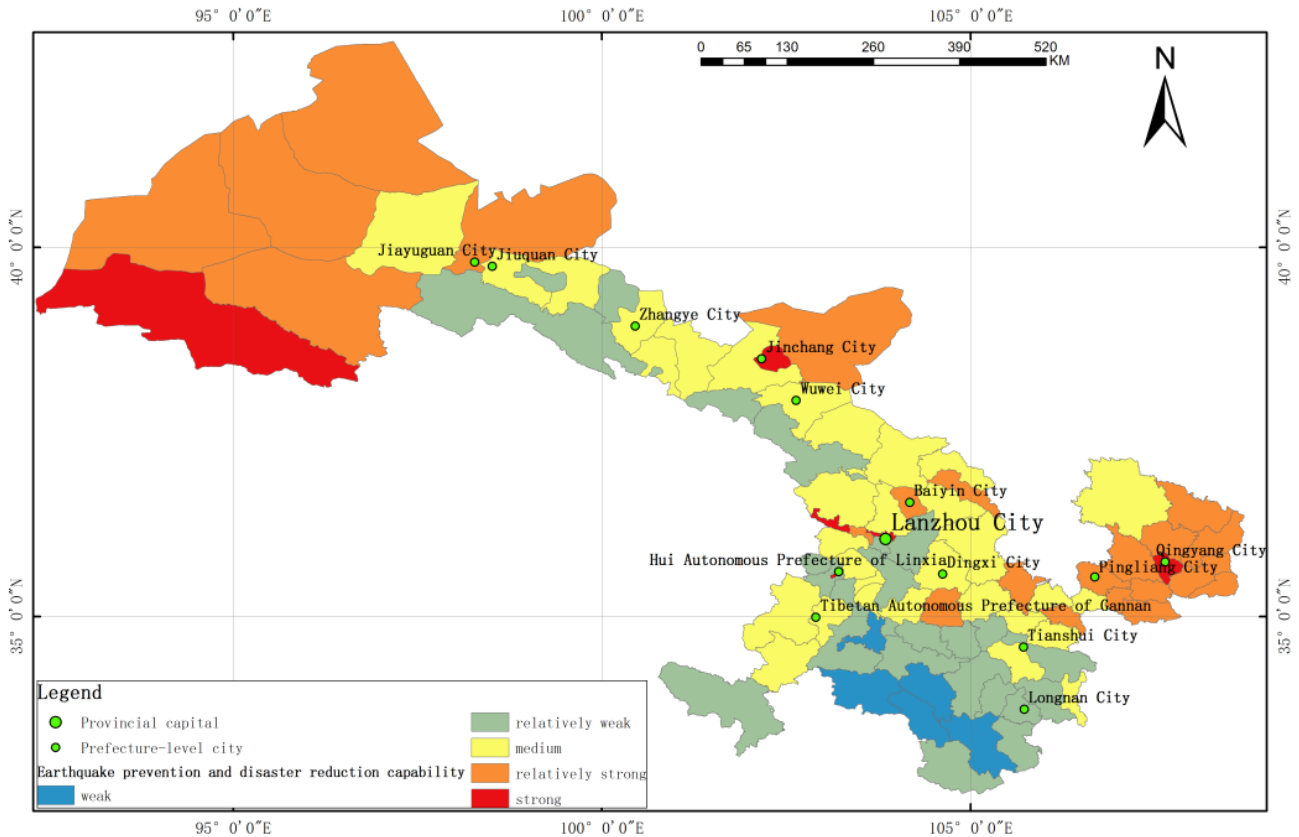


Figure 5 The distribution of earthquake mitigation capacity of various districts and counties in Gansu province.

disaster reduction capability while Zhouqu County possesses the weakest earthquake prevention and disaster reduction capability; the overall earthquake prevention and disaster reduction capability of northwestern and northeastern regions in Gansu is higher, in which the earthquake prevention and disaster reduction capability of Aksay-Subei District, Jinchuan District, Xifeng District, Linxia City District and Lanzhou City District is particularly prominent; the earthquake prevention and disaster reduction capability of Sunan-Tianzhu District and Gannan-Longnan District is relatively weaker; the geographical environment has a great impact on the earthquake prevention and disaster reduction capability, which is demonstrated as that the earthquake prevention and disaster reduction capability of regions with violent tectonic activities and dramatic topographic inequality tend to be weak; the whole province should improve the construction of infrastructure and fundamental resources in order to

compensate for the insufficiency in environmental supporting capability.

In addition, the assessment method used in this paper provides a hierarchical thinking framework. By combining qualitative judgment with quantitative inference, this paper assesses the earthquake prevention and disaster reduction capability of county-level administrative units in Gansu Province and obtains their spatial distribution characteristics, providing certain theoretical reference. However, this assessment method is subject to obvious shortcomings in adopting expert scoring method during the determination of the judgment matrices and the factor weights, which involves subjective human factors, easily leading to controversy. Furthermore, due to the lack of individual data and collection difficulties, the assessment indicator system established in this paper is not perfect enough. Therefore, it is more convincing to further explore the independent factors that have an impact on earthquake

prevention and disaster reduction capability and include them in the assessment indicator system.

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