Landslide hazard evaluation based on linear rupture plane method

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Abstract. In recent years, landslide disasters have occurred frequently, making the evaluation of the susceptibility of landslide hazards a major difficulty and hot topic in current research. The current research focuses on the use of statistical models or information models to analyze landslide hazards. However, the accuracy is not high. We first study the mechanism of landslide geological disasters. Based on this, combined with multi-source geological data, a linear rupture plane method (LRP) is employed to construct the landslide hazard evaluation system. LRP regards the failure surface of the slope as an approximate plane and the section as an approximate straight line. It uses the principle of limit equilibrium to calculate the safety factor of slope. In the paper, the Ziyang area with frequent landslide disasters is taken as the research area. Choosing landslide hazard points in Ziyang County as the sample data, we select seven factors including slope height, slope angle, soil bulk density, soil cohesion, internal friction angle, precipitation intensity and seismic intensity as influencing factors. Based on the LRP, we construct an evaluation system to divide the landslide into three grades: high-risk area, low-risk area and safe area, which provides effective technical support for the early warning and prevention planning of landslide disasters.

1 Introduction

Landslide disaster refers to the natural disaster caused by earthquakes, precipitation, human activities, and other factors, under the combined influence of multiple factors such as gravity and sliding force. In fact, on 31 May 1970, a large earthquake shook the highest part of the Peruvian Andes. Millions of cubic meters of rock dislodged from a mountainside and initiated a rock avalanche that traveled more than 14 km in 3 min, burying a city and killing more than 25,000 people [1]. On 17 February 2006, due to long-term tectonic activity, a landslide of 15 million m³ buried more than 1100 people on Leyte Island in the Philippines [2]. In 2018, a landslide occurred in Leshan City, Sichuan Province, China, with a volume of about 50,000 cubic meters [3].

Fig. 1. Large-scale landslide in Leshan City.

For decades, scholars have never stopped studying landslide disasters. Yu Kai researched the effects of rainfall intensity, rainfall duration and rainfall type on slope stability [4]. Qi Xing thought that landslide evaluation needs to consider three aspects of monitoring equipment, monitoring plan and early warning model [5]. Based on the slope material, elevation, slope, aspect, curvature and other nine factors, Chimidi used GIS statistical methods to evaluate and partition landslides in Jinbi Town, western Ethiopia [6]. Bagheri has done a research in which two types of artificial neural networks including multilayer perceptron (MLP) and Gaussian radial basis function (RBF) were used for the zonation of seismic landslides at a 1:50,000 scale [7].

Although several international and national research about landslide disasters have been studied, we still cannot have a more systematic model to carry out a more accurate early warning of the landslide. Therefore, we put forward a new method that combines the geological data, rainfall data, seismic data, and other multi-source data in the past years to carry out disaster assessment for the landslide point in Ziyang County of Shanxi Province, and established a multi-element integrated landslide disaster early warning model. We first collected landslide data from Shanxi Province in recent years, including rainfall, local geological conditions, etc. Then we compared the geological data, rainfall data, and seismic data of the landslide area with the non-landslide area, find out the major differences and focus on that factor. After reviewing a large amount of geological and

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rainfall data, we employed a modeling method: the landslide is regarded as rigid body sliding, and the external induced factors such as rainfall and earthquake change the force of the landslide body. By using the existing landslide data in Shanxi as training samples, we constructed an evaluation system of the landslide zone. In the aspect of landslide early warning, this paper put forward the possibility of Synthetically Evaluating Landslide Disaster by integrating various landslide data. Compared with the existing data, this method has high feasibility, and also provides a new way of landslide early warning for later scholars.

2 Mechanism

2.1. Mechanism of landslide hazard

The mechanism of landslide hazard is very complicated. To understand the mechanism, we must understand the basic conditions for the formation of landslides at first. It requires (1) Loss of support in front of the mountain. It provides free conditions for the sliding of the mountain, so that there is enough sliding space; (2) Cutting faces on both sides. They create conditions for the soft soil layer to slide down; (3) A weak rock layer. From the type of rock layer, those soft rock groups with sand, gravel, and weathering crust have low shear strength and cannot withstand the effects of gravity and downward displacement and deformation. Besides, the pressure of the rear soil layer on the leading edge soil layer will also cause the occurrence of landslides[8].

Fig. 2. Principle of landslide disaster.

2.2 Inducing factors of landslide

There are many factors that cause landslides. The paper introduces the factors affecting landslide from the perspective of internal factors and external factors.

2.2.1 Internal Factors

(1) Topographic factors include Elevation, Slope, and Aspect. As the elevation increases and the slope increases, the possibility of the landslide is larger. The slope direction indirectly affects light, temperature, and rainfall.

(2) Depending on the hardness of the rock, we usually classify the rock into four categories, I is the hardest, and IV is the softest. The physical parameters of various types of rocks are assigned as shown in the following table [9].

Table 1. The physical parameters of various types of rocks.

Rock Type	c' (MPa)	ϕ' (°)	λ (KN·m-3)	Examples
I	0.035	40	27.0	igneous rocks, quartz diorite
II	0.027	35	25.0	limestone, dolomite, dolomitic limestone, grey dolomite
III	0.020	20	22.0	Shale, phyllite, mudstone, ophiolite
IV	0.015	10	15.0	Terrace gravel, sand

(3) The groundwater has a softening effect on the surrounding rock and soil, and the scouring effect on the slopes of the banks. What's more, it has the hydrodynamic pressure and the hydrostatic pressure to the river.

2.2.3 External Factors

(1) Precipitation will increase the hydrostatic pressure and hydrodynamic pressure of the slope, increase the self-weight of the slope, and further reduce the shear strength of the slope. Atmospheric precipitation is injected into the sliding body, increasing the water content of the rock, softening and increasing the bulk density of the rock and soil, softening the rock and soil, and reducing the shear strength of the rock. Rainfall infiltrates into the bedrock surface or the water-breaking layer below the weathered rock soil to become a lubricant, which reduces the anti-slip property of the contact surface, resulting in the occurrence of landslide.

(2) Earthquake causes the internal structure of the slope soil to be destroyed and changed. Meanwhile, earthquake will influence the groundwater, the sudden increase or decrease of whose level is very unfavorable for the stability of the slope. In addition, the occurrence of a strong earthquake is often accompanied by many aftershocks. Under the repeated vibration shock of the seismic force, the slope earth and rock body are more prone to deformation, and finally it will develop into a landslide.

(3) With the needs of human economic development, human beings have carried out many activities, which have caused a certain degree of damage to the mountain and deepened the possibility of landslides, such as underground mining, open pit mining, surface excavation, quarrying etc.

3 Establishment of landslide susceptibility evaluation system

3.1. Study area

Ziyang County is located in the southern part of Shanxi Province, the upper reaches of the Han River, and the

north of Daba Mountain, with a total area of 2,204 square kilometres. In Ziyang County, there are many mountains and valleys, and the terrain is high in the south and low in the north. The landform is complex, and the geological environment is very fragile. Rainstorms are concentrated in summer and autumn, and heavy rains often occur in this time. The Han River flows through the whole territory from west to east, with numerous tributaries and abundant water. In this region, the Cambrian, Ordovician and Quaternary strata related to geological disasters are widely exposed. Due to the influence of tectonic action, the rock mass is severely broken, and the weathering is strong, resulting in a large amount of loose deposits. Simultaneously magmatic rocks are widely distributed in the area, and affected by long-term weathering, the residual layer has high sand content and loose soil. These are the material basis for the high incidence of landslides and debris flows. In recent years, with the increasing human engineering economic activities, the original stability of many slopes has been destroyed, and the number of landslide disasters has also increased.

Under the influence of complex geological structures, deep faults, strong flow erosion, neotectonics movement, human engineering activities and other internal and external geological processes, geological disasters such as landslides and collapses often occur Ziyang County. According to field investigation, there are 878 geological hazard points in Ziyang County in recent years, of which more than 90% are landslide hazards. These geological hazards, mainly landslides, seriously threatened the safety of people's lives and property, and hindered the development of local social economy.

Fig. 4. Satellite map of Ziyang County

3.2 methods

The shape of sliding surface of landslide is related to soil quality. Generally, the sliding surface of cohesive soil landslide is circular arc, while that of sandy soil landslide is plane. The landslides in Ziyang County are

mainly depositional landslides with loose material structure, small bonding force and strong permeability, and most of the sliding surfaces are planar. Therefore, the linear rupture plane method (LRP) is employed to construct the landslide hazard evaluation system in this paper.

3.2.1 Linear rupture plane method

The linear rupture plane means that when the slope is destroyed, its fracture surface approximates the plane and the section approximates the straight line. Figure 1 shows a sandy slope with a slope height of H , an inclination of α , a slope angle of β , a soil weight of γ ($\triangle ABC$), a cohesive force of c , and an internal friction angle of ϕ [10].

Fig. 3. Schematic diagram of linear rupture plane method

Obviously, the sliding force T generated by the weight of the sliding body ($W = \gamma$) on the sliding surface AC is

$$T = W \sin \alpha \quad (1)$$

and the sliding resistance T' generated by the shear strength of soil is

$$T' = W \cos \alpha \tan \phi + cL \quad (2)$$

The safety factor F_s of the slope can be expressed by the ratio of anti-sliding force to sliding force:

$$F_s = \frac{W \cos \alpha \tan \phi + cL}{W \sin \alpha} \quad (3)$$

3.2.2 landslide susceptibility evaluation system

Using the raster re-classification tool in the spatial analysis function of GIS software, according to the landslide safety factor, the Natural distance classification method is used to divide the area into three categories: high-risk zone, low-risk zone and safe zone. The principle of natural distance classification is to minimize the differences within categories and maximize the differences between categories. This classification method maintains the consistency within categories and the differences between categories, which is an objective classification method [11].

Table 2. Classification of geological hazard risk in Ziyang County

Serial number	Range of F_s	Risk classification
1	0 ~ 0.33	high-risk
2	0.33 ~ 0.67	low-risk
3	0.67 ~ 1	safe

3.3 Analysis of the Results

In the 869 landslide points in Ziyang County, the risk of landslide is classified into three levels by LRP method. Among them, there are 90 landslide points in the safe area, accounting for 10.35%, 522 points in the low-risk area, taking up 60.07%, and 257 points, accounting for 29.58%.

In order to further explore the hazards of landslide disasters on water systems, houses, etc., we can superimpose landslide susceptibility grading maps with these geographic feature maps in arcgis for geospatial analysis. As shown in Figure 4, we can conclude that the area near the river is a high-risk area for landslides. It is of great guiding significance for emergency response to emergency rescue and early warning of the barrier lake.

Fig. 4. Evaluation of landslide susceptibility in Ziyang County

4 Conclusions

In this paper, we have established a landslide susceptibility evaluation system to divide the Ziyang county into different danger zones, and the results indicate that the method performs well. In the method of LRP, we utilize the principle of limit equilibrium to calculate the safety factor of slope. Therefore, the utilized technique can show the deformation, displacement state and trend of geological disasters, provide quantitative data for geological disaster prevention and inform relevant departments to take timely protective measures to reduce or avoid the loss of life and property caused by landslide disasters.

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