Risk Analysis of Geological Disasters in Southwest China

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Abstract: In this study, four provinces (cities) in southwest China were taken as the study area, and eight risk evaluation indexes were selected to construct the evaluation index grading system, including elevation, slope, relative elevation, soil erosion, annual precipitation, NDVI, land use and population. The analytic hierarchy process was used to obtain the weight coefficients of each evaluation index, a geological hazard risk assessment model for the study area was established, and spatial calculation and visual expression were performed by ArcGIS. The results show that the area of moderate-risk is the largest, accounting for 37.46% of the total area; followed by the low-risk area, which accounts for 23.89%; the proportions of high-risk areas and extremely high-risk areas are 23.59% and 15.07%. According to the risk analysis results, the geological disasters area with high risk include southwest Yunnan, central Sichuan, southwest Guizhou and northeast Chongqing.

1. Introduction
China has many types of natural disasters which were widely distributed and leading personal and property losses. The mountainous areas of southwest China are widely distributed, with complex geological conditions and severe tectonic movements. They are areas with high incidence of natural disasters such as earthquakes, snow disasters, droughts, and landslides, which seriously threaten people's lives and property. In the sub-region of the southern plateau of China, the main geological disaster combination is characterized by collapse, landslide, debris flow, ground collapse and soil erosion, followed by rock burst and water inrush. Human activities, geological environment and climate are important factors that affect the development of geological disasters. Geological disasters such as landslides, collapses, mudslides, etc. seriously threaten human life and property. Once a natural disaster occurs in a harsh environment, the special characteristics of the environment will greatly hinder emergency rescue. Therefore, the risk analysis of geological disasters plays an important guiding role and application value in the regional disaster prevention and reduction and emergency resource allocation.

In recent years, the use of GIS technology for regional geological disaster risk analysis has attracted the attention of experts. GIS technology combined with model analysis for geological disaster risk assessment can be used to classify regional geological disaster disasters and provide a reference for disaster prevention and mitigation and emergency resource preparation. In addition to traditional cause analysis and impact factor analysis, there are also vulnerability assessment, risk assessment, and detailed assessment of geological disaster risks.

This study takes four provinces (cities) of southwest China as the study area. The Yunnan-Guizhou Plateau, Sichuan-Tibet Plateau, Sichuan Basin, and surrounding mountains are distributed in the study area. The Yunnan-Guizhou Plateau can be further divided into the Yunnan Plateau and the Guizhou
Plateau, with an average altitude of 2000 m and 1000 m, the Sichuan Basin is about 500 m above sea level. The emergency resources in the alpine region of the study area are limited, and transportation is underdeveloped. Once an emergency occurs, a series of survival support issues such as difficulties in local support, medical care will pose a huge obstacle to emergency response. It may cause huge casualties and property losses. Geological disaster risk analysis is a sign of the degree of geological disaster activity, which helps to understand the development stage of disaster activities and predict the future level of disaster activities\textsuperscript{[11]}. Geological disaster risk analysis provides an important basis for regional disaster reduction projects and emergency resource allocation.

2. Methodology and data
Geological disaster risk analysis is based on the evaluation of the typical geological disaster types and their spatial distribution characteristics in the region, and considers the combined effects of multiple factors. In this paper, an integrated evaluation method was employed to associate the multiple indexes.

2.1 Determination and classification of evaluation factors
The first step of geological hazard risk analysis is to build an evaluation system and select evaluation indexes. In existing studies, The indicators used at high frequencies mainly include elevation, slope, lithology, topographic relief, distance from the fault zone, average precipitation, land use\textsuperscript{[12]}. This study selects evaluation factors based on the development of geological disasters in the study area, and divides them into two parts: impact factors and vulnerability factors. There are 6 selected impact factors, including elevation, slope, relative elevation, soil erosion, average precipitation and NDVI; there are 2 selected vulnerability factors, including land use and population. These factors together constitute a regional risk assessment index system (Figure 1).

![Evaluation index system of geological disasters](image)

At this stage, there is no standard suitable for all regions in terms of the danger classification. Qualitative aspects: The more intense the geological hazards are, the more dangerous they are and the more serious the losses are. In practical applications, while classifying the danger degree of geological disasters, it should be divided according to the specific conditions of the study area. According to the pregnant environment of the southwestern region, the evaluation indicators are divided into low-risk, moderate-risk, high-risk and extremely high-risk in combination with expert opinions. Each index is quantified using an assignment method. The value of 1 indicates the lowest risk and the value of 4 indicates the highest risk. The grouping of each impact factor is shown in Table 1\textsuperscript{1}. The corresponding hierarchical spatial distribution is shown in Figure 1.

| Evaluation factors | Low-risk | Moderate-risk | High-risk | Extremely high-risk |
|--------------------|----------|---------------|-----------|---------------------|
| Elevation (m)      | 0-1219   | 1219-2333     | 2333-3578 | 3578-6304           |
| Slope (degree)     | 0-10     | 10-15         | 15-35     | 35-46               |

\textsuperscript{1} Data source: Institute of Geographical Sciences and Resources, Chinese Academy of Sciences (http://www.resdc.cn)
| The relative elevation (m) | 0-230 | 230-460 | 460-770 | 770-2114 |
|---------------------------|-------|---------|---------|---------|
| Soil erosion              | Micro-level erosion | Mild erosion | Moderate erosion | Strong erosion |
| Precipitation (mm)        | 0-4000 | 4000-9000 | 11200-13700 | 13700-20399 |
| NDVI                      | 0-0.45 | 0.45-0.68 | 0.68-0.81 | 0.81-0.92 |
| Land use                  | Water area | Forest and Grassland | Agricultural land | Construction land |
| Population                | 0-260 | 260-6000 | 6000-25000 | 25000-67009 |

**Reclassify assignment**

|   | 1 | 2 | 3 | 4 |
|---|---|---|---|---|

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**a. Precipitation**

**b. Soil erosion**

**c. Slope**

**d. The relative elevation**

**e. Elevation**

**f. NDVI**
2.2 Evaluation model and weight coefficient

Analytic Hierarchy Process (AHP) is a method of multi-objective evaluation and decision making. It can provide a comprehensive solution for constructing problems, representing, correlating, and quantifying elements\(^{[13]}\). The evaluation factors were classified into impact factors and vulnerability factors and defined as the criterion layer. The impact factors include elevation, slope, relative elevation, soil erosion, NDVI, and annual precipitation. Vulnerability factors include population size and land use, which are defined as the sub-criteria layer. The criteria layer and the sub-criteria layer are respectively compared to evaluate factors, and the relative importance of impact factors is analyzed on the basis of expert opinions. The results of the judgment matrix show that the CR value of each evaluation factor type is less than 0.1 after the consistency test, indicating that each judgment matrix has satisfactory consistency and has passed the consistency test. The judgment matrix is shown in Table 2-4, and the weight coefficient of geological disaster evaluation index is shown in Table 5.

| Evaluation factors | Impact factors | Vulnerability factors | weight coefficient |
|--------------------|----------------|----------------------|-------------------|
| Impact factors     | 1              | ——                  | 0.875             |
| Vulnerability factors | 1/7          | 1                    | 0.125             |

| Impact factors | Elevation | Slope | The relative elevation | Soil erosion | NDVI | Precipitation | Weighting coefficients |
|----------------|-----------|-------|------------------------|-------------|------|---------------|------------------------|
| Elevation      | 1         | —     | —                      | —           | —    | —             | 0.053                  |
| Slope          | 3         | 1     | —                      | —           | —    | —             | 0.144                  |
| The relative elevation | 3     | 3     | 1                      | —           | —    | —             | 0.284                  |
| Soil erosion   | 3         | 1     | 1/2                    | 1           | —    | —             | 0.111                  |
| NDVI           | 5         | 1/2   | 1/3                    | 3           | 1    | 1             | 0.179                  |
| Precipitation  | 3         | 3     | 1                      | 2           | 1    | 1             | 0.230                  |

| Vulnerability factors | Population | Land use | Weighting coefficients |
|-----------------------|------------|----------|------------------------|
| Population            | 1          | —        | 0.667                  |
| Land use               | 1/2        | 1        | 0.333                  |
The risk of geological disasters is expressed by the risk index. The geological disaster risk evaluation index can comprehensively and quantitatively express the danger degree of regional geological disasters by integrating multiple factors[14]. The higher the risk index, the greater the risk.

According to the weight coefficient calculated by the analytic hierarchy process, a geological disaster risk assessment index is constructed[11], as the following formula:

\[ F = \sum_{j=1}^{m} R(j) \cdot X(i, j) \]  

In the formula: \( F \) is the geological disaster risk index; \( m \) is the total number of participating indicators; \( R(j) \) is the weight value of each evaluation index; \( X(i, j) \) is the assigned data obtained by grading the original data of each evaluation index according to the evaluation index. Substituting the weight of the geological disaster risk assessment index into the formula:

\[ F = 0.046 \cdot X_{11} + 0.126 \cdot X_{12} + 0.249 \cdot X_{13} + 0.097 \cdot X_{14} + 0.201 \cdot X_{15} + 0.157 \cdot X_{16} + 0.041 \cdot X_{21} + 0.083 \cdot X_{22} \]

In the formula, \( X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}, X_{21}, \) and \( X_{22} \) represent the evaluation index factor elevation, slope, the relative elevation, soil erosion, annual precipitation, NDVI, land use, and population.

3. Results

According to the weight coefficient of each factor(table2) and formula (1), the risk assessment index of geological disasters in the study area was calculated, and the risk assessment index of geological disasters in the study area was divided into four zones: low-risk, moderate-risk, high-risk and extremely high-risk. The geological disaster zoning was obtained (Figure 3). The area of the four disaster assessment zones was statistically analyzed. The results showed that the low-risk and moderate-risk zones accounted for 23.89% and 37.46% of the study area, mainly distributed in the northeast of Yunnan province, the east and west of Sichuan province, the southwest of Chongqing city and the northwest of Guizhou province. High-risk and extremely high-risk zoning area accounts for about 23.59% and 15.07%, in the study area are mainly distributed in the north-central part of the research region, the northeast and southwest, mostly located in the central Sichuan province and west, south of Sunnan province. The high-risk and extremely high-risk area of low vegetation coverage, rainfall, topography and relative elevation is big, serious soil erosion, the area for tops the list of key areas to prevent geological disasters.
4. Conclusion
This study took four provinces (cities) in southwest China as study area, and selected eight risk assessment indicators, including elevation, slope, relative elevation, soil erosion, annual precipitation, NDVI, land use, and population. In this study, an evaluation index grading system was constructed, and the weight coefficient of the evaluation index was obtained through the analytic hierarchy process, and a risk assessment model for geological disasters in the study area was established. The calculation shows that the area of medium-risk areas in the study area is the largest, accounting for 37.46% of the total area; followed by the area of low-risk areas, accounting for 23.89% of the area of the study area; the proportions of high-risk areas and extremely high-risk areas are 23.59% and 15.07%. According to the geological disaster risk assessment index, the study areas in southwest Yunnan, central Sichuan, southwest Guizhou, and northeast Chongqing all have high geological disaster risks. It is recommended to establish an effective prevention and protection mechanism based on the dangerous zoning of geological disasters to avoid large-scale engineering construction from seriously affecting the fragile environment. At the same time, pay attention to emergency materials allocation in residential areas around high-risk areas and extremely high-risk areas. It is of great significance to reduce the loss of people and property caused by geological disasters and maintain the stability of the regional geological environment.

This paper provides a reference for the study of regional geological disasters by evaluating geological disasters in the study area. Due to the complexity of geological disaster risk assessment and the obvious regional characteristics, there are also shortcomings in this study. For example, if there are multiple geological disasters in the study area, a unified assessment method will have an impact on the accuracy of the assessment. In future research, attention should be paid to the application of models and the selection of factors and determination of weights in order to improve the accuracy of evaluation.

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