Landslide Susceptibility Assessment Based on Slope Unit and Information Value Method in Changbai Mountain District

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Abstract: In order to evaluate the susceptibility to geological disasters in the Changbai Mountains, slopes are used as the basic evaluation unit. Under the ArcGIS platform, the information volume model was used to conduct a zoning evaluation of the susceptibility to geological hazards in the Changbai Mountains in the study area. The evaluation results show that the overall geological hazards in the Changbai Mountains present a "C" shaped distribution, with higher geological hazard risks on the outside and lower geological hazard risks on the inside. The extremely high-risk area is located in Antu County, and the high-risk area is located in the western part of Fusong County and the western part of Linjiang City. The landslide-prone areas in the Changbai Mountains (including extremely prone and highly prone areas) cover a total area of 2995km^2, accounting for 19.85% of the entire region. The application of information quantity model to evaluate landslide susceptibility has high prediction accuracy. The proportion of existing landslide points falling in very prone areas and high prone areas is 72.86%, which truly reflects the objective reality.

Keywords: Geological Hazards; Changbai Mountain Area; Slope Unit; Susceptibility Evaluation; Amount of Information

1. Introduction

Geological disasters in mountainous areas, especially landslides, have become one of the key topics in the field of international geography and geology research due to their sudden and destructive effects. In recent years, with global climate change and expanding human activities, risk assessment and prediction of geological hazards in mountainous areas have received increasing attention [1-3]. In order to effectively prevent and mitigate the impact of these natural disasters, it is particularly important to conduct zoning assessment of landslide disaster susceptibility.

In the in-depth discussion of domestic and foreign research progress in this field, a variety of landslide susceptibility evaluation methods have been developed. Among them, traditional methods such as analytic hierarchy process, logistic regression, and information volume model are widely used because of their solid theoretical foundation [4-6]; at the same time, emerging methods such as machine learning technology such as support vector machines have also begun to emerge in this field [7]. With the widespread use of GIS technology, these methods can process spatial data more precisely and provide more accurate judgments on the susceptibility to geological disasters [8].

Despite significant progress in existing methods, the selection of evaluation units remains a critical point in research. Traditional grid cells cannot accurately describe the landslide susceptibility of complex terrain to a certain extent. In contrast, the method of setting the slope as the evaluation unit can better reflect the actual topographic and geomorphological characteristics and improve the accuracy of the evaluation [9-11]. Based on the development status of geological landslides in the Changbai Mountains, Using 10 evaluation indicators of land use and rainfall, an information model is applied, and based on specific geomorphological units, an extensive evaluation of the propensity for landslides within the region is carried out, aiming to provide scientific guidance and reference for geological disaster prevention and regional safety management.

2. Data and Research Area

Changbai Mountain is located in Northeast China, as shown in Figure 1. It is a key ecological security barrier and a treasure house of biodiversity. Located in the Pacific Ring of Fire, the region exhibits a complicated geological framework, and the terrain is dominated by mountains and plateaus. Mount Changbai's Heavenly Lake volcano stands as the emblematic geological landmark of the area and China's biggest active volcano. Geologic factors have induced intense alterations in the topography, with notable development of inclined lands, which has crafted a diverse array of terrain types.

Regarding climatic conditions, the region is influenced by a temperate monsoonal climate, showing obvious seasonal changes and vertical climate zone distribution. The summer is humid, and precipitation is concentrated; the winter is dry and cold, and the snow cover lasts for a long time. These climate characteristics have a significant impact on geological disasters such as soil erosion and landslides in the region.

The ecological environment in the region is sensitive and fragile, and frequent human activities and natural factors converge, exacerbating regional disaster risks. Landslide disasters, in particular, pose a high risk of disaster due to the particularity of terrain and climate conditions. Therefore, the combination of slope units and the information method is of great significance for evaluating the susceptibility to landslide disasters in the Changbai Mountains and can furnish a scientific foundation for the prevention and alleviation of disasters.

The geological disaster data in this article come from the Changbai Mountain Highway Geological Survey data. The elevation, soil and land use data come from the Earth Resources Data Cloud Platform. The fault data come from the Geological Cloud Platform 1:500,000 geological map. Lithology The data comes from the 1:500,000 geological map, and the NDVI data comes from the USGS website.

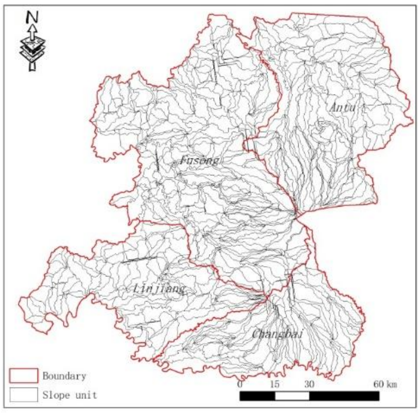

Figure 1. Slope Unit Map of Changbai Mountain Area

3. Research Methods

The model gauges the link strength between critical factors and the focal topic by the measure of information volume. Using information models for landslide susceptibility evaluation involves transforming the measurements of influence factors into information values that indicate landslide occurrence, based on data from known landslides. [12].

The landslide phenomenon (y) is affected by a combination of factors (xi, i = 1,2,⋯,n). Various factors have different effects on landslides. The categories and combinations of various influencing factors must be comprehensively considered. The calculation formula of the information volume model is:

$$I(\mathrm{y}, \mathrm{x1\ x2 \cdots xn}) = \ln \frac{\mathrm{P(y,x1\ x2 \cdots xn)}}{\mathrm{P(y)}} \quad (1)$$

Where I(y,x1 x2 ⋯ x n) is the amount of information provided by the factor combination x1， x2⋯xn; P(y,x1 x2⋯xn) is the probability of landslide occurrence under the combination of factors x1， x2⋯xn; P(y) is the probability of landslide occurrence.

According to conditional probability operation, formula (1) can be further written as:

$$I(\mathrm{y}, \mathrm{x1\ x2 \cdots x\ n}) = I(\mathrm{y}, \mathrm{x1})1 + I\,\mathrm{x1}(\mathrm{y}, \mathrm{x2}) + \cdots + I\,\mathrm{x1x2 \cdots xn} - 1(\mathrm{y}, \mathrm{xn}) \quad (2)$$

The formula denotes I x1(y, x2) as the informational content that factor x2 offers about the likelihood of landslides, conditioned on the factor x1. Equations (1) and (2) are theoretical models of the amount of information. In actual calculations, the sample frequency can be used to calculate the amount of information, approach:

$$I(\mathrm{xi},\mathrm{H}) = \ln\frac{\mathrm{Ni}/\mathrm{N}}{\mathrm{Si}/\mathrm{S}} \quad (3)$$

In the formula: I(xi ,H) represents the quantity of insight contributed by the assessment factor xi regarding the incidence of landslides; S is the total number of evaluation units in the study area; Si is the number of units containing evaluation factors xi in the study area; N is the number of units containing landslides in the study area The total number of distributed units; Ni is the number of units where the landslide falls within the evaluation factor xi.

Calculate the total amount of information Ii provided on the occurrence of landslides under n combinations of factors in a single evaluation unit, approach:

$$I\mathrm{i} = \sum_{\mathrm{i}=1}^{\mathrm{n}} I(\mathrm{xi}, H) = \sum_{\mathrm{i}=1}^{\mathrm{n}} ln(\frac{\mathrm{Ni}/\mathrm{N}}{\mathrm{Si}/S}) \quad (4)$$

The total information value Ii is used as a comprehensive indicator of the impact of the evaluation unit on the occurrence of landslides. A greater unit information value suggests a higher likelihood for landslides to occur, indicating increased susceptibility of the area to such events.

4 Results and Analysis

4.1 Division of Slope Units

Slope unit division refers to dividing continuous slope areas with similar terrain characteristics or ground object attributes into several units for geological surveys, landslide risk assessment, land use planning and other applications. Landslides typically take place on slopes, which are the fundamental terrain units prone to such events. Therefore, the slope unit is an ideal unit for landslide susceptibility evaluation, and it is also consistent with the actual situation. This article uses ArcGIS as the platform and divides slope units based on a numerical elevation model (DEM). Therefore, this article refers to the methods introduced by Xie [13] to establish slope units in ArcGIS. The process begins by deriving the river network (valley contours) from the base DEM dataset with ArcGIS's hydrology analysis features, creating a positive relief watershed; afterward, the DEM data is reversed to switch the elevations, and employing the same hydrology analysis, the river network (ridge contours) for a negative relief catchment area is established. In the final step, the union of the catchment areas created from the positively and negatively contoured topography yields two slope divisions. These divisions are illustrated in Figure 1.

4.2 Evaluation Methods

Variables chosen for evaluation encompass elevation, incline, orientation, slope situation, undulation, micro-topography, fault clearance, aquatic system separation, road remoteness, NDVI, geological stratification, types of soil, patterns of land use, and annual rainfall. Calculate the single information value of each element at different levels and use the partition statistics function to extract the single information value of each slope unit. 10 evaluation factor layers were obtained. Reclassify the continuously distributed data in the factor layer to obtain 10 classified factor layers. The classification of each layer is shown in Table 1; the evaluation factor layers after the 10 classifications were spatially analyzed with the landslide distribution map in ArcGIS to obtain the distribution density of landslides in different factors and different classifications, and then calculated according to formula (4) The information value of each factor layer's impact on landslides by each category is shown in Figure 2. Perform spatial overlay analysis on 10 information content layers to generate a landslide susceptibility index map with the total information content value as the evaluation index.

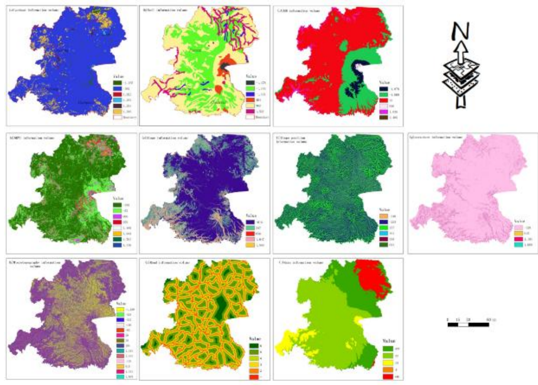

Figure 2. Distribution of Information Content of 10 Evaluation Factors

Table 1. Information Value of Each Evaluation Factor

Evaluation factor layer	Classification	Classification Value	Information Value
DEM	<500	1	1.835
	500-1000	2	0.058

	1000-1500	3	-1.609
	1500-2000	4	-1.078
	2000-2500	5	0.916
	>2500	6	2.485
Slope	<10	1	-0.616
	10-20	2	0.247
	20-30	3	1.047
	30-40	4	1.566
	>40	5	0.656
Slope position	ridge	1	0.157
	uphill	2	0.338
	mid slope	3	0.191
	flat slope	4	0.811
	downhill	5	-0.248
	valley	6	-0.223
Curvature	<10	1	-0.128
	10-20	2	1.181
	30-30	3	1.668
	>30	4	0.615
Micro landform	canyon, deep stream	1	0.104
	shallow valley	2	-0.162
	Highland	3	0.039
	U-shaped valley	4	-0.527
	plain	5	-1.109
	open slope	6	1.435
	Up slopes and terraces	7	-0.528
	ridge in local valley	8	1.191
	A hilltop	9	-0.083
	Mountain top, high ridge	10	-0.02
NDVI	<2000	1	4.366
	2000-3000	2	1.701
	3000-4000	3	1.46
	4000-5000	4	1.668
	5000-6000	5	0.970
	6000-7000	6	0.608
	7000-8000	7	-0.052
	>8000	8	-0.388
Landuse	farmland	1	1.386
	woodland	2	-0.382
	grassland	3	-1.155
	Water body	4	1.025
	architecture	5	1.293
	unused land	6	1.203
Soil	brown	1	0.962
	meadow	2	1.521
	white	3	-1.155
	Swamp	4	-1.121
	Forest	5	0.454
	volcanic	6	-1.178
Distance from road	<200	1	0.235
	200-500	2	-0.3
	500-1000	3	-0.461

	1000-2000	4	-0.06
	2000-5000	5	0.506
	>5000	6	-0.731
Annual precipitation	<700	1	0.488
	700-800	2	-0.207
	800-900	3	-0.055
	900-1000	4	-0.032
	>1000	5	2.02

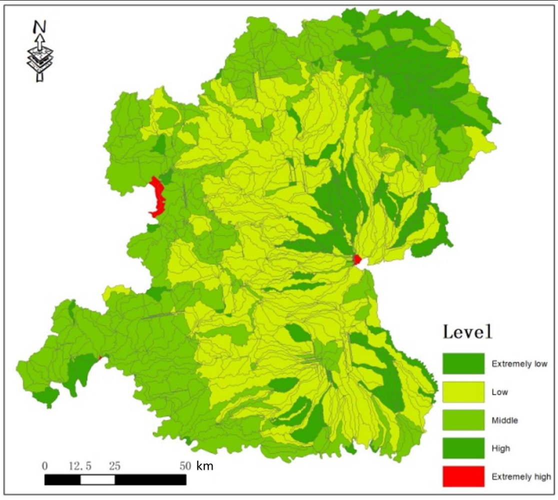

Figure 3. Geological Hazard Risk Assessment Classification Chart in Changbai Mountains Based on Slope Units

A higher aggregate information value indicates a greater collective impact of various factors on landslide occurrence, signaling an increased likelihood of landslides, in other words, the higher the landslide susceptibility. Utilizing the natural break classification method in ArcGIS, landslide susceptibility in the Changbai Mountains is categorized into five levels: extremely high, high, moderate, low, and very low susceptibility, as depicted in Figure 3. The area of extreme susceptibility is found in Antu County, whereas areas with high susceptibility are predominantly in the western parts of Fusong County and Linjiang City, forming a "C" shaped pattern. The vulnerability to geohazards follows a pattern of being higher on the exterior and lower towards the interior.

The distribution of susceptibility grades and actual landslides is shown in Table 2. The landslide-prone area in the Changbai Mountains (including extremely susceptible and highly susceptible) covers a total area of 2995km2, accounting for 19.85% of the entire region, and contains a total of 306 landslide points, accounting for 72.86% of the total number of landslides. As the susceptibility level gradually increases, the number of actual landslide points contained in each prone area also gradually increases, and the rate of landslide occurrence also increases, indicating that the susceptibility zoning obtained using the information model is consistent with the actual landslide development. The distribution characteristics are consistent, and the evaluation results are reasonable.

Table 2. Information Value Values Corresponding to Susceptibility Levels and Comparison with Actual Landslide Distribution

susceptibility level	Information value	Area/km2	Proportion of area/%	Number of landslides	Proportion of landslides/%
extremely low	-4.13~-0.12	3303.8172	21.90	1	0.24
Low	-0.12~1.53	4758.1812	31.54	27	6.43
middle	1.53~3.40	4030.5132	26.71	86	20.48
high	3.40~6.68	2248.0992	14.9	115	27.38
extremely high	6.68~9.23	746.9064	4.95	191	45.48
total	——	15087.52	100	420	100

5. Conclusion and Discussion

This study combines the slope unit and the information quantity method to evaluate the landslide susceptibility. The results show that it is feasible to use the information quantity model and use the slope segment as the basic unit to evaluate the landslide susceptibility in the study area. Geological hazards in the Changbai Mountains generally present a "C"-shaped distribution. The risk of geological disasters is higher on the outside and lower on the inside. The extremely high-risk area is located in Antu County, and the high-risk area is located in the western part of Fusong County and the western part of Linjiang City.

The landslide-prone area in the Changbai Mountains (including extremely susceptible and highly susceptible) covers a total area of 2995km2, accounting for 19.85% of the entire region, and contains a total of 306 landslide points, accounting for 72.86% of the total number of landslides. Compared with the traditional rectangular grid unit, using slopes as evaluation units improves the consistency with the actual topography, and the final susceptibility map can more accurately reflect the geological environmental conditions for landslide formation.

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