Current status and prospects of quantitative geohazard risk evaluation

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Abstract. Landslides, collapses, and debris flow are the most common types of geohazard, and their disaster losses are also the most serious. Geohazards not only cause casualties, but also cause serious economic losses. In order to reduce the losses caused by these disasters, it is crucial to conduct quantitative evaluation of geohazard risks. This article summarizes the methods and techniques of geohazard risk evaluation, summarizes the methods of geohazard hazard assessment, vulnerability assessment methods of disaster-bearing bodies, and methods and expressions of geohazard risk assessment, which can help researchers and decision makers better understand the risk characteristics and influencing factors of landslides and debris flows, provide scientific support for disaster prevention and control, and have significant practical value and guiding significance.

Keywords: landslide, collapse, debris flow, geohazard, risk assessment, quantitative.

1 Introduction

With the increasingly rapid development of social modernization, human engineering activities are frequent, large-scale water conservancy and hydro-power plant construction, slope land development and utilization, and mineral resources exploitation, coupled with extreme weather such as continuous rainfall or heavy rainfall, resulting in ecological environment damage and collapse, and generating geohazards such as mudslides and landslides. Landslides and mudslides are the most important types of natural disasters, with characteristics of wide distribution, high frequency, fast movement, and serious disaster losses.

Since the 21st century, major disasters have occurred frequently at home and abroad, and factors such as the disharmony between man and nature and the decline of rural areas have magnified the impact of disasters on human beings. geohazard not only seriously endanger people's daily lives and living environments, but also restrict the sustainable development of China's social economy, resources, and environment, and even hinder social development.

There are many types of natural disasters in China. The purpose of conducting a comprehensive risk survey of natural disasters nationwide is to find out the "natural

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background" of natural disasters, and to improve the comprehensive prevention and control ability of natural disasters with problem-oriented approach. Risk assessment and monitoring and early warning of disasters can greatly eliminate the hidden dangers of disaster risks or minimize the losses caused by disasters [1]. In order to prevent and reduce landslides and debris flows, quantitative risk assessment is essential, which is an important scientific basis for geohazard prevention and mitigation work, and also an important foundation for the preparation of land space planning at all levels.

Geohazard risk assessment is crucial for hazard control. To recognize and quantitatively describe the risk is the key. This comprises two scenarios: (1) the probability of hazard event occurrence, and its influence extent; (2) elements in danger in the potential risk zone, their values, vulnerabilities.

In this article, the authors systematically collect and organize the research status of geohazard risk assessment, and summarizes the evaluation methods of geohazard risk and vulnerability of disaster-bearing bodies. Through a case study of a debris flow hazard in west China, the hazard, the components and steps of risk assessment were demonstrated.

2 Geohazard risk assessment: State of art

From the 1970s to the 1980s, the United States and other western countries began to qualitatively assess the risk of geohazard. In the 1990s, geohazard risk assessment began to shift from qualitative assessment to quantitative assessment. Carrara et al. used a statistical analysis model combined with GIS system to conduct a geohazard risk assessment study in central Italy [2]. Yin et al. used a fuzzy comprehensive evaluation model to comprehensively evaluate the risk of geohazard in China, and prepared a map of geohazard risk prediction in China [3]. Lirer and Vitelli used GIS system to evaluate the risk of lava flow hazards to people and property in Vesuvius, Italy [4].

In the 21st century, geohazard risk assessment has received attention from governments around the world. The assessment results are mostly used to guide engineering planning and disaster prevention and mitigation work. Chung et al. selected evaluation indicators such as lithology, elevation, and slope to evaluate the risk of landslides [5]. Remondo et al. used statistical models to quantitatively evaluate the risk of landslide geohazards in the Guipuzcoa region of Spain, and also predicted the potential loss caused by landslides in the next few decades [6]. Deng applied high-precision satellite remote sensing technology in the process of geohazard investigation and evaluation, and established a method system for studying geohazards using high-precision satellite remote sensing technology [7]. Hu et al. took Xunzhong Town, Dehua County, Fujian Province as the research area, proposed that geohazards are a dynamic process, and for the first time used event tree, fuzzy comprehensive evaluation model, combined with GIS to conduct geohazard evaluation. Du et al. took the Anning River basin as an example, recognized 198 debris flow gullies as evaluation samples based on remote sensing interpretation and field investigation, selected suitable evaluation factors, and used deterministic coefficient and geographical detector coupling model to calculate the classification value and factor weight of each evaluation factor, and conducted debris flow susceptibility evaluation [8]. Ji et al. took Jiangcun Street, Xi'an City, Shaanxi Province as the research area, divided the slope unit based on DEM data and conducted a survey, selected the main influencing factors of geohazard development in Jiangcun Street through statistical analysis, and used the analytic hierarchy process to conduct susceptibility evaluation [9]. Then, the extreme rainfall hypothesis method was used for risk evaluation, and the vulnerability evaluation model was selected. Finally, the geohazard risk evaluation of the area was obtained. Guo et al. took landslides induced by the Wenchuan earthquake in mountainous areas as the research area, selected 10 landslide impact factors, conducted collinearity analysis on the factors, and then used frequency ratio method and decision tree evolution improved gradient boosting decision tree, random forest and coupling model to conduct co-seismic landslide susceptibility evaluation [10].

Comprehensive analysis of relevant research results at home and abroad shows that the risk assessment of geohazard initially focused on a single type of geohazard, and the assessment was mainly qualitative. With the deepening of research, the risk assessment of geohazard began to focus on different types of geohazard, and the assessment shifted from qualitative assessment to semi-quantitative and quantitative assessment. The vulnerability assessment of geohazard started later than the risk assessment, mainly evaluating the loss degree of the threatened objects caused by geohazard. The risk assessment of geohazard is carried out on the basis of the risk assessment and vulnerability assessment, mainly to carry out risk zoning for geohazard and provide countermeasures and suggestions for disaster prevention and mitigation.

In the decades of development of geohazard risk assessment research, scholars at home and abroad have introduced a large number of mathematical analysis methods, including statistical methods such as information quantity method, statistical index method, frequency ratio method; machine learning methods such as logistic regression, decision tree algorithm, support vector machine model, random forest model, etc. [11-19] These mathematical analysis methods combined with GIS systems make the results of geohazard risk assessment more scientific and accurate. geohazard risk assessment research has made great progress, covering most areas related to geohazard. However, the development is extremely uneven, focusing more on the analysis of the distribution law, formation mechanism, and trend prediction of geohazard, and the evaluation accuracy is not enough. It should be developed towards fine geohazard risk assessment.

3 Methods for geohazard risk assessment

The loss caused by geohazard includes two elements: the occurrence of geohazard events and the impact on disaster-bearing objects such as life, property, and infrastructure, resulting in serious damage. Therefore, risk is a function of the spatial and temporal distribution of the probability and impact intensity of geohazard, as well as the spatial and temporal distribution of the disaster-bearing body and its ability to withstand the impact of geohazard. Therefore, the risk assessment of geohazard can be divided into two aspects: the risk assessment of disaster-causing bodies (disaster-causing bodies) and the vulnerability assessment of disaster-bearing bodies (disaster-bearing bodies).

3.1 Geohazard assessment

The author summarizes the following six main methods for landslide and debris flow hazard assessment, including multi-factor comprehensive evaluation method, information entropy theoretical model, artificial neural network method, fuzzy comprehensive analysis method, multivariate statistical analysis method, and regression analysis method, and analyzes the advantages and disadvantages of these methods (Table 1).

The advanced geohazard assessment techniques go towards the quantitative ones. The premise of statistical analysis is to know the distribution of landslide disasters in the study area (training area). According to mathematical statistics theory, a mathematical statistical model is established to determine the influence parameters and occurrence of landslides. After being verified in the testing area, it is applied to areas with the same or similar geological environment to predict the distribution law of disaster risk in the study area. The reliability of the evaluation results obtained by statistical analysis method directly depends on the accuracy of the original data in the testing area, and the model cannot be widely used in any region. A large number of studies have shown that statistical analysis is currently the most suitable method for regional geological disaster risk assessment and zoning. It is based on strict mathematical statistics theory, the mathematical model is simple and easy to understand, and it can be well integrated with GIS technology, allowing a large amount of data to be reasonably standardized, managed, analyzed, and stored. In addition, the error of statistical analysis can be quantitatively estimated.

Table 1. methods for quantitative hazard analysis of geohazards

Method	Implementation	Advantages and disadvantages
Artificial neural network method	Establish an appropriate network structure based on specific issues; Establish a learning sample set and expected output; Train the network until convergence; Use a convergent network for predictive evaluation.	Can converge well and evaluate samples well. This model can simulate quantitative evaluation by experts, avoiding human interference during the evaluation process. However, the required data is difficult to collect, and this method cannot be used when the data is insufficient.
Multivariate statistical analysis method	Establish a mathematical statistical model that affects the parameters and the occurrence of landslides. After verification in the testing area, apply it to areas with similar or identical geological environments to predict the distribution pattern of disaster risk in the study area.	Based on strict mathematical and statistical theories, the mathematical model is simple and easy to understand, can be well integrated with GIS technology, and errors can be quantitatively estimated.

Multi factor comprehensive evaluation method	Select evaluation indicators, determine the weight of evaluation factors, assign segmented values to each evaluation factor, and calculate disaster risk.	The calculated value is a definite value, and this method can be used in multiple places, not just in one place. However, it is difficult to obtain data on the scale, frequency, and density of debris flow gullies. The results obtained indirectly through empirical formulas are not accurate enough.
Information entropy theory model	Establish an information entropy evaluation model. In hazard assessment, if an evaluation factor has a small degree of difference in different prone areas of a certain disaster, it indicates that the factor plays a small role in evaluating disaster hazard, and the corresponding information entropy is large, and vice versa; Based on the degree of difference in evaluation factors, combined with information entropy theory, obtain the weights of each evaluation factor for evaluation.	It has good objectivity, a relatively simple calculation process, and convenient data acquisition. However, the data source is single, the development is not mature enough, and there is little applied research. The reliability of the obtained results needs further verification.
Regression analysis method	Process statistical data and establish a regression relationship function expression between the dependent variable and the independent variable for risk assessment.	The calculation method is simple and the evaluation results are meaningful. But it requires a large amount of data support and involves a large number of influencing factors in the calculation.
Information quantity method	Referring to the actual situation of geological disasters or damaged areas that have occurred, the measured values or important parameters reflecting various factors affecting regional stability are converted into information values reflecting regional stability. By calculating the amount of information provided by various influencing factors on the research object, the degree of closeness between each influencing factor and the research object is evaluated.	For research areas with a larger number of unit divisions, it is more advantageous, but it can only reflect the likelihood of disasters occurring under specific combinations of different influencing factors, cannot reflect the differences of each factor, and requires a large amount of data.
Numerical simulation method	Divide the digital elevation model into terrain grids, use non Newtonian fluids and central finite difference method to solve the control equation of debris flow movement, and use numerical quantitative methods to simulate the flow process and accumulation range of debris flow, and evaluate dangerous areas.	It can fully analyze the movement characteristics and rheological state of debris flows, and has good results in predicting the accumulation range of debris flows and dividing the risk assessment zones. The simulation accuracy is high and the credibility is high.

3.2 Vulnerability assessment of disaster-bearing body

The following six main methods for landslide and debris flow vulnerability assessment were summarized, including comprehensive evaluation method, information quantity method, logistic regression model, BP neural network model, random forest model, and numerical simulation method. The advantages and disadvantages of these methods were analyzed (Table 2).

The most important thing in vulnerability assessment is the recognize and design of risk-bearing categories. The economic elements of houses, roads, pipelines, power-transmitting lines, farmland, and attached values. All of the elements potentially at risk should be considered and collected.

Table 2. methods for vulnerability assessment of disaster-bearing body

Method	**Implementation**	**Advantages and disadvantages**
Comprehensive evaluation method	Screen out vulnerability indicators, establish a vulnerability evaluation matrix, or use mathematical models to determine the comprehensive vulnerability of the disaster bearing body.	The evaluation results are more objective as they are not affected by historical disaster loss recorded data. The main difficulty lies in the difficulty in determining the specific values of the vulnerability matrix.
Value accounting method for disaster bearing bodies	By dividing the types of disaster bearing bodies and extracting the basic attributes of their distribution, the value reflected in the disaster bearing body is calculated, and vulnerability evaluation is carried out.	Using the monetized disaster bearing body as the evaluation basis, it is assumed that the disaster bearing body is completely destroyed in the disaster, and population vulnerability is ignored in the calculation of value, which differs greatly from the actual situation. However, the vulnerability evaluation for the region is concise and intuitive.
BP neural network model	Using neurons as the basic unit, data is propagated forward from the input layer to the hidden layer for processing and then propagated to the output layer. The propagation error is calculated through a loss function for backpropagation, and the gradient descent method is used to correct the weights of each connection and train repeatedly until the error requirements are met.	Has strong modeling ability, but is prone to getting stuck in local optima during the training process, has a long training time, and is sensitive to initial parameters and data preprocessing.
Random Forest Model	When conducting classification prediction, corresponding decision trees are constructed using each sample set. Each decision tree can select the optimal classification result, and then the final result is predicted through voting.	High accuracy, able to handle a large number of input features, can handle noisy and missing data well, and can avoid overfitting problems. The computational complexity is high, requiring a large amount of training data, and the results are difficult to interpret.
Fuzzy comprehensive analysis method	Establish a target set and evaluation set for the evaluation problem, and then use a fuzzy transformation method for synthesis.	Quantify non quantifiable factors and use membership degrees to comprehensively evaluate geological hazards affected by multiple factors. However, the evaluation results are not precise enough; Subjective influence is significant, lacking objectivity.

3.3 Quantitative evaluation of geohazard risk

For property losses, the corresponding expression is:

$$R_{property} = P_H \times P_{SH} \times V_{property} \times E \tag{1}$$

Here, $R_{property}$ refers to the value of property losses caused by landslides each year; P_H refers to the probability of landslide occurrence each year; P_{SH} refers to the spatial impact probability of landslides; $V_{property}$ refers to the vulnerability of property; E refers to risk factors.

For casualties, the corresponding expression is:

$$R_{person} = P_H \times P_{SH} \times P_{TS} \times V_{person} \tag{2}$$

Here, R_{person} refers to the annual probability of individual death; P_H refers to the annual probability of landslide occurrence; P_{SH} refers to the spatial impact probability of landslides; P_{TS} refers to the temporal impact probability of spatial impact; V_{person} refers to the vulnerability of the population.

4 Case study of risk assessment of a typical debris flow

Taking a typical debris flow in western China as an example, the implementation of geohazard risk assessment and the use of risk assessment results are discussed.

Through detailed ground surveys and numerical simulations, we can obtain the probability of debris flow occurrence under different rainfall conditions, the possible impact range of debris flow, and the impact force at different locations. In this way, we can obtain a quantitative distribution map of debris flow hazard(Fig.1a).

In the investigation of geohazard bearing bodies and vulnerability assessment, firstly, the disaster bearing objects in the debris flow affected area are identified one by one based on high-resolution remote sensing images, and their respective characteristics are preliminarily counted. Then, through field survey of the disaster bearing objects, the characteristics of disaster bearing bodies are collected one by one, and the survey forms were filled out. For property disaster bearing bodies, vulnerability refers to the possibility of not being damaged when suffering from geohazard. Taking houses as an example, it is related to factors such as structure, construction age, maintenance status, etc. For personnel disaster bearing bodies, vulnerability refers to the probability of survival when suffering from geohazard, which is related to factors such as gender, age, education level, and health status of personnel (Fig. 1b).

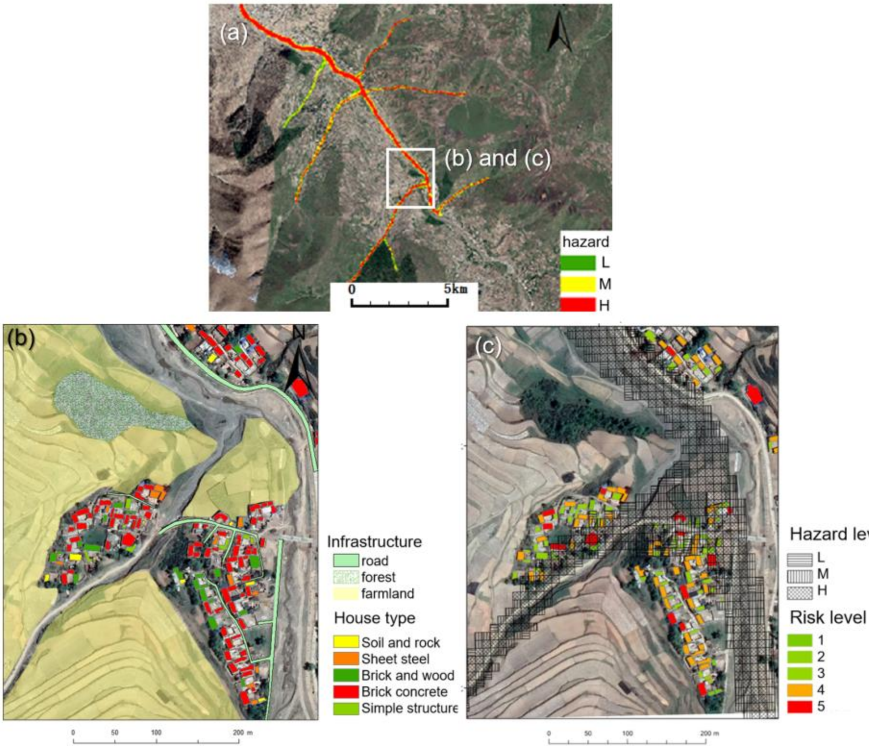

Fig. 1. Risk assessment of a typical debris flow in west China.

With a detailed risk assessment map, a distribution map of disaster-bearing bodies, and the vulnerability of each disaster-bearing body, the risk of geohazard can be calculated (Fig. 1c).

Fig 1a- Fig 1c provides a demonstrative case of geohazard assessment, vulnerability assessment, and risk evaluation. The results can serve the risk mitigation and control of geohazards, and national territory spatial planning.

5 Conclusions

The current research system is not yet perfect, and the research on vulnerability assessment of disaster-affected objects needs to be further strengthened and deepened. There are various methods for regional geohazard risk assessment, each with its own advantages and disadvantages, which can be flexibly and comprehensively applied to improve the reliability of the assessment.

Due to the immature risk assessment theory and the influence of human factors, the risk assessment model of geohazard varies from person to person, region to region, and type to type. The authenticity and credibility of the assessment results of different assessment models are questioned. Therefore, it is necessary to further optimize the risk assessment model of geohazard and establish a comprehensive model of geohazard risk assessment to ensure the rationality and rightness of the assessment model. Currently, the risk assessment of landslides mainly focuses on the risk assessment of single disasters, ignoring the disaster chain effect of landslides. Taking the Wenchuan earthquake disaster area as an example, the earthquake triggered a large number of landslides and mudslides. If these landslides enter the river channel, they may block the river channel, form a barrier, and form a barrier lake upstream. When these barrier lakes expand to a certain size, they will pose a threat to the stability of the barrier. The collapse of the barrier may further cause floods downstream. In this process, geohazard such as earthquakes, landslides, mudslides, and floods are interconnected and interact with each other. Traditional single disaster risk assessment cannot effectively assess the possible harm caused by this disaster chain effect. The risk research of this disaster chain should become the focus of attention in the academic community in the future.

Risk assessment of landslides and debris flows requires a large amount of data support. In the future, data sharing and integration should be strengthened to improve the quality and availability of data. Future research should focus on establishing more refined risk assessment models, incorporating multiple factors such as geology, meteorology, and hydrology to improve the accuracy and reliability of risk assessment.

With the increasing number of geological hazard risk assessment work, there is an urgent need to introduce relevant regulations and technical requirements to standardize the technical work of geological hazards.

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