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Original Paper

Research on the Joint Evaluation of Geological Disaster Susceptibility Based on Fractal Theory and Hierarchical Analysis Method

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Abstract

In recent years, strong earthquakes and extreme climate events occur frequently in southwest China, forming a large number of mass geological disasters, which seriously threaten the life and property safety of local people. Therefore, so it is particularly important to carry out the refined evaluation of regional geological disaster susceptibility. On the basis of summarizing the previous research results, in the mountain area of mianzhu, Sichuan province, selected elevation, undulation, slope, stratum, fault, drainage, highway, based on the fractal theory (FT) joint level analysis (AHP) evaluation model, realize the study area fine geological disaster prone evaluation, make up for the traditional method in terms of weight determination and calculation accuracy. The evaluation results show that the extremely high prone area and the high prone area are basically concentrated in the low fluctuation area, low slope area, dense water system area and fault concentration area, with an area of 90.38km2 (13.63%). The AUC value of the combined model was 0.865, indicating that the evaluation results have high accuracy and reliability, which can provide necessary support for the geological disaster prevention and control work in Mianzhu city, and can also provide reference for the evaluation of geological disaster susceptibility in similar areas.

Keywords

fractal theory, hierarchical analysis method, susceptibility evaluation

1. Introduction

The susceptibility assessment of geological disasters refers to the possibility of geological disasters under the joint action of various internal and external index factors, and is the basis of the risk assessment and risk assessment of geological disasters. The specific evaluation methods for the susceptibility assessment of geological disasters include three methods: heuristic inference method, statistical method and nonlinear method. Among them, heuristic inference method is an evaluation method combining qualitative analysis and quantitative analysis, such as fuzzy comprehensive evaluation method and hierarchical analysis method, including information model, logistic regression model, etc. Nonlinear method mainly refers to machine learning, including support vector machine, artificial neural network, decision tree, multi-layer perceptron, etc. These evaluation methods and coupling models have been applied in the evaluation of regional geological disasters, with high evaluation accuracy. With the development of the research, the heuristic inference method is simple but subjectively biased; although the statistical method is objective, it is difficult to distinguish the differences between the attribute factors; and the nonlinear method has high accuracy, but the calculation process is too complicated. These problems lead to the low accuracy and reliability of regional geological disaster prone evaluation, and they still face many unsolved problems in the process of geological disaster reduction and prevention.

Fractal theory can be used to characterize the real attributes and conditions of complex things, and can provide quantitative basis for the selection of evaluation indicators of geological disaster susceptibility, and the dimension value can be used to quantitatively describe the spatial distribution characteristics of geological disasters. Therefore, many scholars introduce the fractal theory into the evaluation of geological disaster susceptibility. For example, Juchunyan et al., applied the fractal theory to the spatial analysis of geological disasters in scenic spots to prove that the dimension value can represent the actual relative importance of the index factor; Wang et al., analyzed the sensitivity of the landslide based on the fractal theory and found that the larger the index factor, the higher the sensitivity to the index factor; Liu et al., used the variable dimension fractal theory to quantify the relationship between the landslide and the index factor and conducted the weight calculation. It can be seen that fractal theory can make up for the subjective bias of heuristic inference method in calculating the weight of index factors and the difficulty of statistical method to distinguish the mutual specificity of index factors, and can accurately and objectively represent the real attributes, complexity and difference of index factors.

Through reading and summarizing the relevant literature, the author found that there is no established standard for the calculation of the index factor weight when the predecessors used the fractal theory to evaluate the susceptibility of geological disaster. Therefore, this paper puts forward the joint model of fractal theory and hierarchical analysis, and tries to make up for the deficiency of fractal theory in determining the weight of index factors, so as to improve the calculation accuracy of the weight value of index factors, and then improve the accuracy of geological disaster susceptibility evaluation. The application of hierarchical analysis at home and abroad tends to be mature. For example, with the combination of hierarchical analysis and information method in the research area, the results show that the model is highly operable and the evaluation results are highly reliable; He et al., used the hierarchical analysis method to evaluate the susceptibility of geological disasters in Wanyuan city, and the results showed that the hierarchical analysis method can reasonably determine the weight value of the index factor. It can be seen that the hierarchical analysis method is a combination of subjective and objective evaluation method, and the calculation process is simple and easy to understand. It itself has good operability and accuracy, can solve the nonlinear evaluation method, calculate the tedious problem, simply and effectively calculate the weight value of the target object.

Based on this, based on the northwest mountainous area of Mianzhu City, the previous research results, select 7 index factors of elevation, fluctuation, slope, stratum, fault, water system and highway; establish the joint evaluation model based on fractal theory and hierarchical analysis, calculate the importance of the index factor and determine the weight with the help of ArcGIS software; realize the inspection and evaluation results with ROC curve and historical disaster points. The verification results showed that the AUC value obtained through the joint model was 0.865, and the historical disaster spot density in very high and high prone areas was high and the occupation area was small, indicating that the joint model met the accuracy requirements of regional geological disaster susceptibility evaluation, and the evaluation results were reasonable and effective. The joint model makes full use of the advantages of fractal theory and hierarchical analysis. The combination of the two not only realizes the quantification of the actual importance of each index factor, but also avoids the subjective uncertainty of the previous weight calculation. The evaluation of geological disasters in the research area is reasonable, and the results obtained have some persuasion.

2. Basic Principle of the Evaluation Model

2.1 Fractal Theory

According to the fractal theory, the dimension can represent the real properties and state of the object and is not affected by the observation scale and accuracy, and the larger the dimension, the more complex the object and the more rough; the larger the dimension of the geological disaster index factor, the stronger the effect to the geological disaster.

2.2 Hierarchical Analysis Method

Hierarchical analysis can combine expert experience and practical decision problems to determine the weight value of the object semi-quantitatively, so as to avoid the situation that the weight contradicts the actual importance.

Generally, the 1-9 scale method is used to establish the judgment matrix for each layer of the evaluation system (Table 1).

Table 1. The Meaning of Judgment Matrix and Random Consistency Index Criteria

scale	meaning	RI	short-cut process
1	Two factors compared, have the same importance	1, 2	0
3	Compared to the two factors, the former is slightly more important than the latter	3	0.58
5	Compared to the two factors, the former is significantly more important than the latter	4	0.90
7	Compared to the two factors, the former is strongly more important than the latter	5	1.12
9	Compared with the two factors, the former is extremely important than the latter	6	1.24
2,4,6,8	The median of the judgment adjacent as described above	7	1.32
count backwards	If the importance ratio of a to b is c, the reverse value is 1 / c	…	…

2.3 Evaluation Model of Fractal Theory Joint Hierarchical Analysis Method

Through analysis, it is found that hierarchical analysis can effectively avoid the mismatch between the actual importance and weight of things, but in the process of establishing the judgment matrix, the subjective influence of decision makers is inevitable. Therefore, combine it with the fractal theory, each takes its advantage. Through fractal theory, the dimension value of each index factor, namely the actual importance. Using the actual importance of the index factor and the rules given in Table 1, the judgment matrix is calculated and established to obtain the weight value of each index factor, and then realize the susceptibility evaluation of the research area.

3. Case Analysis

3.1 Overview of the Study Area

Mianzhu city belongs to Deyang City, Sichuan Province, Located at the junction of Chengdu Plain and Longmen Mountains; Developed water system in the area, Mainly mianyuan River, Shiting River, Baishui River, etc.; The northwest of the area is mountainous, The southeast is a plain, The boundary line is obvious; The northwest strata of the region, except for the Ordovician system, From the Jurassic system to the earthquake Dan system are distributed; Complex geological structure in the area, The northwest is in the south part of the central fault zone of Longmen Mountain, The southeast is located in the west-north section of the Longmen Mountain front mountain fault zone, The north is in the middle of the fault zone of Longmen Mountain.

The Wenchuan earthquake and the extreme climate caused a large number of geological disasters in the mountainous areas of Mianzhu city, which threatened the lives and property of the people in the area and restricted the local social and economic development. The author has collected a total of 197 disaster points in the study area, including 8 unstable slopes, 80 landslides, 36 collapses and 73 debris flows. Due to the small difference in the sensitivity of each factor to the four types of geological disasters, it is no need to distinguish them from the different types of disasters.

3.2 Data Sources

Data sources of this paper: "Geospatial Data Cloud" (download 30m level DEM data to extract topographic and landform data), study area 1:200,000 geological map (extract geological data), and national basic geographic database (extract highway and water system data).

3.3 Evaluation Factor Selection and Grading

The occurrence of geological disasters is the result of a combination of various factors, mainly including landform, hydrogeology and other factors. Through the analysis of the development characteristics and spatial-temporal distribution pattern of geological disasters in the study area, it is found that the difference in vertical distribution of the fluctuation of the geological disasters is obvious; the steep change of slope leads to the different spatial distribution of geological disasters. As the basic component of slope body, rock and soil mass plays a controlling role in the stability of slope body in the study area. The rock and soil structure around the fault is damaged and the stability is poor; the river erosion, erosion and lower cutting cause the development of slope cracks; the typical human engineering activities such as slope cutting, excavation and blasting have the most direct impact on geological disasters, which may lead to accelerated destruction of geological disasters.

Therefore, according to the previous research experience and the distribution and development of geological disasters in the research area, seven factors of elevation, fluctuation, slope, stratum, fault, water system and highway were selected as the evaluation indexes. In A rcGIS, fault distance, drainage distance and highway distance are characterized for fault distance, water system and highway, respectively.

Mianzhu city northwest for the mountain, the southeast for the plain, the boundary is obvious. When using ArcGIS for spatial analysis, in order to avoid the impact of the plain part on the evaluation results, the mountainous area of Mianzhu city was selected as the research area, and the natural breakpoint method was used to classify the factors according to the previous research experience and the distribution law of geological disasters in the area.

3.4 Evaluation Results

3.4.1 Important Degree analysis of Index Factors

In this paper, the measurement value of a physical quantity corresponding to the feature scale is expressed as the probability of disaster occurrence (namely the density of disaster dots), and is used for the normalization calculation of the segment interval of each index factor (Table 2). After normalization, the dimension value of each index factor is calculated by cumulative and variable dimension fractal. Take the elevation by the natural breakpoint method of ArcGIS, no disaster distribution in the 9th interval and r=1,2,3,..., 8; determine the hazard density of the segment interval and map in the double log coordinate; transform the first and the second order fractal theory, until the curve has obvious linear relationship to obtain the cumulative and dimension values of each factor.

Table 2. Factor Segmentation Parameter Table

appraise metric	classify siding-to-siding block	dot density	appraise metric	Grading interval	dot density
tall rule	566-786m	0.74	distance break layer distance leave	100-200m	0.22
	786-968m	2.14		200-400m	0.21
	968-1126m	0.54		400-600m	0.30
	1126-1275m	0.20		600-800m	0.507
	1275-1423m	0.10		800-1000m	0.43
	1423-1570m	0.035		1000-1200m	0.20
	1570-1725m	0.039		1200-1400m	0.41
	1725-1889m	0.023		1400-1600m	0.16
slope linear measure	0-10.96°	0.70		1600-1800m	0.10
	10.96-19.52°	0.59		1800-2000m	0.24
	19.52-26.71°	0.42		>2000m	0.1
	26.17-32.88°	0.24	distance water tie distance leave	0-200m	1.02
	32.88-39.04°	0.11		200-400m	0.61
	39.04-45.21°	0.069		400-600m	0.40
	45.21-52.74°	0.051		600-800m	0.17
	52.74-63.70°	0.074		800-1000m	0.12
rise bend over linear measure	0-80m	0.39		>1000m	0.12
	80-147m	0.71	distance state-owned road distance leave	0-200m	1.27
	147-200m	0.16		200-400m	0.52
	200-257m	0.047		400-600m	0.30
	257-335m	0.019		600-800m	0.17
the earth layer	Cambrian system	0.79		800-1000m	0.30
	In the trifold	0.12		>1000m	0.13
	sinian system	1.18	the earth layer	Pleistocene series	0.0068
the earth layer	Continental Upper Triassic-Lower Jurassic	0.11		Holocene series	0.32
	Platform ase-Chinese Triassic	0.21		Mesoproterozoic Erathem	0.42

appraise metric	classify siding-to-siding block	dot density	appraise metric	Grading interval	dot density
	Siluric	0.57		upper Permian series	0.26

Through the calculation of fractal of each factor, it is found that the 7 index factors selected in this paper have obvious fractal characteristics, which are 1.66 (elevation), 1.64 (fluctuation), 1.46 (slope), 1.42 (stratum), 1.14 (distance from fault), 0.48 (distance from water system), and 0.40 (distance from highway). According to the definition of branch theory—"the greater the dimension of the index factor, the stronger the trigger of geological disasters", "dimension value characterize the real properties and state of things", the index factor on the study of geological disasters from large to small order: elevation, fluctuation, slope, formation, fault distance, drainage distance, the distance from the highway.

3.4.2 Weight Analysis of Index Factors

After accumulation and fractal, the dimension value of the index factor is obtained. The index dimension is ranked in importance by the size of the dimension value, and combined with Table (1), the judgment matrix is jointly established to make up for the subjective assumption of the judgment matrix. According to the 1-9 scale method to establish the judgment matrix and calculate the corresponding weight.

The weight values of the scheme layer elements (elevation, fluctuation, slope, stratum, distance from fault, distance from water system and distance from highway) to the decision target layer (evaluation index system of geological disaster susceptibility) are 0.3146, 0.2564, 0.1521, 0.1288, 0.0807, 0.0375 and 0.0282, respectively. Among them, the maximum eigenvalue of the judgment matrix is 7.4755, and the consistency ratio (CR) is 0.0561.

It shows that the joint model can accurately determine the weight value; the evaluation results meet the objective real properties of things and meet the needs of refined evaluation. The evaluation method and the results are reasonable and reliable.

3.5 Analysis of the Susceptibility Assessment Results

Through the induction and analysis of each evaluation factor, the geological disasters mainly occur in the areas with low fluctuation and low slope, and there are almost no geological disasters above the altitude of 1800m. The calculation results show that the number of geological disasters decreases with the slope; geological disasters are widely distributed in fault, water system and highway show some distance effect on geological disasters within 2 km from fault and 1 km from water system and highway.

The grid calculation function of ArcGIS was used to complete the spatial analysis of the evaluation index and divided the geological disaster susceptibility in the study area into five categories: very high (4.95%), high (8.68%), medium (10.22%), low (12.76%), and very low prone (63.39%). Through the analysis, the paper shows that under the influence, the strength and stiffness of rock and soil mass decrease and the slope rebound, and the rock and soil mass around the fault is subjected to pull, pressure, shear, resulting to structural fracture and fracture development, making the rock and soil mass weathering and fracture and geological disasters breed; the dense areas are the breeding areas of geological disasters. The evaluation results show that most of the geological disasters are concentrated near Qingping Town, Tianchi Township and Zundao Town, and they are basically distributed along the water system, faults and valleys.

4. Conclusion

Accurate evaluation of geological disaster susceptibility can provide necessary support for disaster reduction and prevention work. Taking the northwest mountainous area of Mianzhu city as the research area, this paper constructs a joint model based on fractal theory and hierarchical analysis method, and carries out the evaluation research of geological disaster susceptibility. The main conclusions are as follows:

(1) Based on the previous experience and the distribution law of disaster points in the research area, seven factors of elevation, fluctuation, slope, stratum, fault, water system and highway were selected as evaluation indicators, and fractal theory and hierarchical analysis were used to jointly evaluate geological disaster susceptibility. The results show that the index weight value determined by the joint model is consistent with the actual importance value of the factors quantified by the fractal theory, indicating that the joint model can characterize the diversity and complexity of the evaluation target and improve the accuracy of the evaluation.

(2) The evaluation results of geological disaster susceptibility in the study area show that the extremely high geological disaster susceptibility areas are mainly concentrated around the water system and fault with low fluctuation and low slope. Among them, Qingping town and Zundao town are frequent geological disasters, which need to focus on prevention.

(3) The prone zoning map obtained by the joint model is consistent with the actual distribution of geological disasters in the study area. The AUC value of the joint model is 0.865, indicating that the joint model is reasonable, meets the requirements of fine evaluation of geological disaster susceptibility, and can provide support for geological disaster risk management and disaster prevention.

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