Acadlore Transactions on Geosciences
https://www.acadlore.com/journals/ATG

Evaluation of Post-Earthquake Geological Environment Carrying Capacity Based on AHP-GIS Coupled Analysis Method

Huan Chen[1*], Anbang Huang[1], Bo Peng[1], Yimin Liu[2]

[1] Institute of Exploration Technology of CAGS, 610081 Chengdu, China
[2] School of Mechanical Engineering, Tianjin University of Technology, 300384 Tianjin, China

[*] Correspondence: Huan Chen(chuan@mail.cgs.gov.cn)

Received: 01-02-2023 **Revised:** 02-01-2023 **Accepted:** 03-06-2023

Citation: H. Chen, A. B. Huang, B. Peng, and Y. M. Liu, "Evaluation of post-earthquake geological environment carrying capacity based on AHP-GIS coupled analysis method," *Acadlore Trans. Geosci.*, vol. 2, no. 1, pp. 14-23, 2023. https://doi.org/10.56578/atg020102.

Abstract: Pingwu County, located in the north of Sichuan Province, China, was severely affected by the Wenchuan Earthquake in 2008. The county is part of the Fujiang river basin, and a large number of earthquake-induced geological hazards have developed in the area since the earthquake. Post-earthquake reconstruction in key towns and regional development is important and requires a scientific evaluation of the geological environment's carrying capacity. In this study, geographic information system (GIS) - analytic hierarchy process (AHP) coupled analysis method is used to combine the post-earthquake geological environment background, disaster point distribution, and social development in the area to construct an evaluation system of geological environment carrying capacity based on ten evaluation indicator layers of geological environment, ecological environment and social environment. The weight of each evaluation indicator is calculated using the AHP analysis method, and the carrying capacity of the geological environment in Pingwu County for each GIS grid is calculated, thereby obtaining a division map for carrying capacity. The results of the evaluation show that the geological environment carrying capacity of the Pingwu County is balanced (critical overload) and surplus (not overloaded). Further, no overload condition is present, and the distribution of loading is related to human construction. In general, the carrying capacity of an area is low in areas with a high degree of construction and other related activities. Based on the evaluation results of the carrying capacity of the geological environment, this study provides suggestions for optimizing the construction of the central area of Pingwu County, controlling the scale of regional construction, maintaining the original nature of ecological species in the natural reserve area and prohibiting development and transformation, and providing a clear direction of development for the post-earthquake development planning of this area.

Keywords: AHP-GIS coupled analysis method; Environmental carrying capacity; Post-earthquake; Key towns; Classification map of carrying capacity

1. Introduction

Since the "5.12" Wenchuan Earthquake, natural disasters such as mudslides, landslides, and collapses caused by the earthquake have seriously threatened the stable development of the social economy and ecological environment in mountainous earthquake-stricken areas, and have become the focus of government functional departments [1-3]. The Fujiang River Basin is an important watershed in the upper reaches of the Yangtze River. It is located in the transition zone of Longmen Mountains, at the junction of Longmen Mountains and the Sichuan Basin. The natural geological conditions in the watershed are complex with fragile ecological environment. This area belongs to the extremely severe disaster area of the Songping Earthquake in 1976 and the Wenchuan Earthquake in 2008. The Jiuzhaigou Earthquake in 2017 had a greater impact on the Jiuzhaigou area in the basin, and a large number of earthquake-induced geological disasters developed in the area. After the Wenchuan Earthquake, the post-disaster reconstruction process of key towns in the Fujiang River Basin has advanced rapidly, and human engineering activities (municipal engineering construction, water conservancy, hydropower, and mineral resources development) have become increasingly intense, and the only geological environmental capacity is far from enough to meet the needs of urban construction and development. On the one hand, in urban construction, it's necessary to extend to the dangerous areas of geological disasters (such as leaning back to steep slopes; occupying debris flow accumulation fans and landslide accumulation bodies; leaning forward to the river and occupying river channels), and on the other hand, man-made land by means of excavation and filling, such urban construction exceeding the environmental capacity and strong disturbance to the geological environment, will induce a large number of geological disasters and may cause extremely serious losses [4-6]. Therefore, from the perspectives of geological environment, ecological environment, and social environment, the geological environment carrying capacity of the region is evaluated to solve the constraints and restrictions on the expansion speed of key cities and towns by the geological environment, ecological environment, etc., and provide scientific guidance for post-earthquake reconstruction and regional development in the disaster area. At the same time, it has important theoretical and practical significance for improving the regional ecological environment and sustainable development.

Geological environment carrying capacity refers to the maximum potential that the geological environment can withstand the impact and change of human activities under the condition that the structure of the geological environment system does not undergo qualitative changes and the function of the geological environment system is unfavorable to the development of human society and economic activities in a certain period and a certain area, as well as under certain environmental objectives [7]. The evaluation of the carrying capacity of the regional geological environment needs to comprehensively consider the dynamic change characteristics of the geological environment in the region and the influence of human engineering activities and other factors, and select representative indicators for comprehensive evaluation based on the principle of comprehensiveness and systematicness [8]. In 1972, Meadows et al. [9] clarified the importance of the environment and the basic connection between resources and population, laying a scientific foundation for sustainable development. Cendrero et al. [8] took the Santander Bay region as an example to apply environmental carrying capacity to land and water resource management in the northern Spanish coastal region. This study quantitatively characterized environmental units and developed land use planning policy based on the natural capacity of the environment.

The concept of carrying capacity in China first appeared in 1991 in the Comprehensive Research on the Environment of China's Coastal Economic and Technological Development Zones: General Report on Comprehensive Research on Environmental Planning of Meizhou Bay Development Zone in Fujian Province". This research report mainly focused on the carrying capacity of environmental elements, such as water environment geological carrying capacity, land carrying capacity, tourism environmental geological carrying capacity, etc. [10]. Ma Chuanming and other scholars believe that the geological environmental carrying capacity, as an important link between the geological environment and human activities, not only affects the activities generated by human survival and development, but also affects and restricts its own survival and development [11]. The establishment of the geological environment carrying capacity evaluation indicator system is a complex process, which includes both natural ecological geological conditions and human activities with social attributes. At this stage, some scholars have used a variety of indicator systems and evaluation models to complete the evaluation of the carrying capacity of geological environment in multiple regions. Shu [12] introduced the geological environment safety evaluation method into the evaluation indicator system of geological environment carrying capacity, and verified the comprehensive evaluation indicator system of geological environment safety. Wang and Li [13] used the AHP-GIS coupled model to evaluate the geological environmental carrying capacity of the Shandong Peninsula, mainly using the Analytic Hierarchy Process (AHP) to determine the weight of each evaluation indicator, and using the method of combining GIS spatial analysis and attribute database linking to classify the geological environmental carrying capacity of the area. Li [14] proposed a county geological environment carrying capacity evaluation method based on a cluster analysis algorithm, established an evaluation indicator system, and used GIS technology to extract, analyze, and process the evaluation indicator layer to obtain a county geological environment carrying capacity distribution map.

At present, scholars at home and abroad focus on the conceptual description of the geological environmental carrying capacity of key towns in mountainous areas. There are relatively few indicator systems and evaluation models for the evaluation of carrying capacity, and they have not been able to combine the geological environment background of the research area well. And less attention has been paid to the analysis and research on the geological environment carrying capacity of key reconstructed cities and towns after the Wenchuan Earthquake. In this study, key cities and towns in the Fujiang River Basin are constrained and restricted by factors such as the Wenchuan Earthquake, geological environment, and ecological environment during the post-disaster reconstruction process. Some cities and towns have been overloaded, causing geological disasters, environmental pollution, and unbalanced social and economic development. How to scientifically evaluate the geological environment carrying capacity of the Fujiang River Basin, especially key cities and towns, and the post-earthquake development planning are imminent.

Based on the research results of the Fujiang River Basin 1:50,000 Pingwu Area Environmental Geological Survey project, this study mainly evaluates the post-earthquake carrying capacity of Pingwu County and its key towns in Mianyang City. Through historical data and on-site investigation, it obtains the geological structure background and geological hazard characteristics of the area, selects local factors related to geological environment elements as relative evaluation factors, and constructs a geological environment carrying capacity evaluation system based on 10 evaluation indicator layers in three aspects of geological environment, ecological environment and social environment through GIS-AHP coupled model; analyzes and calculates the carrying capacity of geological environment in Pingwu County on the basis of determining the weight of each evaluation indicator; determines the bearing capacity threshold and bearing capacity status of the geological environment in key cities and towns in Pingwu County, and provides a clear development direction for the post-earthquake development planning of the region.

2. Geological Environment Background of Pingwu County

Pingwu County is located in the northwest of the Sichuan Basin, the eastern edge of the transition from the Qinghai-Tibet Plateau to the Sichuan Basin, and the upper reaches of the Fujiang River, a secondary tributary of the Yangtze River. Geographical coordinates: East longitude 103°50′~104°58′, north latitude 31°59′~33°02′, 120km long from north to south, 110km wide from east to west, covering an area of 5,974km^2.

There are still many environmental geological problems in Pingwu County, mainly including the following aspects: 1. Soil erosion. Pingwu County is located in the Fujiang River Basin. In recent years, due to the impact of earthquakes and human engineering activities, soil erosion has become increasingly serious; 2. Rainstorms and floods. Pingwu County is full of mountains, with a stronger water collection capacity of valleys, extreme events occur frequently, and flood disasters are also serious. Floods are not only related to the rainfall at that time, but also related to the accumulation of precipitation in the early stage and upstream, as well as the slope and the permeability of the soil layer. In recent years, the frequency of flood disasters has been increasing year by year, mostly concentrated in May to September [15]. Especially after the 5.12 Wenchuan Earthquake, there were a large amount of collapsed deposits in the valleys, which blocked the channels and caused poor drainage. Floods were easily induced in heavy rainfall and caused the destruction of houses and bridges, the washing away of arable land, the loss of life and livestock, bringing about a huge economic damage; 3. Uneven settlement. Pingwu County has many mountains and little flat land, most of the structures are built on the hills, and the foundations often need to be cut or filled. The foundation of the structure is placed on the foundation of rock and soil with different physical and mechanical properties, which is easy to produce uneven settlement; 4. Earthquakes. Seismogenic structures in the seismically active area of the northwest triangular fault block mainly include Minjiang, Huya, Songpinggou and drill ground faults, etc. There have been 20 earthquakes recorded of magnitude 5 or above since 1630, including 5 earthquakes of magnitude 6~6.9, and 3 earthquakes of magnitude 7 or above. The two Songping earthquakes in 1976 had a great impact on the survey area. At 14:28 on May 12, 2008, an 8.0-magnitude earthquake occurred on the Zhongyan fault in Longmen Mountain. The Pingtong-Xiangyan-Nanba-Shikan line along the fault line in Pingwu County became a metopeismic area, with an earthquake intensity as high as 11. As of May 12, 2010, the Wenchuan Earthquake had a total of 73,447 aftershocks, including 315 aftershocks above magnitude 4, and 27 aftershocks above magnitude 4 in Pingwu County and its adjacent areas, with the largest magnitude being 6.1. According to the relevant provisions of the national standard GB18306-2001 China Earthquake Parameter Zoning Map on earthquake parameters in Sichuan, Gansu, and some areas of Shaanxi, in the earthquake-resistant design of construction projects in the central areas of towns at the county level and above in the relevant areas after the Wenchuan Earthquake, it's necessary to adjust the seismic fortification intensity, the design basic seismic acceleration value and the assigned design seismic grouping. The peak ground acceleration in Pingwu County was 0.20g, and the characteristic period of the ground motion response spectrum was 0.4s. According to the detailed survey of geological disasters in the past [15], there were 406 hidden danger points of geological disasters in Pingwu County. Among them, landslides were the most developed, with a total of 262, accounting for 64.53%; followed by debris flows, with 66 developments, accounting for 16.26%; 47 collapses, accounting for 11.58%; 31 unstable slopes, accounting for 7.64%. The threat types of geological hazards in Pingwu County were mainly towns, settlements, schools, scattered farmers and roads. There were 381 points of threats to towns, settlements, scattered farmers, and schools, threatening 7,601 people in 1,772 households. There were 25 geological hazards that threaten highways (provincial roads and county roads). Geological disasters in Pingwu County threatened a total of RMB365.88 million yuan of property.

3. Evaluation of Geological Environment Carrying Capacity of Pingwu County

3.1 Basic Principles of Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a systematic analysis method that combines qualitative analysis and quantitative analysis and quantifies the decision-making of complex problems with multiple objectives and criteria. The analysis process group of AHP should have the following 4 steps [16-18]: (1) Establish a hierarchical structure model; (2) Construct a comparison matrix; (3) Calculate the weight value of each influencing factor; (4) Test consistency of single factor and multiple factors. Since the AHP combines the qualitative analysis advantages of the expert scoring method, and uses an appropriate mathematical model for quantitative analysis, it makes up for the shortcomings of qualitative and quantitative analysis, so it is suitable for evaluation fields that have both qualitative and quantitative indicators [18]. When applying the AHP to make a decision, it is necessary to analyze the relationship between the various factors in the system first, to make the problem organized and hierarchical, and to construct a hierarchical structural model [19, 20]. The flow chart of the AHP program design is as Figure 1.

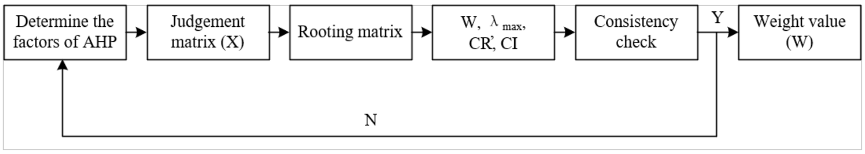

Figure 1. AHP analysis program flow chart

The second and third steps mainly include the following three aspects of method theory:

(1) Constructing the comparison matrix: The establishment of the comparison matrix is the key to the whole AHP, and whether the comparison matrix is scientific or not is directly related to the accuracy of the AHP (Table 1). The establishment of the comparison matrix generally requires the advice of experts and the relevant experience of similar studies to rank the importance of each influencing factor as a whole. In this study, the more commonly used 1-9 degree comparison method is used to measure the importance of different influencing factors (Table 2).

In the comparison matrix in Table 1, A_n in the first column represents different influencing factors in the same level, and A_n in C in the first row represents the influencing factors of the adjacent upper layer. By constructing the comparison matrix, it's possible to compare and rank the importance of different influencing factors. a_{ij} indicates the comparative value of the importance of the two influencing factors, a_{ij} and a_{ji} are reciprocals of each other, and the determination of the comparative value is based on the upper layer C.

Table 1. General form of comparison matrix

C	A_1	A_2	**...**	A_n
A_1	a_{11}	a_{12}	...	a_{1n}
A_2	a_{21}	a_{22}	...	a_{2n}
...	...	...	...	...
A_n	a_{n1}	a_{n2}	...	a_{nn}

Table 2. 1-9 comparison method scale

Value	Meaning
1	Both factors are equally important.
3	The former is slightly more important than the latter.
5	The former is more important than the latter.
7	The former is strongly more important than the latter.
9	The former is extremely more important than the latter.
2, 4, 6, 8	Indicate between odd numbers
Reciprocal	The importance of a and b is c, and the ratio of b to a is 1/c.

(2) Single-level ranking: It refers to the relative importance of a certain influencing factor at a certain level relative to a certain influencing factor at the previous level in the hierarchical structure model. The specific calculation method is to solve the eigenvector *W* and the largest eigenvalue λ_{max} of the comparison matrix A, and normalize the obtained eigenvector *W* to obtain *W'*, which is the weight ranking of the influencing factors in level A to target layer C.

$$M_i = \prod_{j=1}^{n} a_{ij} \tag{1}$$

$$\overline{w_i} = \sqrt[n]{M_i} \tag{2}$$

$$w_i = \overline{w_i} / \sum_{i=1}^{n} \overline{w_i} \tag{3}$$

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} \tag{4}$$

M_i is the multiplication of eigenvector W, $\overline{w_i}$ is the eigenvector W obtained directly, and w_i is the eigenvector W' after normalization processing, and λ_{max} is the largest eigenvalue.

(3) Consistency test of single factor and multiple factors:

The theoretical formula of consistency test of single factor and multiple factors is as follows:

$$CR = CI / RI \tag{5}$$

$$CI = \frac{1}{m-1}(\lambda_{\max} - m) \tag{6}$$

CI is the general consistency indicator of the comparison matrix, RI is the average consistency indicator of the comparison matrix, CR is the random consistency ratio of the comparison matrix, m is the order of the matrix, and λ_{max} is the largest characteristic root. The empirical value of RI can be obtained by looking up the Table 3.

Table 3. RI experience value

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

When the random consistency ratio CR<0.1, the comparison matrix has relatively ideal consistency, and the smaller the value of CR is, the better the consistency of the comparison matrix is.

(4) Total hierarchical order:

Summarize the single-level ranking results to obtain the total level ranking. The consistency check formula for the total level ranking is:

$$CI = \sum_{j=1}^{m} a_j CI_j \quad RI = \sum_{j=1}^{m} a_j RI_j \quad CR = \frac{CI}{RI} \tag{7}$$

When the random consistency ratio CR<0.1, it indicates that the consistency of the total level ranking is better.

3.2 Construction of Evaluation Indicator System Based on AHP

This section takes Pingwu County, Mianyang City, which is located in the Fujiang River Basin, as the research object. According to the post-earthquake geological environment background, ecological environment, disaster point distribution and social development in this area, it constructs a geological environment carrying capacity evaluation system based on a total of 10 evaluation indicator layers in three aspects: geological environment, ecological environment and social environment, and then calculates the content of the geological environment carrying capacity evaluation indicator system at different levels. The structure of Pingwu County's geological environment carrying capacity evaluation indicator system is shown in Figure 2, which mainly includes three subsystems: Geological environment subsystem, ecological environment subsystem and socioeconomic subsystem.

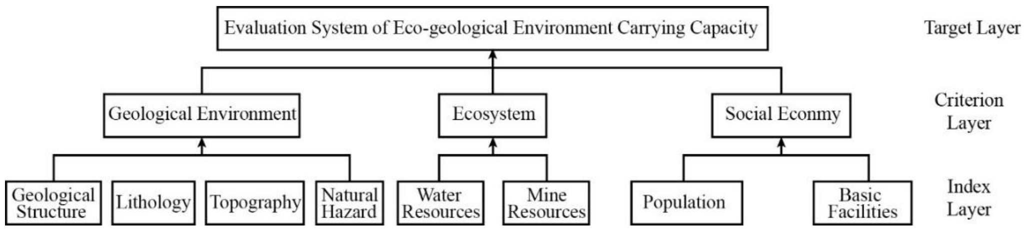

Figure 2. The evaluation indicator system structure of geological environment carrying capacity

The establishment of the evaluation system in Figure 2 is based on the premise that each factor is independent of each other, and the factors related to the carrying capacity of the geological environment are selected as the evaluation indicators. Among them, the ecological environment, as an important factor of environmental geology, is also an important part of the geological environment carrying capacity of Pingwu County. It mainly includes water resources, mining resources and tourism resources. Taking the ecological environment as a criterion in the evaluation system not only inherits the core concept of geological environment carrying capacity [21], but also combines the ecological construction and future development direction of Pingwu County. To specifically and comprehensively measure the regional environmental geological carrying capacity [22], it is not comprehensive enough to only determine the susceptibility of geological disasters and the supply capacity of environmental resources, and the social environment involving population, economic and infrastructure factors is also a key to the quantitate environmental carrying capacity model. The distribution of population density and the distribution of regional economic development are also important factors in the carrying capacity evaluation system.

3.3 Indicator Weight Selection

Pingwu County, Mianyang City is located in the structurally developed area of Longmen Mountain. Geological environmental factors directly restrict the development of this county. Referring to the evaluation criteria of geological hazards in previous studies [4, 23], it determines an important criterion layer—geological environment in the evaluation system of the geological environmental carrying capacity of Pingwu County, establishes the first-level indicator layer related to geological structure, stratum lithology, etc., and refines it to the second-level indicator such as fault zone density and fault distance, forming a complete and systematic indicator system that is easy to quantify in GIS [14].

According to the degree of impact of the evaluation indicators on the environmental geology of the research area, the evaluation indicators are scored by the expert scoring method, and then the scoring is statistically analyzed to obtain the importance scores of each indicator and the weight value of each indicator, as shown in Table 4. Table 4 shows that geological hazards in the geological environment, mines in the ecological environment, and demographic and economic factors in the social environment are the dominant factors in the carrying capacity of the geological environment; followed by geological structure, stratum lithology, and infrastructure factors; the remaining indicators has a little impact on the bearing capacity of the geological environment.

Table 4. Indicator layer weight selection table

Target layer	Quasi-measurement layer	Indicator layer	Weight
Evaluation system of environmental geological carrying capacity in Pingwu County	Geological environment	Geological structure factor	0.1012
		Formation lithology factor	0.1062
		Topographic factors	0.1164
		Geological hazard factor	0.1185
	Ecosystem environment	Water resource factor	0.0515
		Mine resource factor	0.1719
		Tourism geological factors	0.0374
	Social economy	Demographic factor Economic factor	0.1844
		Infrastructure factor	0.1125

3.4 GIS Implementation Method

For the evaluation of the geological environment carrying capacity of Pingwu County, this section mainly uses the spatial analysis method of vector data in ArcGIS, mainly including overlay analysis and buffer analysis.

(1) Overlap analysis. Overlay analysis is one of the methods commonly used in geographic information systems to extract spatial implicit information. Overlay analysis is to superimpose various data layers composed of relevant theme layers to generate a new data layer, and the result synthesizes the attributes of two or more level features, while overlap analysis not only generates new spatial relationships, but also associates attributes from multiple data layers of input to produce new attribute relationships [24, 25]. Among them, the feature layers to be superimposed must be based on the same coordinate system and the same area, and it is also necessary to check whether the datum planes between the superimposed layers are the same. Identify overlays. The input layer and another layer are identified and superimposed. In the area where the graphics overlap, the attributes of the identified layer will be assigned to the map elements of the input layer in this area, and there are also some changes in the graphics; layer merging. Layer merging preserves all map features from the input and overlay maps by combining the area extents of the two layers. The overlay layer is implemented using R language, so the output layer should correspond to the range of the input layer or the overlay layer or the overlay of both.

(2) Buffer analysis. Buffer analysis is an information analysis method that forms a certain buffer polygon entity around a selected group or type of map features (points, lines or polygons) according to the set distance conditions, so as to realize the expansion of data in two-dimensional space [24-26]. In this study, the method of using AicGIS to create a buffer zone is based on the generation of polygons. According to the distance of a given buffer zone, it forms a buffer polygon layer around point, line and area features. It is completely based on vector structure, and from the operation object, the process of using vector operation method to build a buffer to the final buffer, results are all vector data.

3.5 Evaluation Results of the Geological Environment Carrying Capacity of Pingwu County

According to the 10 evaluation indicators in the three criteria of geological environment, ecological environment and social environment, the weight value of each indicator is determined by the expert scoring method and the AHP method (Table 4), and the final geological environment carrying capacity map of Pingwu County is obtained by GIS raster calculation. As shown in Figure 3, the geological environment carrying capacity of Pingwu County involves four types of carrying capacity: high, medium, low, and very low, among which there are two states of balance (critical overload) and surplus (no overload), and no overload state is found. In the figure, the balance state is subdivided into two types: high carrying capacity and medium carrying capacity, and the surplus state is subdivided into two types: low carrying capacity and very low carrying capacity.

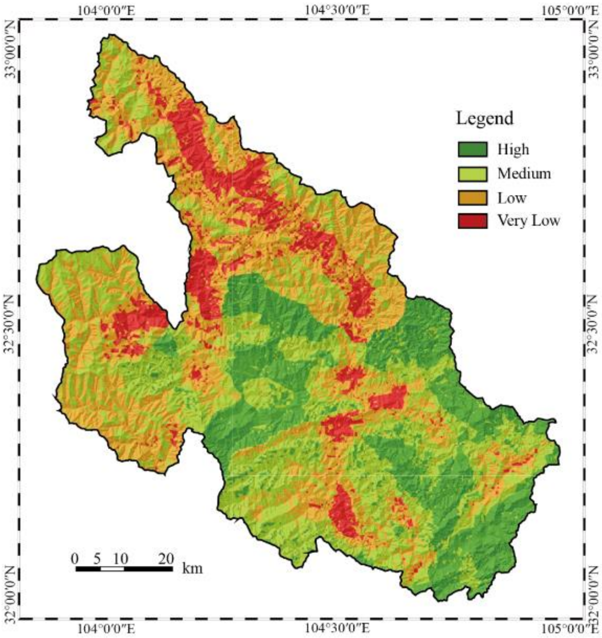

Figure 3. Geological environment carrying capacity map of Pingwu County

4. Discussions

The middle and lower reaches of the Yangtze River Economic Belt are economically developed, the geological survey results and integration are relatively perfect, and there have been some preliminary results for its resource and environmental conditions and major geological problems in land planning and construction [27], while the upper reaches of the Yangtze River have a complex environmental geological structure, the unique geological structure of the coastal area and geological disasters such as earthquakes, debris flows, landslides and other geological disasters have a greater impact on urban development, and factors such as geological environment, ecological environment and social environment also play a strong control and guiding role in the development of key cities and towns and regional planning.

The geological environment in Southwest China, which is located in the upper reaches of the Yangtze River, is very complex, with concentrated rainfall and frequent earthquakes. It is a high-risk area for geological disasters in China. Since the construction of cities and towns in mountainous areas is mostly concentrated on the slope foot, the banks of rivers and loose accumulations, they are seriously affected by geological disasters. In addition, the pace of urban construction is accelerating, and deep excavation and high filling in human activities have become a major direction and means for human beings to expand their living space. Geological disasters caused by human activities emerge in an endless stream. Combined with the regional evaluation results of geological carrying capacity, planning suggestions for different regions are given for carrying capacity zoning, which is an important guidance for future regional planning in this study. Therefore, according to the results of this study, the advantages and disadvantages of different regions are analyzed in detail, and targeted planning suggestions are given, as shown in Table 5.

As a whole, although the regions with poor bearing capacity of geological environment have relatively small area, this part of the regions carries most of the industrial foundation, urbanization infrastructure and other engineering activities in Pingwu County after the earthquake, the diversity of land use types is significantly low, the shallow soil is easily disturbed and polluted, the population density is high, and the natural ecological environment is relatively fragile. This area is mainly located in the edge of the nature reserve, close to the three townships of Baima Township, Muzuo Township and Huya Township, which will be affected more and more strongly in future social and economic activities, and it is necessary to strictly control the way and intensity of land resources development, strengthen monitoring and prevention, and avoid the impact being transmitted to other carrying capacity levels.

Table 5. Summary table of geological carrying capacity evaluation of Pingwu County

Evaluation results and the area	Main advantage	Main disadvantage	Planning advice
Medium (22.64%): Located along the Fujiang River, Pingtong River, and both banks	Some are a cluster of towns, with convenient transportation and rich water and soil resources, which are necessary conditions to support the tourism industry.	Most of them are located in Zhongshan landform structures, and geological hazards are relatively developed. Towns and roads are more threatened by disasters, and strongly affected by human activities; the developable area of towns is limited.	1. The main towns in Pingwu County combine strong engineering measures and strong ecological control measures in the road area, and the ecological slope control measures are effective. 2. Optimized design of key towns: Give full play to the environmental characteristics of the towns, adapt measures to local conditions, divide the geological environment of the towns into zoning, and restrict improper development of the towns.
High (33.48%): The slopes on both sides of the valley and the buffer zone from human activities to the nature reserve, and some low mountain and hilly landform areas	The reserves of mineral resources are large, the disturbance of human engineering activities is less, the transportation is more convenient, and there are many tourism industries that can be developed in the area.	The situation of ecological restoration in mines is severe, the treatment of clustered areas affected by local small-scale geological disasters, the development and prevention of potential geological disasters	1. Scientifically and rationally mine stock mines, carry out mine environment restoration and management projects for abandoned mines and mines under development, including mine disaster management, mine reclamation and other measures. 2. Carry out ecological geological governance for small geological disaster spots and potential geological disaster areas, and build a green and ecological Pingwu.
Low (32.64%): The transition zone of the nature reserve and the transition zone of Baima and Tucheng	The risk of geological disasters is low, and the population density is low. Among them, there are a large number of tourism development areas and expansion space for existing tourist areas in the transition zone of the protected area.	The undeveloped degree is relatively large, and a large amount of manpower and material resources are needed for transformation.	The development of tourism areas in the transition zone of nature reserves and the reconstruction and expansion of existing tourist areas have formed a unique eco-tourism area in Pingwu County, and created a number of national 5A-level tourist attractions and Qiang characteristic farmhouses.
Very low (11.24%): Baima Township, Muzuo Township, and Huya Township concentrated areas and nature reserves.	Geological disasters are not developed, infrastructure construction has been basically completed, and the population and economy are relatively developed.	The nature reserve belongs to the non-development area, and the development area in the central area of the county has certain limitations.	Optimize the construction of central areas, control the scale of regional construction, and maintain the original nature of ecological species in nature reserves without development and transformation.

5. Conclusion

In view of the fact that cities and towns in the southwestern mountainous area are severely threatened by earthquakes and geological disasters, and that urban construction is deeply restricted by geological environmental conditions and the susceptibility of geological disasters, this study selects a key town which is typical and representative in the Fujiang River Basin-Pingwu as a demonstration area, and has initially obtained the following conclusions through the evaluation of the geological environment carrying capacity:

(1) Based on the three criterion layers of geological environment, ecological environment and social environment, the evaluation system of geological environment carrying capacity divides 10 indicator layers including geological structure to establish the evaluation system of Pingwu County, quantifies each evaluation indicator, and establishes a systematic model suitable for the evaluation of the geological environment carrying capacity of key cities and towns in southwest mountainous areas.

(2) It uses the AHP and GIS spatial processing technology to provide technical support for the evaluation of the geological environment carrying capacity, combined with the expert scoring method to determine the respective weight values of the evaluation factors. The verification results show that the effect of this method is better, but due to the strong geological structure, this evaluation system is only applicable to similar areas in southwest mountainous towns.

(3) In view of the characteristics that the cities and towns in the southwest mountainous area are severely threatened by geological disasters, and the urban construction is deeply restricted by geological environmental conditions and susceptibility to geological disasters, Pingwu County, a typical and representative town in the Fujiang River Basin, is selected as the demonstration area. Through the evaluation and research on the geological environment carrying capacity of mountainous towns, it establishes a set of evaluation theory and technical method system for geological environment carrying capacity in the upper reaches of the Yangtze River, so as to provide scientific and effective guarantee for the construction and planning of cities and towns in southwest mountainous areas.

Funding

This work is Funded by the China Geological Survey Project (Grant No.: DD20190643); National Natural Science Foundation of China (Grant No.: 41804089).

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] X. W. Xu, X. Z. Wen, G. H. Yu, G. H. Chen, Y. Klinger, J. Hubbard, and J. Shaw, "Coseismic reverse- and oblique-slip surface faulting generated by the 2008 Mw 7.9 Wenchuan earthquake, China," *Geology*, vol. 37, no. 6, pp. 515-518, 2009. https://doi.org/10.1130/G25462A.1.

[2] Y. P. Yin, F. W. Wang, and P. Sun, "Landslide hazards triggered by the 2008 Wenchuan earthquake, Sichuan, China," *Landslides*, vol. 6, no. 2, pp. 139-152, 2009. https://doi.org/10.1007/s10346-009-0148-5.

[3] C. Xu, F. C. Dai, and J. Z. Xiao, "Statistical analysis of landslide characteristics induced by the May 12 Wenchuan earthquake," *J. Nat Disast.*, vol. 20, no. 4, pp. 147-153, 2011.

[4] F. Lai, Q. Shao, Y. Lin, X. Yi, X. F. Sun, H. Y. Shao, X. Wian, and P. H. Peng, "A method for the hazard assessment of regional geological disasters: A case study of the Panxi area, China," *Spat Sci.*, vol. 66, no. 1, pp. 143-162, 2019. https://doi.org/10.1080/14498596.2019.1606741.

[5] X. L. Gao, T. Chen, and J. Fan, "Analysis of population capacity in post-earthquake reconstruction areas in Wenchuan," *J. Geogr. Sci.*, vol. 21, pp. 521-538, 2011. https://doi.org/10.1007/s11442-011-0861-6.

[6] Z. D. Peng and K. Yang, "Exploration of research methods for regional environmental carrying capacity," *China Environ Sci.*, vol. 16, no. 1, pp. 6-10, 1996.

[7] C. M. Ma and Y. H. Ma, "Tentative investigation of bearing capacity of geological environment for sustainable development," *Environ Sci. Technol.*, vol. 30, no. 8, pp. 64-65, 2007. https://doi.org/10.3969/j.issn.1003-6504.2007.08.023.

[8] A. Cendrero, "Environmental geology of the santander bay area, northern Spain," *Geo.*, vol. 1, no. 2, pp. 97-114, 1975. https://doi.org/10.1007/BF02415536.

[9] D. H. Meadows, D. Meadows, J. Randers, W. William and Behrens, "Limits to growth," In *Wastewater Treatment with Algae*, Heidelberg, Springer Berlin, 1972.

[10] Z. H. Yao, H. Q. Wang, and X. G. Hao, "Evaluation of geological environment carrying capacity based on set pair analysis: A case study in Daqing," *Environ Sci. Technol.*, vol. 33, no. 10, pp. 183-189, 2010. http://dx.chinadoi.cn/10.3969/j.issn.1003-6504.2010.10.042.

[11] Y. Kawabe, J. Hara, Y. Sakamoto, and T. Komai, "Risk evaluation of toxic chemicals in the geo-environment

by site-specific risk assessment model," *AIP Conf Proc*, vol. 898, no. 1, pp. 227-230, 2007. https://doi.org/10.1063/1.2721286.
[12] S. Shu, "Research on comprehensive evaluation index system of geological environment safety," Doctoral Dissertation, Chengdu Technology University, China, 2016.
[13] K. F. Wang and N. Li, "Assessment of geological environmental carrying capacity in the Shandong Peninsula based on AHP and GIS coupling model," *China Popul. Resour. Environ.*, vol. 2015, no. 1, pp. 224-227, 2015.
[14] Y. X. Li, "County-level geological environmental carrying capacity evaluation based on nuclear K-Means and GIS," Doctoral Dissertation, Chengdu Technology University, China, 2016.
[15] X. W. Qin, Z. Zhang, J. J. Yang, and T. Huang, "Analysis on the secondary geological disaster in Pingwu of 5.12 Wenchuan Earthquake, Sichuan based on remote sensing information," *Geol. Sci. Technol. Inf.*, vol. 28, no. 2, pp. 12-15, 2009. https://doi.org/10.3969/j.issn.1000-7849.2009.02.003.
[16] J. Liu, J. Alexander, Q. Gu, and Y. Li, "Gaussian process regression-based load-carrying capacity models of corroded prestressed concrete bridge girders for fast-screening and reliability-based evaluation," *Eng. Struct.*, vol. 285, Article ID: 116040, 2023. https://doi.org/10.1016/j.engstruct.2023.116040.
[17] J. M. Hummel, J. F. P. Bridges, and M. J. Ijzerman, "Group decision making with the analytic hierarchy process in benefit-risk assessment: A tutorial," *Patient*, vol. 7, no. 2, pp. 129-140, 2014. https://doi.org/10.1007/s40271-014-0050-7.
[18] W. Jin, P. Cui, G. Zhang, J. Wang, Y. Zhang, and P. Zhang, "Evaluating the post-earthquake landslides sediment supply capacity for debris flows," *Catena*, vol. 220, Article ID: 106649, 2023. https://doi.org/10.1016/j.catena.2022.106649.
[19] Z. M. Li, Z. X. Fan, and S. G. Shen, "Urban green space suitability evaluation based on the AHP-CV combined weight method: A case study of Fuping County, China," *Sustainability*, vol. 10, no. 8, pp. 2638-2656, 2018. https://doi.org/10.3390/su10082656.
[20] A. González Ramiro, G. Gonçalves, A. Sánchez-Ríos, and J. S. Jeong, "Using a VGI and GIS-based multicriteria approach for assessing the potential of rural tourism in Extremadura (Spain)," *Sustainability*, vol. 8, no. 11, pp. 1144-1160, 2016. https://doi.org/10.3390/su8111144.
[21] J. N. Wang, L. Yu, J. Wan, and Y. Xu, "Assessment on water environmental carrying capacity in the Yangtze River Delta," *China Environ Sci.*, vol. 33, no. 6, pp. 1147-1151, 2013.
[22] R. Z. Liu, C. W. Wang, J. M. Hao, B. L. Su, and Y. L. Ma, "Measuring environmental carrying capacity," *J. Appl Basic Eng Sci.*, vol. 17, no. 1, pp. 49-61, 2009. https://doi.org/10.3969/j.issn.1005-0930.2009.01.006.
[23] Z. Wang and F. C. Yi, "AHP-based evaluation of occurrance easiness of geological disasters in Mianyang City," *J. Nat Disast.*, vol. 34, no. 1, pp. 14-23, 2009. https://doi.org/10.3969/j.issn.1004-4574.2009.01.003.
[24] Z. Q. Xi and X. Y. Zhai, "Investigation and evaluation analysis of geological hazards based on RS and GIS," *China Resour. Comp Util.*, vol. 31, no. 4, pp. 4, 2013. https://doi.org/10.3969/j.issn.1008-9500.2013.04.017.
[25] J. Malczewski, "GIS-based land-use suitability analysis: A critical overview," *Prog. Plann.*, vol. 62, no. 1, pp. 3-65, 2004. https://doi.org/10.1016/j.progress.2003.09.002.
[26] L. A. Bojórquez-Tapia, S. Diaz-Mondragón, and E. Ezcurra. "GIS-based approach for participatory decision making and land suitability assessment," *Int J. Geogr Inf. Sci.*, vol. 15, no. 2, pp. 129-151, 2001. https://doi.org/10.1080/13658810010005534.
[27] Y. H. Jiang, L. J. Lin, L. D. Chen, H. Y. Ni, W. Y. Ge, H. X. Cheng, G. Y. Zhai, G. L. Wang, Y. Z. Ban, Y. Li, M. T. Lei, C. X. Tan, J. W. Su, Q. P. Zhou, T. L. Zhang, Y. Li, H. Y. Liu, K. Peng, and H. M. Wang, "Resource and environmental conditions and major geological problems in the Yangtze River Economic Belt," *Geol. China*, vol. 44, no. 6, pp. 1045-1061, 2017. https://doi.org/10.12029/gc20170601.