Risk assessment of geological hazards in mountain town scale based on FLO-2D and GIS

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Abstract: Zhouqu County located in the Bailong River Basin of the Longnan Mountain, which is a high geological-hazard-prone area. This paper constructed the index system and evaluation model of geological hazard evaluation at the scale of town in mountainous area by taking Zhouqu County as an example, which carrying out work of geological hazard zoning, vulnerability assessment and risk assessment used by infinite slope model, Flo-2D and ArcGIS software on the basis of analysing geological conditions. The results show that: (1) Together with considering the slope stability and the threat of debris flow utilize the methods of infinite slope model and Flo-2D software and establishing prediction expression of the maximum sliding distance of landslide by using the detailed sample data of 46 locations in the river basin, which effectively improves the accuracy of hazard assessment. (2) The model of vulnerability evaluation eliminates the evaluation indexes with high repeatability, and selects the main property-type disaster bearing bodies for analysis, evaluation and economic accounting, which greatly improves the evaluation efficiency. (3) The risk assessment results can provide reliable technical support for the territorial spatial planning and disaster prevention and reduction of Zhouqu County as well as provide reference for the risk assessment of geological disasters in other towns in Longnan Mountain Area. (4) In addition to rainfall induced by urban geological disasters in mountainous areas of Bailong River Basin, the impact of earthquakes and human engineering activities cannot be ignored. To achieve the goal of high efficiency, rapid and accurate of the model of urban geological hazard risk assessment, it is necessary to conducts in-depth research on dynamic risk assessment technology and methods.

Key words: Bailong River basin; Zhouqu County; hazard evaluation; vulnerability assessment; risk assessment
1. Introduction

China is one of the world's most serious geological disasters and most threatened population due to its mountainous and hilly areas account for about 65% of the land area and its geological conditions are complex, tectonic activities are frequent, the hazards include collapse, landslides, debris flows and others are widely distributed, the prevention is difficult. Especially, the western mountainous area of Longnan is a high prone area and key prevention and control area of geological disasters due to the special geological environment and topography conditions. Restricted by mountainous and hilly terrain conditions, towns of mountain area are mostly located in relatively gentle valley areas. Because of some condition of extreme rainfall, earthquake and human engineering activities intensified and frequent geological disasters, which is a major threat to mountainous towns and residents.

Geological disaster risk evaluation is an effective means of disaster reduction and prevention, and it’s an important part of disaster prevention and mitigation strategy system. Many countries have achieved good application results in geological disaster risk assessment and management. Since the 1990s, Japan, the United States, Western European countries and Hong Kong of China have successively carried out research on geological disaster risk assessment at different scales, and put forward a more detailed technical method system for geological disaster risk assessment [1-3]. In recent years, with the needs of social sustainable development, the international community has paid more attention to some aspects that how to identify geological disasters and their vulnerability and risk characteristics, strengthen the risk decision-making of the chain process of geological disasters, and reduce disaster risks and losses through scientific knowledge. Therefore, ICSU and ISSC jointly launched a comprehensive research plan on disaster risk, In EU countries carried out ‘Safeland’ projects which is quantitative risk assessment and management projects at different scales, The United States has released a strategic plan for natural disasters and developed a more reliable landslide risk assessment model using high-tech technologies [4]. Domestic scholars have carried out pilot projects of geological hazard risk assessment in western mountainous cities and towns such as Danba County in Sichuan Province, Badong County in Hubei Province, Baota District and Baoji Area in Yaran City, Shansi Province. A detailed risk assessment method system and risk management system is formed, which effectively supported the risk assessment of geological hazards in domestic cities and towns [5-9].

With the acceleration of urbanization, the construction of urbanization in mountainous areas puts forward higher requirements for the risk assessment of geological disasters, especially in the planning and construction of land space and the protection of ecological environment in mountainous towns. It is urgent to investigate large-scale geological disasters and quantitative risk assessment of multiple disasters, so as to provide technical support for land use planning and geological disaster prevention.

This paper carried out the risk assessment of geological disasters in urban scale and established a set of risk assessment methods suitable for the urban geological disasters under complex geological conditions by taking Zhouqu County as an example, which used by infinite slope model, Flo-2D software, ArcGIS software and high-precision remote sensing images on the basis of research on the technical methods of geological disaster risk assessment in China and abroad.

2. Regional setting

Zhouqu County, Gannan Tibetan Autonomous Prefecture, Gansu Province is a typically landslide and debris flow disaster prone area in the Bailong River Basin. The area is located between the northeastern Tibet Plateau and the mid-high mountain area on the West Side of Qinling Mountains. Limited by terrain conditions, almost all the villages and towns are located in either the fan-shaped land of debris flow gullies vent in deep-canyon or the plateau of the debris flow deposit or the large-scale ancient landslide accumulation. Zhouqu county is located in the junction zone between Bailong River and three gullies. More than 10 natural villages in this county are situated at ancient debris flow fan of the Sanyanyu and Luojiayu gullies. The flood discharge tunnel is heavily occupied by the urban areas due to excessive tension of land resources. The high-magnitude debris-flow disaster on 8 August 2010, in Zhouqu County, which resulted in the destruction of the whole town. In Zhouqu county’s 27.4 km², the Bailong River from west to east with a river long of 4.5km, 34 medium-large size of deep landslides were developed such as Zuigada, Suoertou, Nanqiao, Longjiang Xincun and Loess Slope. There are 8 catastrophic debris flow such as Zhaijiu Village Valley, Sanyan valley, Luojiu Valley and Helen Village Valley. The density of geological disasters is 1.53/km². It is representative and typical to research choose Zhouqu county as an important town geological hazard risk evaluation in Bailong River area.

The topography of the study area is characterized by middle-high mountain canyon, strong gully cutting and broken terrain, the elevation ranges between 1310 and 2680 m above sea level, the relative height difference of Sanyanyu valley is 2488 m, Slope gradient between 20 – 50°, mainly gravity erosion accumulation landform. The geology of the study area is mainly composed of Middle Devonian Gudaoling Formation phyllite, carbonaceous slate and Carboniferous thick limestone. On the north side of Sanyanyu and Luojiu valley vent developed
3. Urban Risk Assessment System of Geological Hazards

3.1. Risk assessment of urban geological disasters

The types of geological disasters in the study area are mainly landslide and debris flow disasters, so the risk of slope and debris flow in urban areas is mainly evaluated.

3.1.1. Risk assessment of urban slopes

In consideration of the response of rainwater erosion slope surface, erosion slope body and geotechnical physical properties to the slope under different rainfall frequencies, quantitative calculation and analysis were carried out to realize the risk assessment of urban geological hazards. Quantitative calculation and analysis are carried out to realize the risk assessment of urban geological hazards. The optimized infinite slope model and ArcGIS spatial analysis function provide an effective method for the slope hazard assessment. Most of the landslides in the study area are accumulation landslides, which are overlaid with loess or residual rock, and the layered structure of underlying strongly weathered bedrock. This can satisfy the hypothesis of infinite slope model. It is easy to obtain the physical and mechanical parameters of rock and soil, which can meet the needs of model calculation.

The study area is divided into several 10m × 10m grid cells in ArcGIS software and the stability of each grid cell is calculated based on optimized calculation method of infinite slope model. According to formula (1), the calculation steps are as follows: ①According to the types of rock and soil, the slopes in the study area are divided into 6 types and 34 types of landslides and collapses are recorded. The effective cohesion (c′), effective internal friction angle (ϕ′) and rock and soil weight (γ) of each slope unit in the study area are determined by analyzing the existing data and field rock and soil sampling test (Table 1 and figure 1). ②The previous research shows that the slope with terrain slope less than 5 ° seldom occurs geological disaster. According to the requirements of infinite slope model, slope classification map with slope gradient greater than 5 ° is generated by DEM data with 5m accuracy in slope stability calculation. ③Engineering geological analogy method is adapted to determine the value of potential sliding mass thickness based on the analysis of landslide disaster data in Bailongjiang River Basin and the comparison of typical slope exploration data in the study area. ④Considering the influence of extreme
weather in the study area, the results of rock and soil sampling and permeability coefficient test of 21 exploration points in Bailong Basin and 39 sampling points in Zhouqu town area are taken as 0 (no rainfall), 0.3 (5%), 0.6 (2%), 1 (1%) by simplifying the saturation condition of slope soil under different rainfall frequency.

\[ F_s = \frac{c'}{\gamma} + \frac{\tan \phi'}{\tan \gamma} - \frac{\gamma_w \tan \phi'}{\gamma_\text{saturated}} \tag{1} \]

where \( c' \) is Effective cohesion (KPa), \( \phi' \) is Effective internal friction angle (°), \( \gamma \) is the soil mass (t/m³), \( \gamma_\text{saturated} \) is the thickness of potential sliding body, \( \phi_s \) is slope inclination angle (°), \( \gamma_w \) is saturation state in potential slide body (dimensionless), \( \gamma_\text{saturation} \) is the weight of water (t/m³) respectively. To determine the \( F_s \) value of each slope grid unit, the infinite slope analysis model is used by giving the calculation parameters to the evaluation grid unit in the study area. The grid overlay analysis is carried out in the ArcGIS Spatial Analyst environment. The results are slope stability value, expressed as \( F_s \), which more higher means higher stability and lower risk. \( F_s \) is less than 1.0, which indicates that the slope is unstable and highly dangerous, \( F_s \) greater than 1.0 indicates that the slope tends to be stable.

The field investigation found that in the study area, the thickness of the loose accumulation layer is large, the structure is loose, and the soil erosion is serious. The slope stability evaluation should also consider the soil erosion capacity. Previous studies considered that the degree of soil erosion is the result of human activities, slope damage and rock weathering erosion, which can be expressed by the degree of soil erosion (\( F_e \)).

This paper analyzes the erodibility of soil under different rainfall erosivity to quantitatively reflect the spatial distribution characteristics of slope risk in the study area, the parameter are as follows: different land use types \( (k_1) \), the erodibility of different rock and soil mass \( (k_2) \), length and degree of slope \( (L, S) \) and crop cover and management and soil and water conservation factors \( (C, P) \). The value of each factor can be obtained by referring to the previous research results \([12,13]\) and combining with the actual situation of the study area, then the weight \( (w_i) \) is assigned according to the contribution rate of each factor \( w_i = 0.418; w_{ee} = 0.271; w_{es} = 0.172; w_{cp} = 0.139 \), finally the grid map of soil erosion degree of slope in the study area was mapped by formula (2).

\[ F_e = \sum_{i=1}^{n} C_i W_i \tag{2} \]

where \( F_e \) is coefficient of soil erosion degree, \( W_i \) is weight of evaluation factor and \( C_i \) is graded assignment grid layer of evaluation factor.

| Table 1. Shear strengths assigned to geological formations in the study area |
|-----------------|--------|-------|--------|--------|
| Number | \( t \)(m) | \( \gamma \)(t/m³) | \( c' \)(KPa) | \( \phi' \)(°) |
| YT01 | 3.50 | 21.0 | 15.0 | 26.0 |
| YT02 | 3.00 | 17.5 | 30.6 | 28.6 |
| YT03 | 2.00 | 26.0 | 80.0 | 18.0 |
| YT04 | 1.50 | 27.0 | 140.0 | 26.0 |
| YT05 | 3.20 | 14.0 | 22.0 | 21.0 |
| YT06 | 2.50 | 22.1 | 22.0 | 25.0 |
| ZH01 | 6.00 | 22.5 | 26.0 | 30.0 |
| ZH02 | 75.00 | 20.5 | 19.5 | 22.5 |
| ZH03 | 30.00 | 21.0 | 20.0 | 21.0 |
| ZH04 | 12.50 | 22.0 | 27.0 | 31.0 |
| ZH05 | 25.00 | 21.5 | 22.0 | 28.0 |
| ZH06 | 13.00 | 20.0 | 20.0 | 22.5 |
| ZH07 | 12.50 | 21.0 | 23.0 | 22.0 |
| ZH08 | 26.00 | 21.5 | 22.0 | 21.0 |
| ZH09 | 16.00 | 22.0 | 23.5 | 22.5 |
| ZH10 | 6.00 | 20.0 | 24.0 | 23.0 |
| ZH11 | 9.00 | 22.5 | 23.5 | 25.0 |
| ZH12 | 5.00 | 21.0 | 15.0 | 26.0 |
| ZH13 | 9.00 | 22.0 | 24.0 | 23.0 |
| ZH14 | 3.00 | 22.0 | 23.5 | 24.0 |
Comprehensive analysis of urban slope risk is the identification of five elements, including geological body boundary shape characteristics, structure and composition of rock and soil, initial state, rainfall excitation conditions, soil erosion degree and external environmental factors. The analysis of these factors can not only accurately identify the formation mechanism of existing disasters, but also analyze and predict the development of slope deformation in the future. The risk assessment model of urban slope can be simplified as follows:

\[ H = 0.7F_s + 0.3F_d \]  

According to the formula (3), the risk zoning map of Zhouqu urban slope under 50 (2%) annual rainfall (Figure 2) is obtained. The high-risk area is 3.17km², the moderate risk area is 6.04km², the low-risk area and extremely low risk area are 18.19km², accounting for 11.57%, 22.04%, 66.39% of the total area respectively.

3.1.2. Risk Assessment of Urban Debris Flow

The essence of debris flow risk is the probability of debris flow occurrence and its possible risk range under relatively specific rainfall frequency.

With the development of fluid mechanics and the innovation of numerical calculation method, numerical model calculation has been widely used in the study of debris flow and is an effective means to realize the quantitative evaluation of debris flow danger, which can not only reflect the temporal and spatial variation characteristics of debris flow, but also intuitively obtain the dangerous range of debris flow accumulation area. Referring to the research results of Tangechuan’s research team [14,15], based on the FLO-2D numerical simulation, the debris flow intensity index \( \psi^2 d \) is used to characterize the comprehensive damage ability of debris flow, and the spatial distribution of debris flow intensity value in each grid unit is taken as the manifestation of debris flow risk.

Most debris flow disasters in the study area are controlled by rainfall, and almost all debris flow gullies have carried out a large number of engineering prevention measures. Two factors such as different rainfall frequency and engineering control measures are mainly considered during the simulation of debris flow disaster in the study area of future and the risk of debris flow is obtained by combined with the dynamic characteristics of debris flow and the analysis of traditional stormwater model.

- The DEM data of the simulation area is converted into ASCII data format of the simulated debris flow terrain and divided into 10m × 10m catchment unit grid, and different elevation values are given at the same time.
- The rainfall intensity contour map under different frequencies in the study area is derived by using the statistical method of Pearson III (P-P) distribution function through by the rainfall data and 406
meteorological observation points in Longnan mountain area. Combined with the basic characteristic parameters of debris flow, the peak discharge hydrograph of debris flow with different frequencies (5%, 2%, 1%) in the future is obtained. Due to the amplification effect in the process of debris flow movement, the final input value of debris flow process is the flow of debris flow multiplied by the volume expansion coefficient \( \beta F \).

- In the process of debris flow movement, the volume concentration of debris flow \( C_v \) is different caused by the different conditions of underlying surface in different positions, and this data is often difficult to obtain. The value is assigned by referring to the previous debris flow results in the study area and the recommended value in the FLO-2D manual, ranging from 0.58 to 0.7.

- Due to the small scope of study area, other simulation parameters are the same values respectively based on FLO-2D manual such as yield stress and viscosity coefficient \( (\alpha_1, \beta_1) \), Manning coefficient \( (n) \) and laminar flow coefficient \( (K) \), while the specific gravity of sediment \( (\gamma_m) \) is the obtained by the field test results of loose soil.

- The simulation time mainly records the total time of debris flow movement according to the field investigation and data collection, which is basically consistent with the time of peak rainfall intensity.

Taking the 50 years return period rainfall frequency as an example, the specific simulation parameters (Table 2) are input into the FLO-2D model, and there is no human intervention in the whole process. The calculation results are more realistic and objective. According to this method, each debris flow gully in the evaluation area is simulated, and the simulated debris flow intensity index is superimposed on ArcGIS platform. Finally, the risk zoning maps of urban debris flow under different rainfall frequencies are obtained, that is, the risk of urban debris flow \( H_2^* \).

Error analysis: using precision coefficient \( I_n \) to verify the accuracy of the simulation results under the condition of sanyanyu debris flow gully under the 100 years rainfall (8.8 Zhouqu mountain torrent debris flow disaster rainfall). The range of \( I_n \) is 0~1. The closer the \( I_n \) is to 1, the more accurate the simulation results are. The simulation area of sanyanyu debris flow \( A_{sn} \) is 0.523 km², while the actual accumulation area \( A_e \) is 0.46 km², the overlap area of sanyanyu debris flow between the actual and simulation is 0.382 km². The simulation accuracy coefficient is 78.1%, which is obtained by formula (4) and meets the simulation accuracy requirements.

\[
I_n = \sqrt{\frac{(A_e/A_{sn}) \times (A_{sn}/A_m)}{100}} = 0.382/0.523 \times 100 = 78.1\% \quad (4)
\]

**Table 2. The parameters for the FLO-2D numerical simulation (2%)**

| Simulation parameters          | Value     | Basis              |
|--------------------------------|-----------|--------------------|
| computational grid/m          | 10 × 10   | DEM data           |
| Simulation time/h             | 1~2       | Access data        |
| Volume concentration \( C_v \)| 0.58~0.7  | Material collection|
| Specific gravity of sediment \( \gamma_m \) | 2.63~2.7 | Field investigation|
| manning roughness coefficient \( n \) (highway, drainage channel) | 0.05 | FLO-2D manual |
| manning roughness coefficient \( \eta \) (residential district) | 0.3 | FLO-2D manual |
| laminar flow coefficient \( K \) | 3000 | FLO-2D manual |
| \( \alpha_1 \)               | 0.811     |                    |
| \( \alpha_2 \)               | 0.00462   | FLO-2D manual combined with literature [16] |
| \( \beta_1 \)                | 13.72     |                    |
| \( \beta_2 \)                | 11.24     |                    |

3.1.3. Comprehensive evaluation of urban geological hazard risk

In the study of geological hazard risk assessment, it is necessary to predict the movement distance and potential hazard range of geological hazard, which is also the basis of geological hazard risk assessment.
During the research of landslide movement distance, many scholars have established linear regression equations between sliding distance and related height difference of sliding mass, volume of sliding mass and front slope angle of sliding mass by using geometric method and sample data with MATLAB programming, and achieved good results in corresponding area \(^{[17,18]}\). Although there are some limitations in the previous research on the prediction and calculation model of landslide influence range, the evaluation results have certain regional representativeness. In this paper, the sliding distance of 46 landslides with different scales, such as Suoertou landslide and discharge slope landslide is determined based on the field investigation data. On this basis, the formula between the landslide sliding distance \((L)\) and the height difference \((\Delta H)\) and the average slope \((\theta)\) in the sliding source area is established.

\[
L = 1.6962\Delta H^{0.0126} \\
H = 1.005 + 1.705\sin\theta \\
\theta > 33\text{ or }\theta \leq 28
\]

where \(L\) is Prediction of maximum sliding distance of landslide (m), \(\Delta H\) is Elevation differences of front and rear edge of landslide source area (m) and \(\theta\) is mean gradient of landslide source area (\(^\circ\)). The correlation coefficient \(R^2\) is 0.86 and 0.72 respectively in formula (5) and formula (6).

Based on the field investigation of the landslide and the remote sensing interpretation in Zhouqu town area, the maximum sliding distance is calculated quickly by DEM data on ArcGIS platform. Refer to the research results of Tang Yuming \(^{[19]}\), the distance between the insured objects and landslide source area is considered as risk area according to different extension angles (\(\alpha\)). The \(\alpha \geq 25^\circ\), \(\alpha \in (15^\circ \sim 25^\circ)\) and \(\alpha < 15^\circ\) represent that is high risk areas, medium-risk area and low risk area respectively. The occurrence of disaster is the result of the encounter between disaster causing factors or risk factors and disaster bearing factors or victims \(^{[20]}\), which is defined as the risk assessment of disaster causing body (landslide) \(H_r\).

In ArcGIS software, the comprehensive evaluation model and method of geological hazard risk are used to carry out the comprehensive evaluation and analysis of geological hazard risk in Zhouqu urban area, such as landslide and debris flow. The geological disaster dangerous in the study area is divided into four grades: high, medium, low and very low.

The evaluation results are shown in Figure 2.

![Fig. 2. Hazard Zoning Evaluation in the 50-Year Rainfall Frequency of the Study Area](image)

3.2 Vulnerability assessment of urban geological disasters

Since the 1970s, the concept of vulnerability to geological hazards has been discussed in academic circles. With the development of national economy, many experts and scholars consider the resistance ability and damage loss rate of the disaster bearing body in the vulnerability evaluation. Some research contents are combined with social insurance, so the evaluation indexes are various and the operation is inconvenient \(^{[21]}\), which is out of line with the requirement that the actual geological disaster risk evaluation can quickly
provide disaster prevention and mitigation target area. How to select the main content and characteristic index of vulnerability from the reality of the evaluation area, which is easy to operate and quantify, has become the key content of vulnerability evaluation of geological disasters.

In this paper, the definition of vulnerability to geological disasters is based on the definition of vulnerability to natural disasters published twice by the United Nations in 1991 and 1992 [22]: that is, the degree of vulnerability of the disaster bearing body to geological disasters within the affected area, and its value range is [0,1]. Accepted by China’s academic evaluation content: vulnerability of community (population attributes), economic vulnerability (economic level), material vulnerability (infrastructure construction) and resource and environment vulnerability (land resources). When evaluating the vulnerability of disaster bearing bodies in Zhouqu City, the difference of resistance ability of disaster bearing bodies is small because the study area is small and the geological disaster mitigation and prevention measures are relatively perfect. The impact of resistance ability is not considered in the vulnerability assessment of urban geological disasters.

Firstly, the uncertainty of the future geological disasters in cities and towns, the damage degree of the disaster bearing body is difficult to be obtained by calculation. Therefore, the vulnerability index of the disaster bearing body in the study area is mainly used in the study. Second, Material vulnerability and resource and environment vulnerability can be classified as material vulnerability [7], due to the high correlation among vulnerability of community, economic vulnerability, material vulnerability and resource and environment vulnerability. Social vulnerability, resource and environment vulnerability are selected as the contents of Zhouqu urban geological disaster vulnerability assessment based on actual situation of the evaluation area and the principle of ‘people-oriented’.

3.2.1. Identification of disaster bearing body and determination of vulnerability index

(1) The first step of vulnerability assessment is to identify and classify the disaster bearing bodies mainly through data collection and analysis, field investigation, high-resolution remote sensing interpretation, large-scale topographic mapping or aerial photogrammetry. In this study, the data of land use planning and urban population distribution is taken as basis, 1:10000 high-resolution remote sensing or 1:2000 photogrammetric image analysis is taken as the guide, and field investigation and verification are taken as the main means to identify the disaster bearing body. The main contents focus on four aspects: population distribution, buildings, roads and land use.

(2) The secondary indicators of social vulnerability mainly include population distribution. In order to be easy to quantify and operate, this paper uses population distribution density and gives the corresponding loss probability, and finally expresses social vulnerability through the amount of money.

The specific steps are:
- The scale of population activities is determined by the use types of residential buildings, factories, schools and other buildings in the study area and referring to the identification principle of hazard bearing body.
- The corresponding boundary of evaluation area is delineated.
- The evaluation area is divided by 10 m × 10 m grid, and the grid layer is superimposed with the determined residential buildings. The population distribution density value is determined by the building area of residential buildings in the grid.
- The population distribution density grid map of the evaluation area is obtained.

Social vulnerability can be calculated according to formula (7):

\[ \text{Social vulnerability} = \text{Number of people per square meter} \times \text{Average personal value} \times \text{Average damage probability} \]  

(7)

(3) The potential economic losses of different types of infrastructure and land use are selected as the secondary index for material vulnerability. In addition to the population, the disaster bearing bodies in the urban area of Zhouqu are divided into 15 categories according to the types of infrastructure and land use and the field investigation, which including residential buildings, factories, schools, other venues, hydropower stations, national roads, general roads, bridges, drylands, gardens, grasslands, bare land, shrublands, sparse woodlands and water systems. Therefore, the potential losses of several types of disaster bearing bodies are selected to study the material vulnerability.

The vulnerability of residential buildings can be calculated according to formula (8) ~ (9), and other buildings can be calculated by analogy.

Total value of residential buildings = cost per square meter × building areas + indoor property + other property  

(8)

\[ \text{Vulnerability of residential buildings} = \text{total value of residential buildings} \times \text{Overall damage probability} \]  

(9)
In addition, the vulnerability of highway, bridge, dry land and others is calculated according to formula (10), in which: Highway vulnerability = cost per square meter × Road areas × Damage probability

Different types of disaster bearing bodies have different costs. This paper determines the unit price of different disaster bearing bodies refer to prices provided by the professional departments of Zhouqu County and the local economic development potential, as shown in Table 5. The damage probability of disaster bearing body varies with its structure and function. The damage probability of each disaster bearing body is determined by referring to the domestic research results, analyzing the existing geological disaster data in Zhouqu town and combining with the actual situation of the study area. The specific assignment is shown in table 3.

| Type of disaster bearing body | unit-price / (RMB/m²) | Total damage probability |
|------------------------------|------------------------|--------------------------|
| residential buildings        | 3000                   | 0.59                     |
| factories                    | 2000                   | 0.38                     |
| schools                      | 5000                   | 0.27                     |
| other venues                 | 1000                   | 0.1                      |
| hydropower stations          | 4000                   | 0.35                     |
| national roads               | 2000                   | 0.42                     |
| general roads                | 1500                   | 0.58                     |
| Bridges (reinforced concrete bridge) | 2000             | 0.35                     |
| cultivated land              | 15                     | 0.2                      |
| gardens                      | 25                     | 0.2                      |
| shrublands                   | 20                     | 0.3                      |
| sparse woodlands             | 5                      | 0.3                      |
| grasslands                   | 2                      | 0.15                     |
| Bare land                    | 1                      | 0.1                      |
| water systems                | 300                    | 0.1                      |

3.2.2. Calculation method of geological disaster vulnerability

The vulnerability evaluation of urban geological disasters of the Bailong River Basin conducted through the research of quantitative characteristics, spatial distribution and actual value of the disaster bearing body in the study area. The classification statistical calculation method is adopted, and the ArcGIS software is used to construct to evaluate the vulnerability of urban geological disasters based on the type identification, quantity range extraction, field survey verification and value accounting statistical analysis of hazard-affected bodies in the evaluation area. Spatial overlay operation of vulnerability economic value of different types of hazard bearing bodies on ArcGIS platform to obtain vulnerability zoning map of study area. In order to link up with the risk assessment, the vulnerability value range of the hazard bearing body in the evaluation area is set to (0 ~ 1), that is, the total economic value in each grid is normalized:

\[ V = 0.1 + \frac{X - X_{\text{min}}}{X_{\text{max}} - X_{\text{min}}} \times 0.9 \] (11)

where \( V \) is Vulnerability normalization value, \( X_{\text{max}} \) is maximum and minimum economic value in raster data.
Then normalized vulnerability index of hazard bearing bodies is divide into 4 grades through by combination of actual situation in the evaluation area and past disaster losses. When \( 0 < V \leq 0.25 \), the disaster bearing body is extremely vulnerable, when \( 0.25 < V \leq 0.45 \), the disaster bearing body is low vulnerable, when \( 0.45 < V \leq 0.75 \), the disaster bearing body is moderately vulnerable, when \( 0.75 < V \leq 1.0 \), the disaster bearing body is highly vulnerable. Finally, the vulnerability assessment zoning map of disaster bearing bodies in Zhouqu urban area is formed (Fig. 3).

4. Risk assessment and analysis of geological disasters in Zhouqu City

Geological hazard risk assessment has experienced more than 40 years of development. It has become an effective means to guide the land space planning and utilization and disaster prevention and reduction, and also the most direct and effective way to reduce the potential casualties and economic losses caused by geological disasters. The main expressions of risk assessment are 'risk = risk + vulnerability' and 'risk degree = risk degree × Vulnerability' and 'risk = frequency × Hazard degree' and so on \[23\]. However, in reality, the risk of geological disasters has the characteristics of concealment of danger, randomness of loss, complexity of disaster mechanism, unknown and dynamic of disaster information acquisition, fuzziness of risk assessment results and so on.

In order to make the results of urban geological disaster risk assessment better provide detailed information for land space planning, disaster prevention and mitigation measures construction and engineering social and economic activities, this paper optimizes and improves the expression of geological disaster risk assessment, as shown in formula (12).

\[
R = \sqrt{H^2 + V^2} \quad (12)
\]

where \( R \) is Risk degree, \( H \) is Hazard degree, \( V \) is Vulnerability.
The optimized geological disaster risk assessment model can not only reflect the scale of geological disaster risk, but also reflect the specific characteristics of geological disaster risk. According to formula (12), the results of geological hazard risk and vulnerability evaluation obtained by Zhouqu town under the condition of 50 years return rainfall are conducted grid calculate. Finally, the map of geological disaster risk assessment under the condition of 50 years return rainfall are obtained. The risk of map is divided into four levels: high risk area, medium risk area, low risk area and extremely low risk area (Fig. 4 and table 4).

The high-risk areas of geological disasters are about 5.16 km$^2$, accounting for 18.83% of the total area. There are 16 disaster points with a density of 3.1/km$^2$. The areas are mainly located in the south bank of Bailong River in Zhouqu Town. Which is the accumulation platform of gullies exportation, such as Sanyanyu, luojiayu, Henan Village and zhaizigou and the Suoertou Village, Yatou Village, Zhenya Village, Bali Village and loess slope. The areas of threatened buildings are about 121.47 × 10$^4$ m$^2$, and the areas of highway facilities are 20.03 × 10$^4$ m$^2$, other land areas are 372.58 × 10$^4$ m$^2$.

The medium-risk areas of geological disasters are about 6.41 km$^2$, accounting for 23.41% of the total area. There are 20 disaster points with a density of 3.12/km$^2$. The areas are mainly situated around the high-risk area, and its typical location is the residential area on the North Bank of Bailong River in Zhouqu Town. Which are on the middle of suoertou landslide, getatou landslide, dengjiawan landslide and other accumulation bodies, and on the middle of Nanshan slope and the middle upper part of Wachang slope. The areas of threatened buildings are about 8.66 × 10$^4$ m$^2$, and the areas of highway facilities are 8.66 × 10$^4$ m$^2$, other land areas are 558.78 × 10$^4$ m$^2$.

The low-risk and below areas of geological disasters are about 15.82 km$^2$, accounting for 57.76% of the total area. There are 6 disaster points with a density of 0.104/km$^2$. Which are mainly distributed in the South and North mountain slopes where vegetation is better and people live less, and on the accumulation platform of Hampingliang old landslide. The threatened areas of buildings are about 36.14 × 10$^4$ m$^2$, and the areas of highway facilities are 10.75 × 10$^4$ m$^2$, other land areas are 1515.59 × 10$^4$ m$^2$.

| Program | Risk unit | High-risk | Medium-risk | Low-risk | Very-low risk | Total |
|---------|-----------|-----------|-------------|----------|---------------|-------|
| Number of grid units/piece | 51561 | 64103 | 53813 | 104367 | 273844 |
| Areas/km$^2$ | 5.16 | 6.41 | 5.38 | 10.44 | 27.38 |
| Area ratio/% | 18.83 | 23.41 | 19.65 | 38.11 | 100 |
| Disaster points/num | 16 | 20 | 5 | 1 | 42 |
| Disaster density | 3.10 | 3.12 | 0.93 | 0.10 | 1.53 |
Areas of buildings /10^4 m^2

- 121.47
- 90.14
- 25.91
- 10.23
- 247.75

Areas of highway facilities /10^4 m^2

- 20.03
- 8.66
- 6.97
- 3.78
- 39.44

Other land areas /10^4 m^2

- 372.58
- 558.78
- 520.71
- 994.88
- 2446.95

5. Conclusion

Zhouqu County is located in the mountainous area of Bailong River Basin and which was taken as the research object. The risk assessment of geological disasters at town scale was carried out by using the infinite slope model, Flo-2D software and ArcGIS software combined with high-precision remote sensing images and the main conclusions were drawn as follows.

1. The prediction formula of the maximum sliding distance of landslide is established through by the optimized infinite slope model, FLO-2D software and the method of evaluate the risk of urban geological disasters combination ArcGIS software. To a great extent, the efficiency and accuracy of risk assessment are improved.

2. The high-precision remote sensing image or large-scale aerial photogrammetry data can show the information of disaster bearing bodies, and provide a fast, convenient and reliable data source for vulnerability assessment of urban geological disasters.

3. In vulnerability evaluation, the evaluation index with high repeatability is removed, and the main property disaster bearing body is selected for analysis and economic value accounting, which greatly improves the evaluation efficiency.

4. The results of risk assessment can provide reliable technical support for land space planning and disaster prevention and mitigation of Zhouqu County, and provide reference for risk assessment of geological disasters in other towns in Longnan Mountainous Area.

5. In addition to the rainfall conditions, the impact of earthquake and human engineering activities can not be ignored. The risk assessment of geological disasters in mountainous cities and towns in Bailongjiang River Basin meets the goal of high efficiency and accuracy at the same time. The dynamic basic database of geological disaster risk assessment and the theoretical method of rapid assessment technology need to be further studied.

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