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Landslide Susceptibility Evaluation in Yanbian Region

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ABSTRACT : In order to evaluate landslide susceptibility in Yanbian region, this study analyzed 7 factors related to landslide occurrence, such as soil, geology, land use, slope, slope aspect, fault and river by Analytic Hierarchy Process (AHP), and calculated the weights of these 7 hazard-induced factors, determined the internal weights and the relative weights between various factors. According to these weights, combining the Remote Sensing technology (RS) with Geographic Information System technology (GIS), the selected area was evaluated by using GIS raster data analysis function, then landslide susceptibility chart was mapped out. The comprehensive analysis of AHP and GIS showed that there has unstable area with the potential risk of sliding in the research area. The result of landslide susceptibility agrees well with the historical landslides, which proves the accuracy of adopted methods and hazard-induced factors.

Keywords : RS, GIS, Landslide, Susceptibility, Hazard factors, AHP

1. Introduction

Landslide is a geological phenomenon that rock mass of slop slip down along certain sliding surface (Liu, 1993). At present, evaluation methods of slope stability can be roughly divided into two categories: qualitative analysis and quantitative analysis (Xia and Li, 2002). Application of GIS in slope hazards started in the 1970s. It is used more and more widely in the 1980s, especially in the 1990s. Many scholars at home and abroad have carried out studies on landslide based on GIS. For example, Tang (2004) made prognostic map of earthquake-induced landslides caution area in Yunnan province according to four factors such as seismic intensity, terrain slope, rock soil mass types, existing landslide density by overlay analysis function of ArcGis. Carrara, et al. (1991) made a risk evaluation of landslide hazard by GIS techniques and statistical models in 1991. Xu, et al. (2010) made an evaluation on landslide susceptibility induced by 2008 Wenchuan earthquake, developed Wenchuan earthquake induced landslide hazard and related terrain, geological spatial database by using GIS, analyzed 8 landslide-induced factors by transfer coefficient method, and evaluated earthquake-induced landslide susceptibility of combination types of 16 different affecting factors (Xu et al., 2010). Wooten and Richard (2006) made geological hazard risk assessment by fuzzy mathematics and analytic hierarchy process based on GIS. Hereto, the combination of GIS with mathematical modelling method has become one of the key methods of investigating landslide hazard. Zhang and Quan (2013) made an analysis of Baekdu Mountain region landslide susceptibility by AHP based on GIS. Han (2001) made a research on landslides along roads of Yanbian region (Ma et al., 2014). Ma, et al. (2014) made an analysis of geological hazard susceptibility in Antu county, Jilin province based on GIS spatial analysis technology (Han, 2001). Many scholars have made some investigations on landslide in Yanbian region in recently years, however, the most investigation area of these studies are just the local areas of Baekdu Mountain region of Yanbian autonomous prefecture, or a specific landslide, moreover, the related landslide hazards information is decentralized without an efficient system generally, thus, it is necessary to make an analysis of landslide susceptibility of the whole area of Yanbian autonomous prefecture region by GIS, remote technology sensing etc. to improve landslide prediction ability and effective response to it. According to the above finding, this paper made analysis of selected 7 main landslide hazard-induced factors such as geology, river, land use, slope, slope aspect, soil moisture content and fault. And carried out investigation on landslides

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of Yanbian region by Analytic Hierarchy Process and GIS grid analysis to enhance landslide forecast and response ability.

2. Conditions of investigation region

Yanbian autonomous prefecture region is located in the east of Jilin province, the borders of China, Russia and North Korea, lies between 41 degrees 59 minutes and 44 degrees 30 minutes north latitude, between 127 degrees 27 minutes and 131 degrees 18 minutes east longitude. Yanbian autonomous prefecture situated in the upper Baekdu mountain region, mountainous region accounts for 54.8% of Yanbian's total area, plateau accounts for 6.4%, vally accounts for 13.2%, valley plain accounts for 12.3%, hills accounts for 13.3%. Topographically high in the west and low in the east, with a terrain sloping from the southwest, northwest, northeast to the southeast, the lowest region is Hunchun city. The whole landscape appears in three gradient: mountains, hills, basins. Mountains are mostly distributed in the surrounding area, hills are mostly distributed in the edge of mountain, basins are mostly distributed on both sides of the river and distributed between the mountains. Yanbian region has deep ravine, abrupt slope, steep terrain, undulating topography, complex geologic structure, fragmentized rock mass, larger rainfall, furthermore, recently the tectonic earthquake is also very active in Baekdu mountain region. These factors are very easy to cause the occurrence of various geological hazards, especially landslide.

3. Landslide hazard-induced factors

The major factors of landslide hazard can be divided into internal and external factors. Internal factors are mainly topography and landforms, formation lithology, geological structure, hydrogeology etc. Topography and landforms conditions: only in a certain geomorphologic location, with a certain slope might landslide be occur. Formation lithology conditions: rock mass is the material basis for the landslide hazard, in general, landslides are easy to occur in rock and soil mass with reservoir structure, water collection condition and weak surface. The formation of landslide is related to sturdiness and uniformity of rock soil mass, tilt properties of slope and rock stratum, etc. Geological structure conditions: rock mass structure and occurrence have a great effect on hillside stability and formation and development of sliding surface. Generally the steeper the contact surface of accumulational layer and underlying bed, the lager the sliding force, the greater the likelihood of landslide. Hydrogeology conditions: groundwater movement has an important role in landslide formation. External inducing factors such as earthquake, rainfall, snow melt, surface water scouring and soaking, and unreasonable human engineering activities all could change the basic conditions of landslide occurrence, and induce landslide hazards. This paper analyzed 7 main landslide hazard-induced factors: geology, river, land use, slope, slope aspect, soil moisture content and fault. The reason why we select these 7 factors from various hazard-induced factors is because these factors not only include internal and external factors, but also are the greater influencing factors from traditional landslide research results. However, the data of the factors such as earthquake and rainfall is insufficient at present, integrated research can not be carried out, so they will not be considered here in this paper.

3.1 Slope

Slope refers to the angle between horizontal plane and tangent plane of a point on the ground. The slope figure of the paper was made from contour map of Yanbian autonomous prefecture topographic map by Arcgis software, as shown in Figure 1 below. According to landslide hazard evaluation

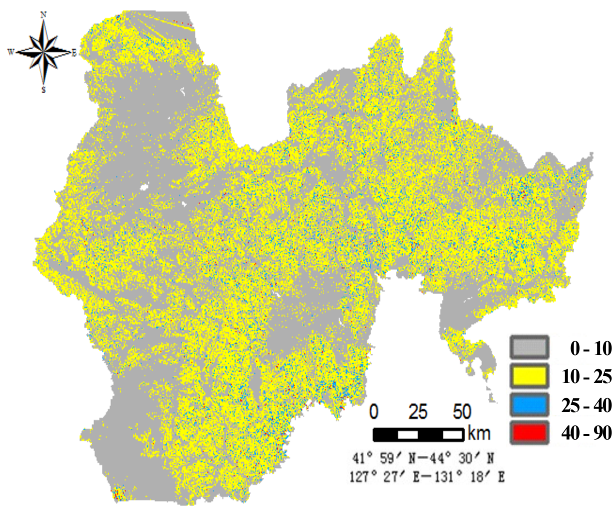

Fig. 1. Slope map

Table 1. Slope reclassification results

Degree	0-10	10-25	25-45	45-90
Reclassification	1	3	5	5

index system and consultation with relevant experts, the importance degree of various slopes to landslide was divided in the paper, slope range was classified into 4 types: 0° to 10°, 10° to 25°, 25° to 45° and 45° to 90°, and each of these 4 types was reclassified, as shown in Table 1 below.

3.2 Slope aspect

Slope aspect refers to the angle between the due north direction of a point on the ground and the projection of normal vector of tangent plane on horizontal plane, which is one of the important factor for analyzing landslide susceptibility. The slope aspect map of this paper was made from contour map of Yanbian autonomous prefecture topographic map by Arcgis software, as shown in Fig. 2 below. The importance degree of various slope aspects to landslide was divided in the paper, the range of slope aspects was classified into 3 types: S, SE, SW; N, NE, E and W, NW, and each of these 3 types was reclassified, as shown in Table 2 below.

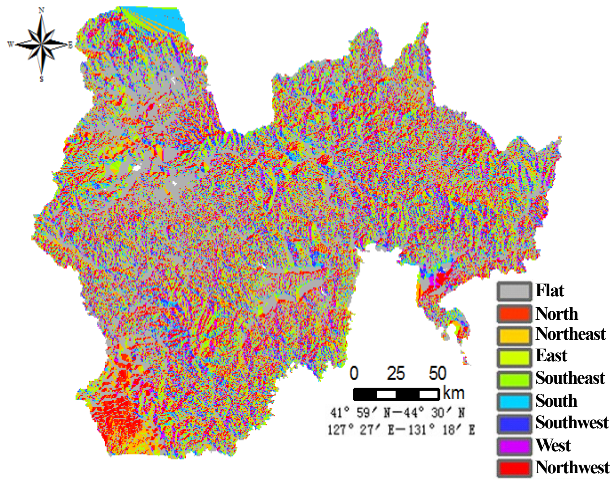

Fig. 2. Slope aspect map

Table 2. Slope reclassification results

Slope aspects	S、SE、SW	N、NE、E	W、NW
Reclassification	5	3	2

3.3 Land use

Different land use condition has different effect on landslides, it is also one of the key influencing factor. This paper converted the land use elements map to grid map by Arcgis software, as shown in Fig. 3 below. Land use was divided into 4 types: residential area, orchard, forest and river, and each of these 4 types was reclassified, as shown in Table 3 below.

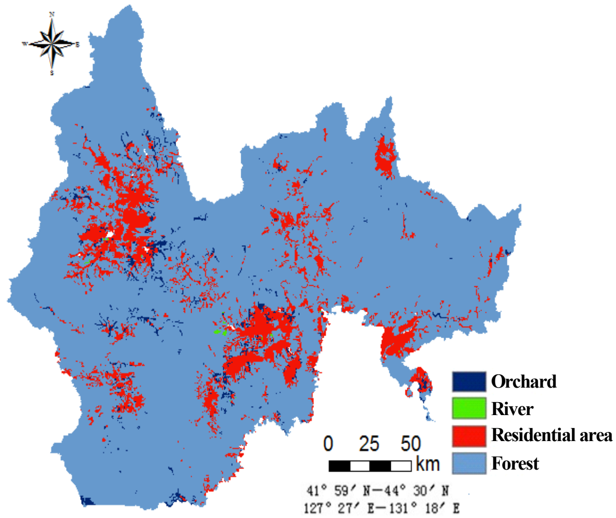

Fig. 3. Land use map

Table 3. Reclassification results of land use

Land use	Residential area	Orchard	Forest	River
Reclassification	1	3	5	2

3.4 Hydrogeology

The hydrogeologic map adopted is Jilin province hydrogeologic map with scale of 1:2500000, we adjusted the coordinate of it by remote sensing software PG, and converted it to grid map by Arcgis software, then selected the map of Yanbian autonomous prefecture region. The hydrogeologic map was mainly divided into 5 types: metamorphic rocks and jointed water-bearing rock group-intrusive rocks and water-bearing rock group (A), extrusive rocks and water-bearing rock group (B), clastic rocks and pore-fracture water-bearing rock group-clastic rocks and water-bearing rock group (C), loose rocks and pore water-bearing rock group with abundant water (D), loose rocks and pore water-bearing rock group with weak water (E), as shown in Figure 4 below. Each of these five types was reclassified according to its water storage capacity, as shown in Table 4 below.

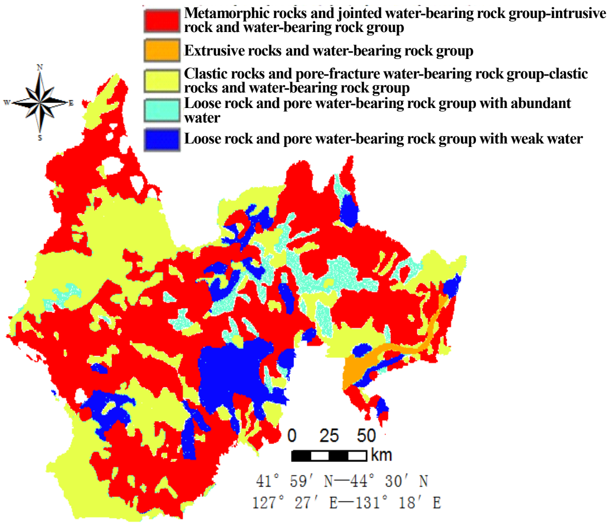

Fig. 4. Slope aspect map

Table 4. Reclassification results of land use

Hydrogeology	A	B	C	D	E
Reclassification	4	5	3	5	1

3.5 Soil

Factors such as soil constituent, permeability, weathering degree etc. have great effect on landslides, especially during rainy seasons, the impact of soil moisture content on landslide is quite significant, because excessive moisture content in the soil can lead to the defects of mountain structure, then occurrence of landslides, which will cause much damage to the people's lives and properties. Thus, the soil moisture content was selected as one of the hazard-induced factors for studying the landslide susceptibility. The soil moisture

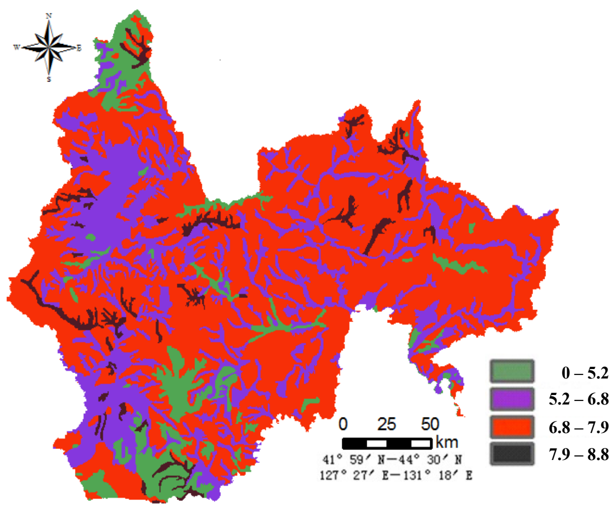

Fig. 5. The soil moisture content map

Table 5. Reclassification results of land use

Hydrogeology	A	B	C	D
Reclassification	4	5	3	5

content map of this paper was selected as a separate layer from Yanbian autonomous prefecture soil, and was converted to grid map, as shown in Figure 5 below. Then, the reclassification was carried out according to soil moisture content, as shown in Table 5.

3.6 River

Hydrology is also a relatively important influencing factor of landslides. when the sliding-prone strata of the slope is cut by weak structure, and its connection with surrounding rock mass is weak or even separated, combined with enough free face in front of it, slip plane is exposed, then landslide is occurred. If lots of free faces are formed as the river sapping, it makes the exposure of a great amount of slip planes, which will facilitate the occurrence of landslides. Thus, it is necessary to consider river hazard-inducing factor. The river map was generated from Yanbian autonomous prefecture river elements map and converted to grid map by Arcgis software, as shown in Figure 6 below. This paper made 4 level buffers for river banks, as shown in Table 6.

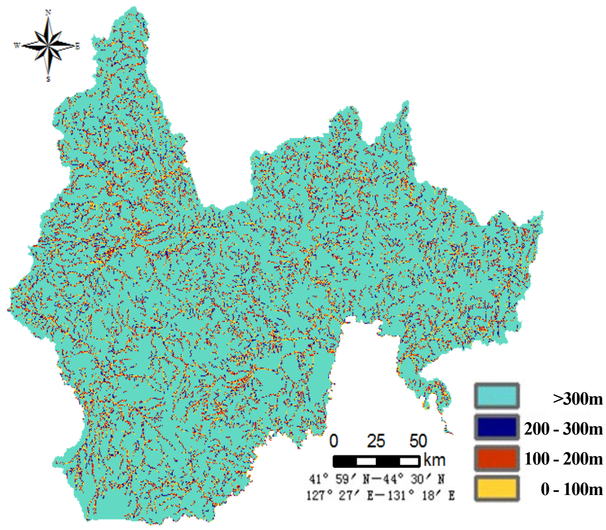

Fig. 6. The river map

Table 6. Reclassification results of land use

Buffer distance	0-100	100-200	200-300	>300
Reclassification	4	3	2	1

Table 7. Judgement matrices and weights of landslide hazard-induced factors

	Slope	Slope aspect	Hydrogeology	Soil moisture content	Land use	River	Fault
Slope	1	9	5	3	6	8	7
Slope aspect	1/9	1	1/5	1/6	1/4	1/2	1/3
Hydrogeology	1/5	5	1	1/2	2	4	3
Soil moisture content	1/3	6	2	1	3	5	4
Land use	1/6	4	1/2	1/3	1	3	2
River	1/8	2	1/4	1/5	1/3	1	1/2
Fault	1/7	3	1/3	1/4	1/2	2	1
Weight	0.437	0.028	0.136	0.204	0.092	0.041	0.061

3.7 Fault

The existence of the fault is mainly because of the damage of the rock soil mass of fault zone and its nearby area, which reduces the integrity of the slope, meanwhile, as the important underground water channel, it will also has inevitably impact on slope deformation and deterioration. Generally the faulted structure of landslide in the whole is rather developmental. Thus, fault is a non-negligible hazard-induced factor. The fault map was generated from Yanbian autonomous prefecture fault elements map and converted to grid map by Arcgis software, as shown in Figure 7 below. This paper made 4 level buffers for fault, and made reclassification for each level, as shown in Table 7.

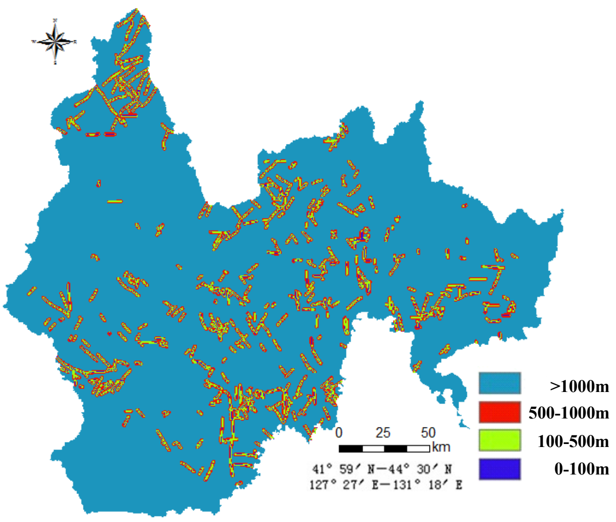

Fig. 7. Fault map

Table 8. Reclassification results of land use

Buffer distance	0-100	100-500	500-1000	>1000
Reclassification	4	3	2	1

4. Research methods

Firstly, this paper calculated the weights of selected 7 landslide hazard-induced factors by Analytic Hierarchy Process (AHP), and reclassified internal factors of these 7 hazard-induced factors according to relatively internal significance by the reclassification function of Arcgis software, then overlayed hazard-induced factors with relative weights for one another by raster data overlay function of Arcgis software, and finally got the landslide susceptibility map.

4.1 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is presented by Saaty (1980), an American professor, which is a simple, flexible and practical multiple attribute decision-making method for making quantitative analysis of the qualitative question. Weights of various hazard-induced factors were determined by AHP, the judgment matrix is shown in the following Table 8.

We checked the consistency of judgment matrix, set the maximum eigenvalue and eigenvector to λ_{max} and W respectively. Values of λ_{max}, W and CR were calculated by MMULT equation of Excel quickly to check Whether they meet the consistency.

The calculation results are: λ_{max}=7.246, eigenvector W=[3.062, 0.198, 0.954, 1.426, 0.645, 0.286, 0.430]. After the normalization processing, the results are: W=[0.437, 0.028, 0.136, 0.204, 0.092, 0.041, 0.061], consistency index(CI)=0.041, according to formula 3.6, the judgment matrix is 7-order matrix, RI=1.32, CR=0.0316<0.1, meet the consistency requirements.

4.2 Classification of landslide susceptibility based on GIS

This paper calculated the weights of each hazard-induced

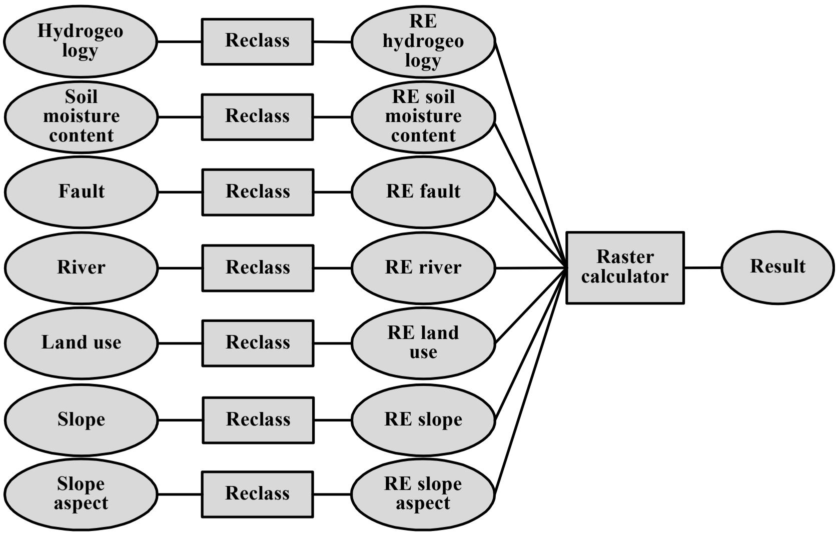

Fig. 8. Grid data overlay process diagram

factor by AHP, then calculated and analyzed them by grid-overlay analyst method. Within the grid data, overlay computing is done by various computations of pixels.

Set x_1, x_2, …, …, x_n to attribute values respectively under the same coordinate from level 1 to level n, set f function to the relationship between the properties and the user demand of each level, set E to attribute value of attribute output layer, then E=f (x_1, x_2, …, x_n) (Tang, et al., 2010). Clicking the model builder of Arcgis software, putting grid calculator and reclassification functions into it, then adding the data into it, we can carry out the reclassification and overlay analysis of grid data.

5. Results and discussion

Yanbian region landslide susceptibility chart is obtained by the above methods and data, as shown in Figure 9 below.

The chart is classified according to natural discontinuities classification method, which includes 4 areas, namely security area, medium-security area, high hazard area, extremely high risk area. Black spots shown in the picture are historical landslide spots, totally 107 spots. It is shown that there are 59 landslide spots in extremely high risk area, accounts for 55% of the total spots, 27 spots in high hazard area, accounts for 25%, 15 spots in medium-security area, accounts for 14%, 6 spots in security area, accounts for 6%.

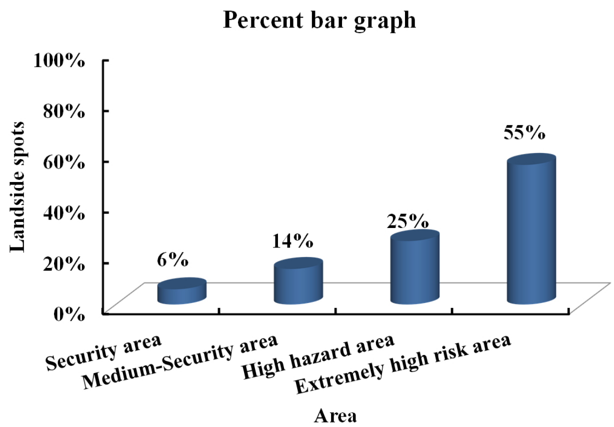

Fig. 9. Yanbian region landslides data graph

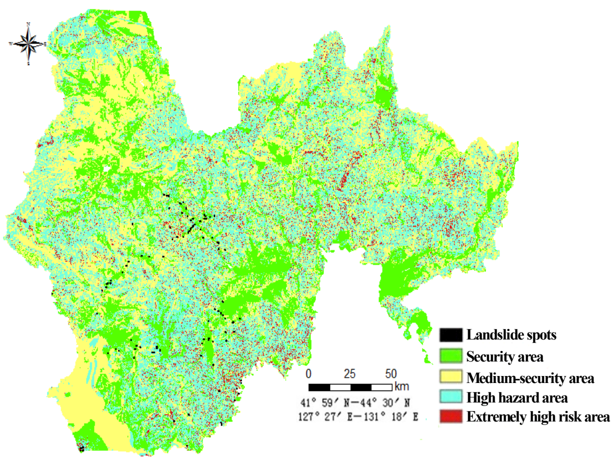

Fig. 10. Landslide susceptibility figure

6. Conclusions

(1) According to the weights results of 7 hazard-induced factors (slope, slope aspect, hydrogeology, soil moisture

content, land use, river, fault), it is shown that slope, hydrogeology and soil have relatively larger impact on landslide.

(2) By comparing Yanbian region landslide susceptibility chart and historical landslide spots chart, it can be seen that coincidence rate of landslides in extremely high risk area, high hazard area and historical landslide spots is about 80%. It is indicated that the combination of AHP method and GIS technology is feasible for analyzing Yanbian region landslides susceptibility.

(3) We can see from the landslides susceptibility chart that extremely high risk landslide regions are mainly distributed around regions of Baekdu Mountain Heaven Lake, Helong city, Antu county etc.

(4) Landslide hazards evaluation based on GIS is fast and efficient, and gains better results, which extends geological hazard assessment theory and practice in terms of methodology, provides more reliable data for further effective landslide prediction and forecast in Yanbian region.

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