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Evaluation of Disaster Susceptibility and Analysis of Influencing Factors in Tuquan County

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Abstract: ***Geological disasters are complex and serious natural disasters that are related to geological conditions and affected by human activities and climate change. Therefore, it is of great significance to evaluate the susceptibility of geological disasters and analyze their main influencing factors. This study took Tuquan County, Xing'an League, Inner Mongolia Autonomous Region as the research object. Eight indicators, including elevation, terrain slope, landform type, geological structure, rock and soil type, vegetation coverage, water flow intensity index (SPI), and terrain wetness index (TWI), were selected for susceptibility evaluation. The final results were divided into four areas: high, medium, low, and non-susceptible areas. The study found that geological disasters in the region are affected by factors such as rainfall, earthquakes, and human engineering activities. Rainfall and human activities are the main triggers for the development of disasters.***

Keywords: Geological Disasters, Susceptibility, Influencing Factors, Disaster Mode**.**

1. Introduction

Geological disasters refer to large-scale, often synergistic rock and soil movements caused by natural or human factors, which cause significant damage to human life, property and living environment on the earth's surface. In recent years, the acceleration of human urbanization has exacerbated the adverse impact on nature. Coupled with global climate change, geological disasters have occurred frequently, posing huge threats and losses to human society. As early as the 1930s, the Soviet Union began to conduct qualitative exploration of the formation and distribution laws of geological disaster zones. Many studies tend to adopt a multi-factor comprehensive evaluation method to establish a geological disaster susceptibility evaluation model based on geological, meteorological and topographic factors. For example, in 2022, Zhao et al. developed six machine learning models to assess the sensitivity of geohazards in the Hengduan Mountain area and developed a geohazard sensitivity map of HMR, which provides information for multi-hazard risk assessment and management in the region [1]. In 2021, Gao et al. adopted a method to establish an optimal weighting scheme for multi-geological hazard sensitivity mapping. The information gain ratio (IGR) method was used to analyze the predictive ability of conditional factors; the support vector machine (SVM) algorithm was used to evaluate the sensitivity of collapse, landslides, and mudflows in the study area; the receiver operating characteristic curve (ROC) and the classification statistics of geological hazard samples were used to evaluate the performance of the model. The optimal weighting scheme for collapse, landslides, and mudflows was determined by combining the analytic hierarchy process (AHP) and the frequency ratio (FR) method [2]. Ma et al. used the Geographically Weighted Regression (GWR) model to divide the study area into regional scales and obtained seven local areas with low spatial autocorrelation of each evaluation factor. Then, 11 influencing factors such as elevation and topography were selected for susceptibility evaluation [3]. C Cao et al. used traditional machine learning methods to analyze landslide susceptibility and applied InSAR technology to modify the inappropriate traditional landslide susceptibility zoning [4]. In recent years, researchers have begun to pay attention to the impact of climate change on the susceptibility to geological disasters. Changes in meteorological factors such as rainfall and temperature have a profound impact on the frequency and formation mechanism of geological disasters.

This paper takes Tuquan County, Xing'an League, Inner Mongolia as the research area. Appropriate evaluation factors are selected to evaluate the susceptibility of debris flow, and the impact of disaster factors and favorable environment on the development of disasters is analyzed. The purpose is to provide a reference for the study of similar disasters.

2. Geological Settings

The study area is located in the northeast of Inner Mongolia Autonomous Region and the central part of Xing'an League. The geographical coordinate range is 120°43′45"-122°10′20" east longitude and 45°11′25"-46°05′12" north latitude. The area is 113.9 kilometers long from east to west and 99.6 kilometers long from north to south, with a total area of 4797.29 square kilometers. The study area is located in the transition zone between the southeast foothills of the Greater Khingan Range and the Songliao Plain. The main landform types are low and medium mountains, low mountains, hills, plains, and valleys (river valleys). The main geological formations in the study area include the Dashizhai Formation of Lower Permian ($P_{1-2}ds^{\wedge}$), the Zhesi Formation of Lower Permian ($P_2zs^{\wedge}$), the Hongqi Formation of Middle Jurassic (J_2h), the Wanbao Formation of Middle Jurassic (J_2wb), the Manketouebo Formation of Upper Jurassic (J_3mk), the Manitu Formation of Upper Jurassic (J_3mn), the Lower Cretaceous (K_1), the Lower Pleistocene of Quaternary (Q_{p1}), the alluvial and diluvial layers of Upper Pleistocene of Quaternary (Q_{p3}^{al+pl}) and the Holocene of Quaternary (Qh).

The study area has a mid-temperate continental semi-arid monsoon climate, with dry and windy spring, hot and rainy summer, cool and short autumn, and cold and long winter. The lowest temperature is -31.1℃ and the highest temperature is 41.2℃. The average annual precipitation is 419.3 mm, with the highest annual precipitation of 692.7 mm occurring in 1998 and the lowest annual precipitation of 229.7 mm occurring in 1967. For the location map of the study area, please refer to Figure 1.

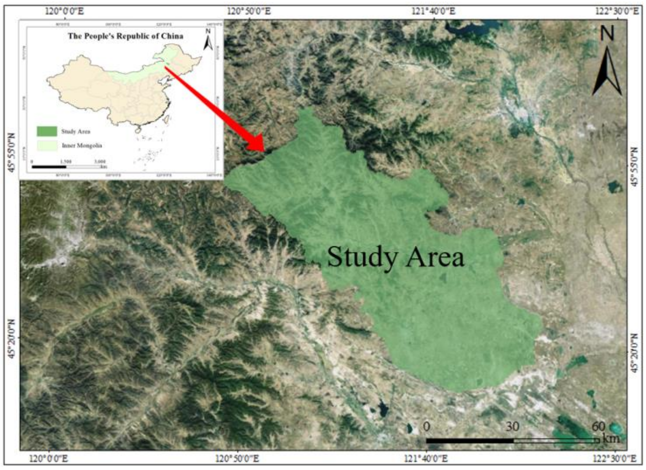

Figure 1: Location of study area

3. Data and Methods

3.1 Information Model

The information quantity method [5-7] is a statistical method based on information theory. It realizes the zoning of regional geological disaster susceptibility by quantifying the information relationship between the occurrence of geological disasters and various influencing factors. This method converts each influencing factor into an information quantity value to reflect its contribution to the occurrence of geological disasters. Finally, the region is classified based on the information quantity value to objectively quantify the environmental sensitivity of geological disasters. The formula for the information quantity of geological disasters under a specific state of a certain factor can be expressed as (Formula 1):

$$I_{Aj\to B} = ln\frac{N_j/N}{S_j/S}(j = 1,2,3 \dots n) \quad (1)$$

In the formula: $I_{Aj\to B}$ —the amount of information about the occurrence of geological disaster B under the corresponding factors A and j states (or intervals); N_j —the number of units of geological disaster distribution under the corresponding factors A and j states (or intervals); N —the total number of units in the survey area where geological disasters are known to be distributed; S_j —the number of units distributed under the factors A and j states (or intervals); S is the total number of units in the survey area.

The calculation of the geological disaster susceptibility index based on the information method is based on the current distribution status of geological disaster points in Tuquan County. This paper uses sample frequency to calculate the information of each single factor. Each indicator is uniformly divided into 25m×25m regular grid analysis units in the study area, and the number of disaster points distributed in each type of grid unit and the number of grid units occupied by this type in the study area are counted, so as to calculate the information value of each indicator respectively. Since each evaluation unit is affected by many factors, and each factor has several states, the total amount of information about the occurrence of geological disasters under the combination of factors in each state can be determined by formula (Formula 2):

$$I = \sum_{i=1}^{n} ln\frac{N_j/N}{S_j/S} \quad (2)$$

In the formula: I is the total information value of geological disasters in a certain unit, indicating the possibility of geological disasters, which is used as the geological disaster susceptibility index; Ni is the area or number of geological disaster points under specific conditions when the i-th state (or interval) is a certain factor; Si is the distribution area of the i-th state (or interval) of a certain factor under specific conditions; N is the total area of the survey area or the total number of geological disasters; S is the total area of the survey area.

3.2 Selection of Evaluation Factors

According to the formation mechanism and characteristics of geological hazards in the study area, combined with the local natural geographical characteristics and data availability [8-11], eight indicators closely related to geological hazards are proposed: elevation, terrain slope, landform type, geological structure, rock and soil type, vegetation coverage, water flow intensity index (SPI), and terrain wetness index (TWI) as evaluation indicators (Figure 2). The quantitative indicators of each factor are shown in Table 1.

Table 1: Geological Hazard Evaluation Factors in the Study Area

Evaluation factor	classification							
elevation (m)	0-300	300-500	500-700	>900				
slope (°)	0-5	5-10	10-15	15-20	20-25	25-30	30-35	>35
landforms	Gully	Plain	Low to medium mountains	Low mountain	Hills			
Distance from fracture	<600	600-1200	1200-1800	1800-2400	2400-3000	>3000		
Rock and soil mass	Hard massive intrusive rock formation	Hard volcanic rock formation	Thin-layered clastic rock	Soft volcanic rock	Gravel soil	Sandy soil	cohesive soil	
vegetation coverage	<10%	10%-30%	30%-50%	50%-70%	>70%			
Streamflow Precipitation Index	-8.642--0.007	-0.007-0.924	0.924-1.810	1.810-2.975	2.975-6.907			
Topographic Wetness Index	0-5.432	5.432-6.863	6.863-8.722	8.722-13.728	13.728-20.451			

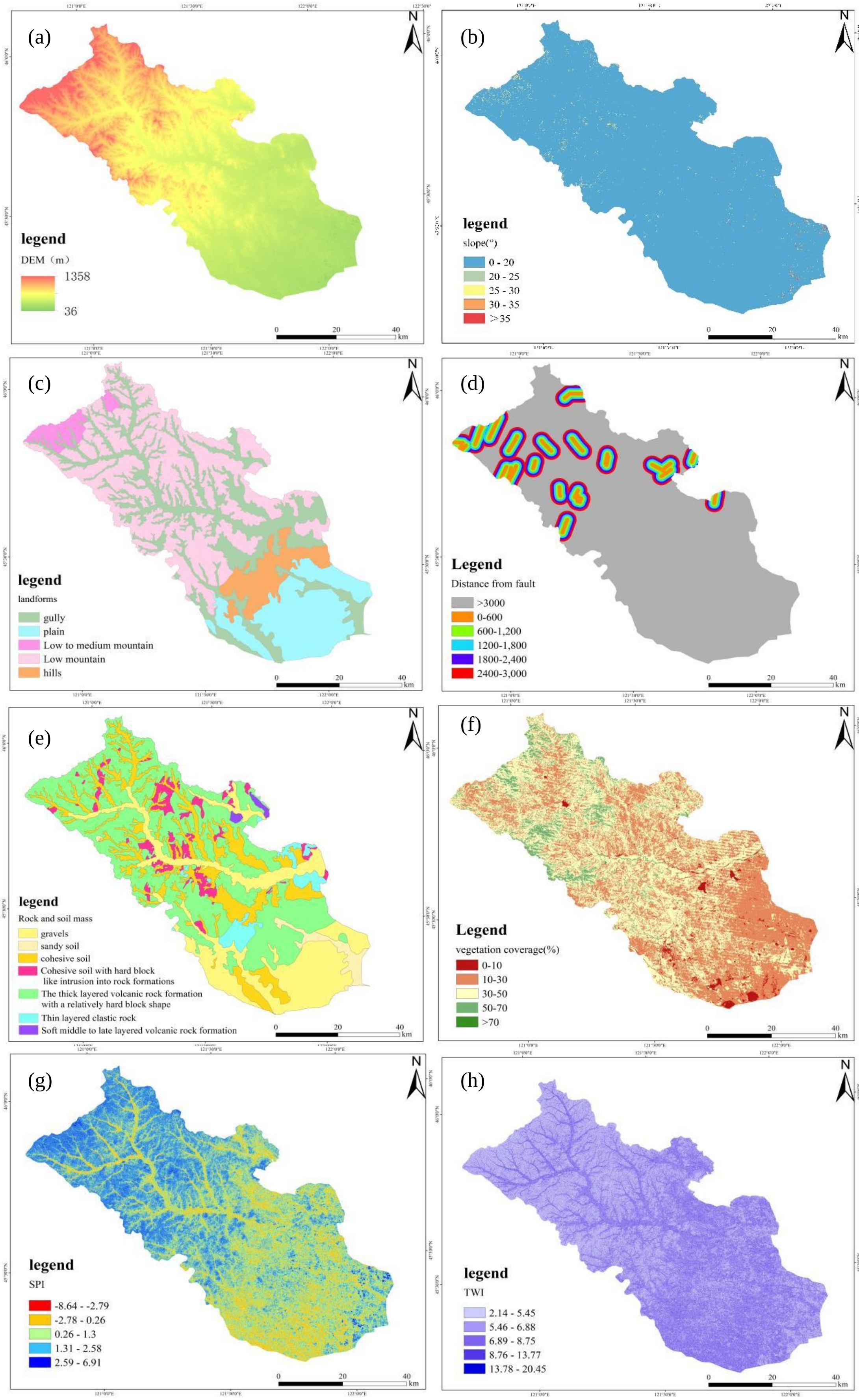

Figure 2: Index Chart of Evaluation Factors in the Study Area;(a) DEM; (b) slope; (c) landforms; (d) Distance from road; (e) Rock and soil mass; (f) Vegetation coverage; (g) Stream intensity index (SPI); (h) Terrain wetness index (TWI)

4. Results

There are many static environmental control factors that affect the occurrence of geological disasters. It is unrealistic to take into account all the factors that breed geological disasters in actual work. Therefore, according to the formation mechanism and characteristics of geological disasters in Tuquan County, combined with the natural geographical characteristics and data collection of Tuquan County, eight indicators, including elevation, terrain slope, landform type, geological structure, rock and soil type, vegetation coverage, water flow intensity index (SPI), and terrain wetness index (TWI), which are closely related to geological disasters, are selected as geological environmental control factors of geological disasters in Tuquan County, namely, geological disaster susceptibility evaluation indicators. In order to facilitate the evaluation of the susceptibility of geological disasters in the study area in the later stage, it is necessary to reasonably classify and quantify each evaluation indicator. With reference to the Technical Requirements for Survey and Evaluation of Geological Hazard Risks (1:50000), the information volume model is used for evaluation, and the distribution map of geological disaster susceptibility in the study area is obtained (Figure 3).

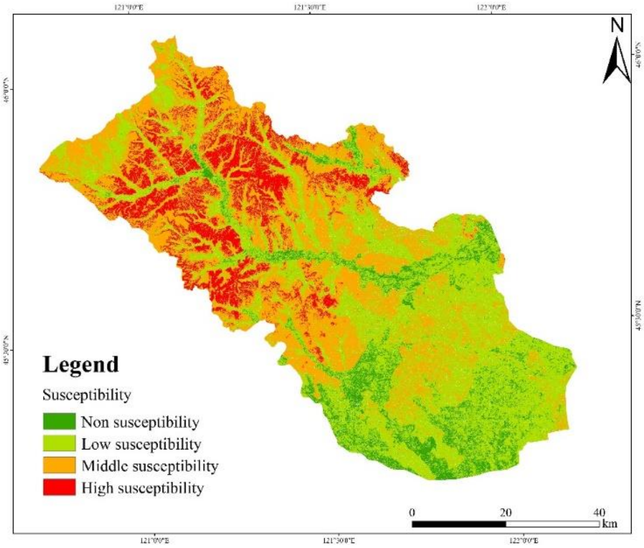

Figure 3: Distribution map of geological hazard susceptibility in the research area

4.1 Distribution of Geological Hazards

Debris flow is the most developed type of geological disaster in the study area. A total of 44 debris flow gullies were found in this field survey. The debris flows in the area were divided into 42 debris flows and 2 water-rock flows according to their material composition, and 41 small debris flows and 3 medium-sized debris flows according to their scale. All 44 debris flows are rainstorm-type rare debris flows. Through on-site investigation of the disaster, it was found that its spatial distribution is closely related to the topography, geological environment, vegetation coverage and the intensity of human engineering activities.

4.2 Geological Hazard Susceptibility Zones

By superimposing and calculating the information of each factor, the natural fracture method is used to divide the boundaries of each sensitive zone and generalize them [12-14]. The study area is divided into four areas: high susceptibility area, medium susceptibility area, low susceptibility area and non-susceptibility area. The high susceptibility area of Tuquan County is concentrated in the low and medium mountainous areas with steep terrain in the north of Tuquan County and the low mountainous areas where human engineering activities have caused strong damage to the geological environment. The medium susceptibility area is mainly distributed in the low mountainous areas south of the high susceptibility area of geological disasters in the middle of Tuquan County in a wedge shape. The low susceptibility area is mainly distributed in the low mountain and hilly areas in the south of the medium susceptibility area and the plain area in the south. The non-developed area of geological disasters is mainly distributed in a small number of hilly areas and a large plain area in the south of Tuquan County.

5. Discussion

5.1 Analysis of Geological Disaster-Breeding Environment

The formation of geological hazards is a complex process, which is influenced by a variety of internal and external factors. Therefore, when assessing geological hazards, various conditions such as topography, lithology, and vegetation impact must be considered comprehensively [8].

Topography is an important condition for the formation of debris flow. The fluctuation of topography is related to the formation and development of debris flow. The control of topography on debris flow disasters is mainly reflected in the slope and elevation [15]. The elevation mainly reflects the terrain fluctuation and cutting erosion intensity of the debris flow basin, and also reflects the development degree of the valley. In the study area, debris flow is concentrated in the range of elevation greater than 200-300m. A total of 31 debris flows have developed, accounting for 70.45% of the total. The slope of the debris flow valley plays an important role in the susceptibility of debris flow. The slopes on both sides of the valley are steep and steep. Under the action of rainfall, the flow rate of the slope water is accelerated and gathered in the valley. At the same time, the slope of the valley indirectly affects the material source reserves of the debris flow. The smaller the slope, the easier it is to accumulate loose deposits, which provides sufficient material sources for the formation of debris flow.

The properties of rock and soil determine the development degree and type of geological disasters to a certain extent. Its type, property and structure determine the material source of the disaster-causing body and control the development type and generation scale of geological disasters. There are 44 debris flow geological disasters in the survey area. The debris flow formation area and flow area are mostly located in the gravel slope structure and gravel soil slope. The soil is relatively loose. Under the influence of factors such as rainfall, the gravel soil is prone to relative displacement, which causes the soil body to become unstable, and then provides a rich source of material for the formation of debris flow geological disasters.

The impact of vegetation on debris flow is mainly manifested in the following three aspects: First, the forest intercepts rainfall through the canopy, and the dead branches and leaves absorb rainfall and rainwater infiltration in the forest soil to reduce and reduce rainfall and rainfall intensity, thereby affecting and intercepting surface runoff; secondly, vegetation increases the surface roughness, slows down the surface runoff speed, and increases its infiltration water, thereby prolonging the surface runoff generation and confluence time. In addition, vegetation blocks the erosion of surface soil by raindrops, and the plant roots can stabilize the surface soil to a certain extent, reducing soil and water loss in the basin. In short, vegetation has a strong inhibitory effect on the development of debris flows.

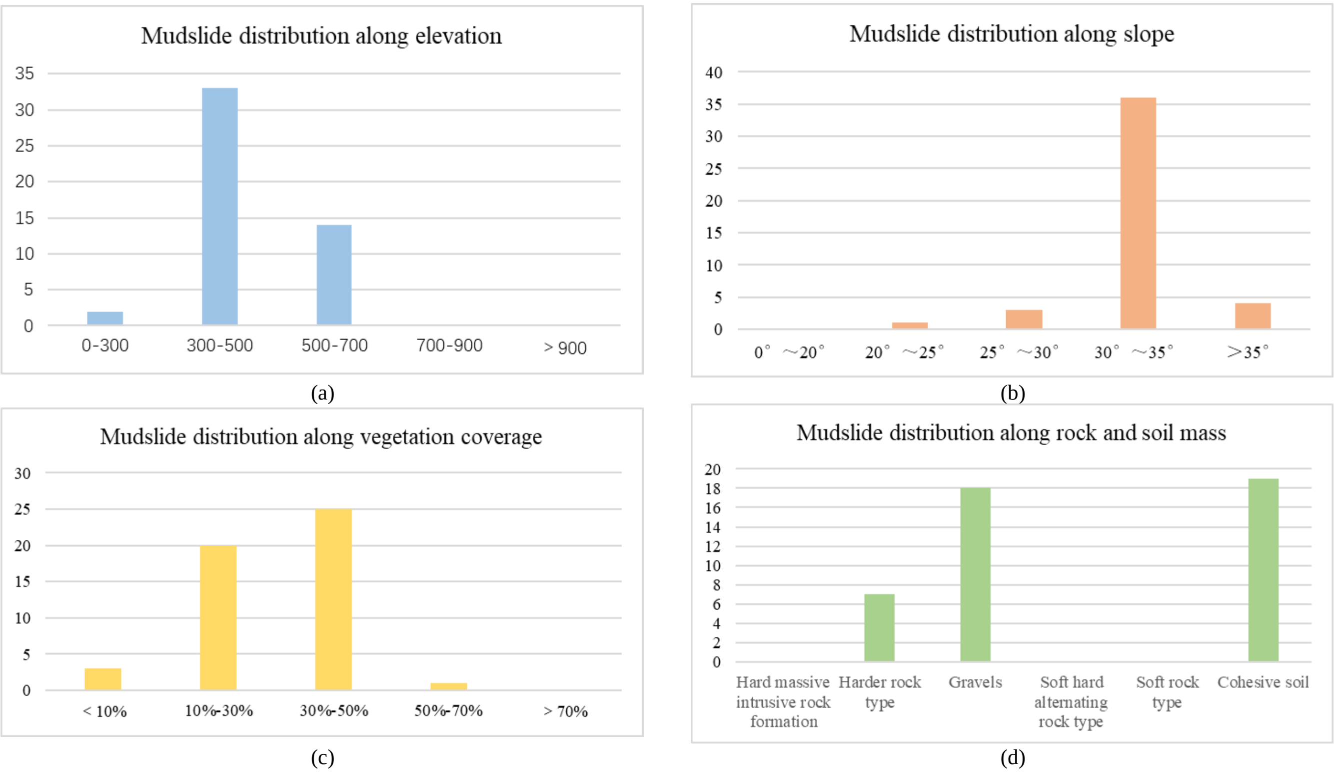

Figure 4: Mudslide distribution bar chart; (a) Mudslide distribution along elevation; (b) Mudslide distribution along slope; (c)Mudslide distribution along Vegetation coverage; (d) Mudslide distribution along Rock and soil mass

5.2 Analysis of Geological Hazard Inducing Factors

Rainfall is a major factor that triggers geological disasters in the region. There are two types of disasters: high-incidence years with heavy rainfall and high-incidence months from June to September. In 1998 and 2012, the rainfall exceeded 550 mm, and geological disasters occurred more frequently, resulting in serious losses, much higher than in other years. Moreover, the rainfall in the region is mainly concentrated in the three months of June to September, accounting for 18.39%, 28.76%, 20.54% and 10.34% of the annual rainfall, respectively, far exceeding the rainfall in other months. The geological disasters that have been recorded in this survey all occurred in June to September.

Earthquakes also have a certain degree of influence on the development of geological disasters in the study area, which is mainly reflected in two aspects: co-seismic geological disasters and post-seismic geological disaster effects [16]. Co-seismic earthquake effects refer to geological disasters such as collapse, landslides, and slips caused by earthquakes; the latter post-seismic effect is mainly manifested in the accumulation of a large amount of loose deposits by earthquake activities. These post-seismic loose deposits are very easy to form landslides, collapses and mudslides under the action of rainfall.

The formation of geological disasters in the study area is also closely related to human engineering activities. With the rapid development of economic construction, human engineering activities have become increasingly intensified in both depth and breadth. This is mainly manifested in the unscientific and unreasonable disturbance of natural slopes, which has broken the natural balance of slopes for a long time in geological history and constitutes one of the main factors that induce geological disasters.

6. Conclusion

This paper conducted a field survey in Tuquan County, Xing'an League, Inner Mongolia, and used the information volume method to evaluate the susceptibility of geological disasters. At the same time, the influencing factors of geological disasters were analyzed, and the following conclusions were drawn:

1) Factors such as elevation, terrain slope, landform, and geological structure were selected as evaluation indicators. The information model method and weighted deterministic factor method were used to analyze the susceptibility of geological disasters in the study area, and the study area was divided into high susceptibility area, medium susceptibility area, low susceptibility area, and non-susceptibility area.

2) A total of 44 debris flows developed in the study area, which can be divided into 42 debris flows and 2 water-rock

flows according to material composition, and 41 small debris flows and 3 medium-sized debris flows according to scale. All 44 debris flows are rainstorm-type rare debris flows.

3) Factors such as rainfall, earthquakes, and human engineering activities affect the development of geological disasters in the study area. Rainfall and human engineering activities were identified as the main triggering factors for the development of disasters in the study area.

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