https://doi.org/10.1051/e3sconf/202452004003

Research on Geological Disaster Risk Assessment Method Based on GIS in Changji City, Xinjiang

Shibin Liao[1,*], Yuxia Liang [1],Jintao Tao[1], Xinyu Geng[2] ,Gulbostan Tursun[2]

[1]Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences Urumqi, Xinjiang, China 830011
[2]Xinjiang Institute of Engineering Urumqi, Xinjiang, China 830023

Abstract. This study takes the risk assessment of geological disasters in Changji City as the research object. By reviewing the detailed investigation report and risk survey documents of 1:50000 geological disasters in Changji City, along with the annual verification, investigation, and exploration results of major hidden danger points, we collected and organized the necessary data for the assessment and integrated multidisciplinary knowledge such as geology, GIS technology, and statistics. The study aims to identify the inducing factors, development characteristics, and distribution law of geological disasters in the area, thereby determining the risk assessment factors. To ascertain the weight of these factors, we employed an evidence weight model and a machine learning method. The vulnerability assessment, incorporating existing basic data and vulnerability factors such as population density, building density, and road density, was conducted using fuzzy mathematics for Changji City. Finally, the risk assessment used the ArcGIS analysis function to calculate the risk and vulnerability assessment results. Through ArcGIS, we superimposed the risk grade and vulnerability grade of geological disasters on a grid, ultimately obtaining the risk assessment results for the study area.

1 Introduction

In recent years, research on geological disaster assessment has made evident progress and development across China, with Xinjiang actively engaging in geological disaster investigation and risk assessment. Geological disaster risk assessment has become a research hotspot for numerous scholars, yielding fruitful research outcomes [1]. Positioned in the northwest of China, Xinjiang shares similarities with the central and eastern regions in terms of the occurrence and development conditions of geological disasters, but it also possesses its distinct features. There are various types of geological disasters in Xinjiang, including sudden collapse, landslide, debris flow, ground collapse, slow desertification, and salinization disasters.

Taking Changji City in Xinjiang as an example, this paper focuses on the risk assessment method for geological disasters. The initial steps in the process involve establishing the susceptibility assessment system and the vulnerability assessment system of geological disasters. Then, the selection of assessment methods and units is crucial and is combined with the assessment of inducing factors, risk, and vulnerability. Among them, the evidence weight model is widely adopted for its ease of operation and comprehensibility of calculation results, which avoids subjective judgment during assessment and aligns more closely with reality[1]. This paper takes Changji City in Xinjiang as the study area and explores the applicability of the evidence weight model in geological disaster risk assessment.

2 Overview of Changji City

Xinjiang's Changji City is located at the northern foot of the Tianshan Mountains, the hinterland of the Asia-Europe continent, and the southern margin of the Junggar Basin. Stretching 260 km from north to south and 30 km from east to west, the city's topography exhibits a distinctive step-shaped configuration, characterized by a substantial elevation difference exceeding 4000 m from north to south. With elevations ranging from 1000 to 4562 m, the southern region comprises the Tianshan Mountain area, which is prone to geological disasters. The central part features an alluvial plain with an altitude of 400-1000 m, with a topographic gradient of 5-8° near the piedmont alluvial-proluvial fan. The northern expanse is a desert area, with an altitude of 400-488 m. Changji City experiences a continental arid climate, marked by notable vertical climate zones due to the influence of its topography. The climate is characterized by hot and dry summers, long and cold winters, significant temperature variations, and large evaporation throughout the year, and the climate changes with topographic shifts. The average temperatures vary across regions: about 2.1℃ in mountainous areas, 6.1℃ in plain areas, and 5.7℃ in desert areas. The annual precipitation distribution is uneven, with more rainfall in the southern mountainous

*Corresponding author's email: liaoshibin@ms.xjb.ac.cn

area and less in the northern plain area. The mountainous region receives an average annual precipitation of about 365.3 mm, the plain area approximately 183.9 mm, and the desert area around 135.9 mm.

In the study area, the high and middle mountain areas in the south belong to the northern Tianshan fold belt of the Tianshan geosyncline area, while the low mountain areas and inclined plains are situated in the Junggar sag area. Since the late Lower Paleozoic, the area has experienced many tectonic movements, which control and influence the distribution, deformation, and displacement of strata, as well as the distribution of groundwater and the buried depth of the water table.

3 Data Sources

The geological disaster data and historical annual geological disaster data used in this research are obtained after fully collecting, analyzing, and studying the previous geological disaster works, especially the Detailed Investigation of Geological Disasters in Changji City, Xinjiang, the Refined Investigation of Geological Disasters in Important Areas in Changji City-Wusu City, Xinjiang, and the first national comprehensive risk survey of natural disasters in Changji City, Xinjiang. (Table1) presents other data input sources.

Table 1. List of input data of geological disaster risk assessment and zoning

Number	Data	Data source
1	Investigation data of hidden geological disasters such as collapse, debris flow, and landslide	Field measurement
2	Peak acceleration of ground motion	“Zoning Map of Peak Acceleration of Ground Motion in China” GB18306-2015
3	Rainfall	"China’s 1 km Resolution Monthly Precipitation Data Set from 1960 to 2020" Qu et al.
4	Remote sensing DEM interpretation data (slope, aspect, elevation, etc.)	Gaofen-2 satellite image
5	Basic geological data (topography, stratum lithology, geological structure, etc.)	Natural resources sector
6	Data of the Third National Land Survey(Distribution of disaster-bearing bodies, administrative divisions, human engineering activities, etc.)	Natural resources sector
7	Geographical base map (roads, railways, rivers, lakes and reservoirs, etc.)	Leading Team Office of First National Natural Disaster Comprehensive Risk Census in Autonomous Region
8	Snow line data	“Manual of Permafrost Investigation” Zhao and Sheng

4 Geological Risk Assessment Method and Model

4.1Susceptibility Assessment

This assessment adopts a quantitative method and utilizes the evidence weight model to assess the susceptibility of geological disasters. Employing GIS-based spatial analysis techniques, the approach involves analyzing the weight coefficients of individual factors across various disaster categories. The results are merged according to the categories and turned into binary layers, which are superimposed and calculated to obtain the quantitative assessment results of collapse, landslide, and debris flow susceptibility. This process enables the quantitative assessment of geological disaster susceptibility. On this basis, realistic geological disaster-prone areas are delineated in accordance with the actual field survey results.

4.1.1 Evidence weight model based on GIS

The evidence weight model conducts superimposition analysis on the weight index of influencing factors related to the formation of geological disasters, aiming to evaluate the susceptibility of such disasters. [2] Each influencing factor in this approach is regarded as the evidence factor of geological disaster susceptibility assessment, and the contribution of each evidence factor to geological disaster susceptibility is characterized by its weight value[6]. Generally, each evidence factor layer is gridded into a discontinuous binary layer, where 1 represents the existence of factor evidence for disaster occurrence, and 0 represents its absence. The weight of the binary evidence factor layer is given by the evidence weight model, and finally, the multivariate layer is superimposed to realize the susceptibility assessment for geological disasters[7]. The analysis process is outlined as follows:

a)Weight calculation

To calculate the weight of each evidence factor, we must first grid the whole study area. Conditional probability is used to calculate the contribution weight of all units in the evidence factor layer to geological disasters. It is assumed that the study area is divided into T units with equal areas, where D is the number of geological disaster units, and $\bar{D}$ is the number of non-geological disaster units. For this evidence factor, B/D and $B/\bar{D}$ denote the number of units where the evidence factor exists within geological disaster units and non-geological disaster units, respectively, while $\bar{B}/D$ and $\bar{B}/\bar{D}$ represent the number of units where the evidence factor($\bar{B}$) does not exist in geological disaster units and non-geological disaster units, respectively[4]. Its weight is defined as:

$$W^+ = \ln \frac{P(B/D)}{P(B/\bar{D})} \quad (1)$$

$$W^- = \ln \frac{P(\bar{B}/D)}{P(\bar{B}/\bar{D})} \quad (2)$$

Where W+ is the weight value of the area where the evidence factor exists, and W− is the weight value of the region where the evidence factor is absent.

The weight of the evidence factor is determined by the ratio of the number of disaster points falling within a specific evidence factor layer to the total number of disaster points, divided by the ratio of the area of the evidence factor layer to the total area of the study area. The positive correlation between the evidence factor and the disaster point is expressed as W+>0 and W−<0, while the negative correlation is W+<0 and W−>0. The weight is 0 when it is not correlated. For the missing area of the original data, its weight value is 0. The relative coefficient C=W+-W− is used to measure the correlation between evidence layers and geological disasters. To eliminate the high C value caused by accidental factors, the calculation results of the above contrast (C value) need to be tested for significance[10], with its formula as follows:

$$Studentized(Contrast) = S^2(Contrast) \Big/ \sqrt{S^2(W^+) + S^2(W^-)} \quad (3)$$

Where $S^2(W^+) = \frac{1}{N\{B\cap D\}} + \frac{1}{N\{B\cap \bar{D}\}}$, $S^2(W^-) = \frac{1}{N\{\bar{B}\cap D\}} + \frac{1}{N\{\bar{B}\cap \bar{D}\}}$, and $S^2(Contrast) = S^2(W^+) + S^2(W^-)$. In Formula (3), $S^2(W^+)$, $S^2(W^-)$, and S^2 (Contrast) represent the variance of W^+, W^-, and Contrast, respectively, and Studentized (Contrast) is the student treatment of Contrast (i.e., C value), which reflects the significance level of C value, as represented as follows (Table2):

Table 2. Corresponding relationship between the significant quantitative index and confidence

Significant quantitative index	0.253	0.542	0.842	1.282	1.645	1.96	2.326	2.576
Confidence	60%	70%	80%	90%	95%	97.5%	99%	99.5%

Finally, through the comprehensive analysis of W+, W−, C values, and their significance level, the original influencing factors are screened according to the significance quantitative index, and then the final susceptibility assessment results are calculated.

b) Evidence synthesis

Based on the weight value calculation and analysis, through the optimization of evidence layers, we select the evidence layer with larger weight values and a close relationship with geological disasters, while eliminating those with smaller weight values and less relevance. Furthermore, the conditional independence test is conducted on evidence factors concerning disaster points, to exclude the evidence layers with relatively small weight values of geological disasters and significant correlation with other evidence factors. For the final set of n conditionally independent evidence factors related to geological disaster points, according to the Bayesian law, the probability of any unit K in the study area being a geological disaster, i.e., logarithmic posterior probability, can be expressed as follows:

$$F = \ln\, O\left(D/\sum_{i=1}^{n} B_i^{K(i)}\right) = \sum_{i=0}^{n} W_i^{\mathrm{K}} + \ln\, O(D) \quad (4)$$

Where:

O-represents the probability, O (D) = D/(T-D);

D- is the number of unit grids with geological disasters;

Bi -represents the i-th evidence layer;

K(i)- is + when the i-th evidence factor layer exists and is − when it does not exist;

Wi- is the weight of the existence or non-existence of the i-th evidence factor.

Finally, we calculate the posterior probability:

$$P = O/1 + O = \exp(F)/(1 + \exp(F)) \quad (5)$$

The value of posterior probability signifies the susceptibility, with its value between 0 and 1. A greater posterior probability value indicates a higher susceptibility, and vice versa.

4.1.2 Assessment unit subdivision

The form and size of the assessment unit subdivision exert great influence on the zoning results. Using grid units offers the advantage of quick subdivision through GIS, leveraging matrix-form grid data for rapid computer-based calculations. However, the drawback lies in the lack of an organic connection between the grid assessment unit and information on topography, geomorphology, and geological environments. The ideal calculation and assessment unit should fully consider the environmental conditions of geological disasters[3]. In this study, the DEM data of 1:50000 scale in the study area are divided into 25×25 m cells, forming the basis for susceptibility assessment.

4.1.3Selection of assessment factors and calculation of susceptibility

The formation conditions, structural characteristics, and various factors affecting the occurrence of geological disasters are the main contents of the susceptibility assessment of geological disasters. Regional geological disasters result from the intricate interplay of topography, meteorology, hydrology, geological structure, and human activities in the study area, which are mainly divided into control factors and inducing factors. In practical application, it is crucial for different study areas to meticulously choose assessment factors according to their actual situations. The selected factors should fully reflect the geological disaster susceptibility in the study area, ensuring that each factor is representative, concise, and independent. Meanwhile, data can be easily obtained quantitatively. Based on an extensive investigation of geological environment background in this area and detailed understanding of geological disaster preparation conditions[8], the disaster preparation in Changji City mainly focuses on nine factors for comprehensive analysis, including topographic and geomorphic conditions (e.g., geomorphic zoning, slope, aspect, and regional height difference), meteorological and hydrological conditions (e.g., engineering geological rock groups, land cover types, distances from roads, and nuclear density of water systems), and geological structural conditions (fault distances).

The weights of each index in the zoning of geological disaster susceptibility in the study area are calculated and determined by the evidence weight model. The correlation analysis between single factors and geological disasters is obtained by calculating the grading weights of each disaster preparation condition in the study area.

According to the values of CONTRAST and Studentized CONTRST, positive correlation evidence factors are selected, and the category of positive correlation of each evidence factor is processed by binarization. Thus, the assessment results of the susceptibility of collapse, debris flow, and landslide are obtained.

4.2 Risk Assessment

4.2.1 Assessment method

The hazard degree of geological disasters refers to the destruction and threat intensity of geological disasters to the affected body. In fact, its risk is assessed based on the assessment of stability, susceptibility, and hazard degrees of geological disasters, to comprehensively analyze the risk scale, hazard spread range, and the importance of the affected body. Particularly, in assessing the geological disaster risk in the study area, a qualitative analysis is primarily employed, supplemented by a quantitative approach. Generally, with poor stability (high susceptibility), large scale, and broad extent of harm, a geological disaster body results in severe consequences and high risk when disasters occur. Conversely, a smaller geological disaster risk is associated with more stable and less susceptible geological bodies.

4.2.2 Risk assessment of geological disasters

a) Assessment unit

According to the specific requirements of the geological disaster risk survey in Changji City, the whole study area is divided into 25×25 m assessment grid units to carry out the risk assessment.

b) Selection of assessment factors

Quantitative assessment of geological disaster risk is based on the susceptibility assessment of geological disasters. Utilizing GIS-based spatial analysis, we quantify and score the importance of geological disaster affected bodies (such as city, village distribution, mountain grassland distribution, mine, road, etc.). In this geological disaster risk assessment of Changji City, rainfall (Fig1) and earthquake (Fig2) are selected, and after the weighted average, the geological disaster risk assessment is carried out to obtain the final quantitative assessment results and realize the quantitative assessment. (Fig3).

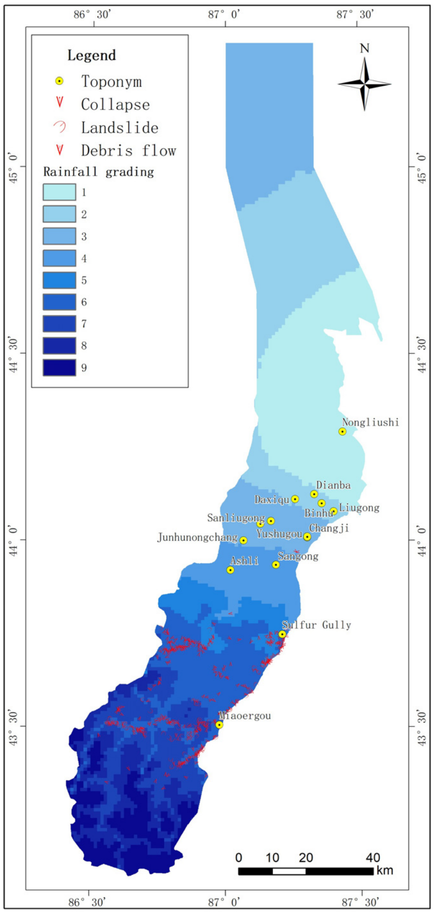

Fig.1. Rainfall distribution map

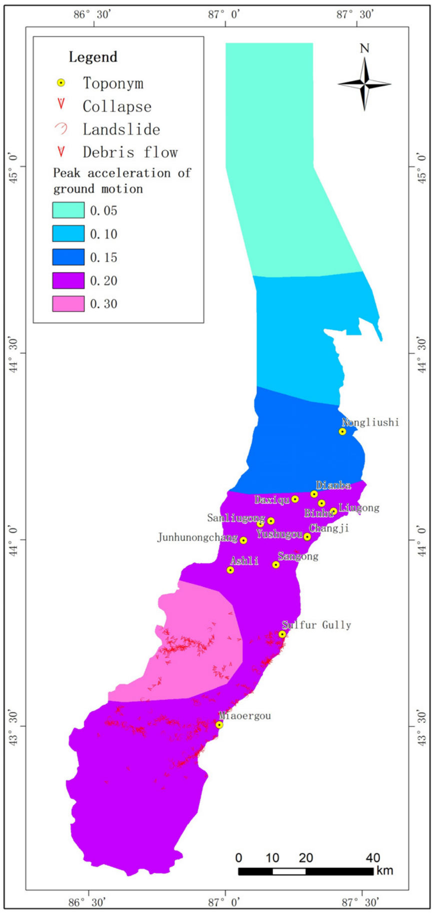

Fig.2. Distribution of peak acceleration of ground motion

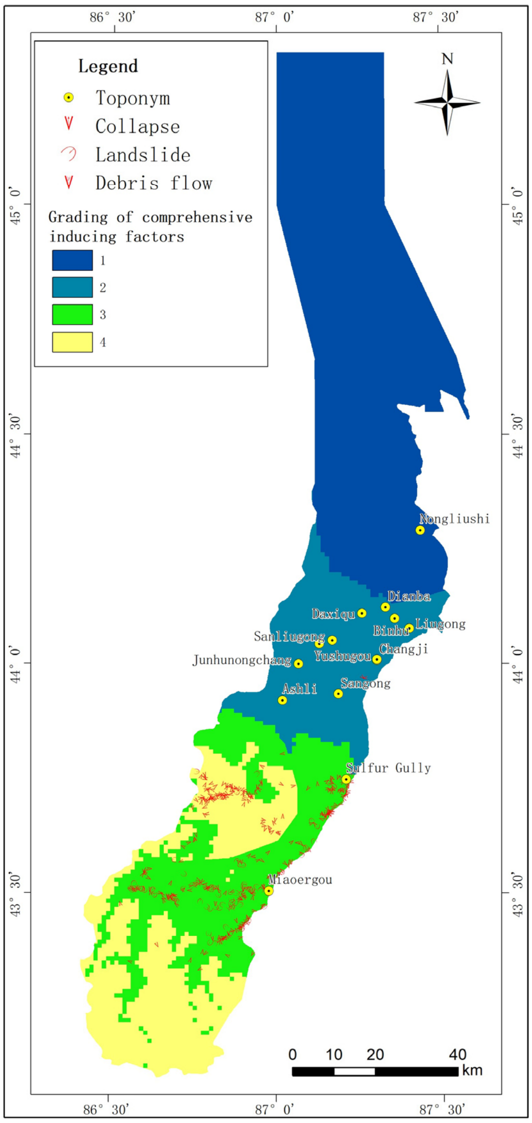

Fig.3. Grading diagram of comprehensive inducing factors

4.3 Vulnerability Assessment

By reviewing the literature and combining the characteristics of the study area with the collected data, we divide the vulnerability of geological disasters in the study area into three vulnerability categories: people, buildings, and roads. The density of population, buildings, and roads associated with these disaster-bearing entities serves as vulnerability assessment indexes, and expert assessment is used to score these indexes[5]. All indexes are superimposed in GIS to get the zoning results of geological disaster vulnerability assessment.

4.3.1 Assessment method

Vulnerability assessment of geological disasters is crucial for their risk assessment. Based on statistics of regional landslide, collapse, debris flow, and other geological hazards, as well as analysis of the disaster distribution law, mathematical models are used to quantitatively evaluate the relationship between disaster resistance and loss value of various types of disaster-bearing bodies and the type, intensity, and inherent characteristic strength of these bodies. Vulnerability reflects the social attributes of geological disasters, and the degree of regional social and economic development is also an important influencing factor. By adjusting the economic and industrial structure, the disaster-bearing body's ability to resist disasters can be enhanced, and thus the loss caused by disasters will be reduced. Vulnerability assessment can not only provide basic social and economic data for geological disaster risk assessment but also offer a scientific basis for regional disaster prevention, mitigation plan formulation, and project implementation[10].

4.3.2 Vulnerability assessment index

The disaster-bearing bodies in the study area encompass roads, residential areas, agricultural and animal husbandry facilities, transmission lines, and mining facilities. The threatened roads are primarily divided into highways and sidewalks, with the former including county roads and township roads, while the latter predominantly consists of mountain dirt roads. The selected vulnerability indexes are as follows:

a) People vulnerability

Combining the population threatened by geological disasters and hidden dangers with the actual collected data, we conduct a distance analysis of residential areas and then reclassify them.

b) Traffic roads and facilities

According to Technical Rules, "vulnerability values shall be assigned to transportation facilities according to different types and grades". Based on the analysis of road buffer zones, the vulnerability level of traffic roads and facilities is delineated.

5 Results of Geological Disaster Risk Assessment

Based on the analysis and assessment results of geological disaster risk and vulnerability, we comprehensively consider the relevant factors of geological disaster risk analysis and assessment. By combining qualitative and quantitative analysis and using the model formula of geological disaster risk assessment, we summarize the disaster law and model of geological disasters in the study area and establish the geological disaster risk assessment index system under different disaster preparation conditions, to complete the comprehensive zoning assessment of geological disaster risk. Geological disaster risk is generally the characteristic expression or measurement of sudden geological disasters. Evaluating the risk degree and determining the scope of serious risk areas can provide a scientific basis for geological disaster risk management and disaster prevention and mitigation projects[9].

Table 3. Suggestions on risk grading of geological disasters

Risk / Risk Level / Vulnerability	Extremely high	High	Medium	Low
Extremely high	Extremely high	Extremely high	High	Medium

High	Extremely high	High	Medium	Medium
Medium	High	High	Medium	Low
Low	Medium	Medium	Low	Low

Based on analyzing the basic characteristics, components, and calculation methods of geological disaster risk, this study conducts vulnerability assignment operations for all developed geological disaster points in the study area. Following the principle of higher risk, the risk and vulnerability assessment results of geological disasters are superimposed. By using the matrix analysis method and combining with the suggestion table of geological disaster risk grading (Table 3), we divide the study area into the extremely high risk area, high risk area, medium risk area, and low risk area of geological disasters, and finally derive the risk assessment results of geological disasters in Changji City (Fig4).

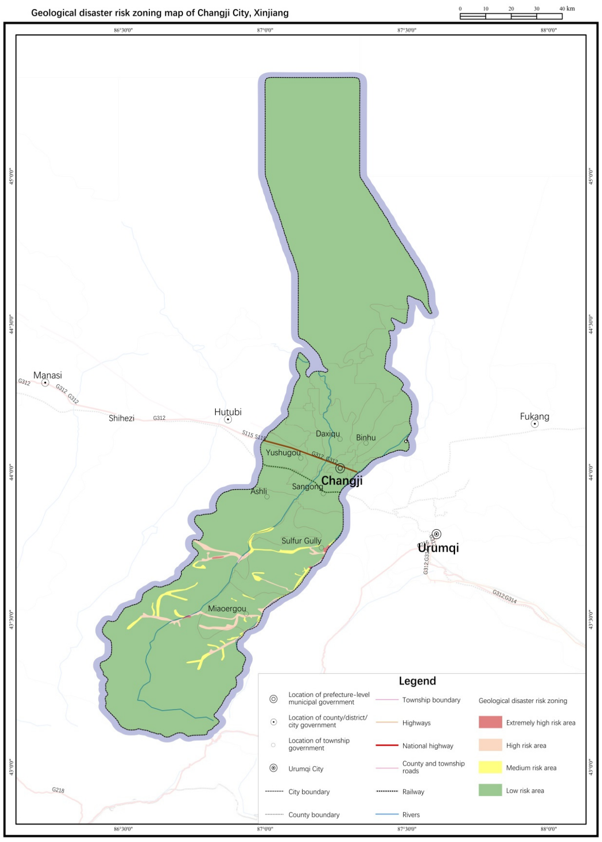

Fig.4. Geological disaster risk zoning map of Changji City

6 Conclusions

a) A geological disaster risk assessment system based on geological big data is constructed. Building upon the natural environment and human activities, this paper discusses the influence of geological disaster risk factors on geological environments, determines the grading of influencing factors of geological disasters, and distributes weights among factors by an analytic hierarchy process. We establish a geological disaster risk factor database to store data and a risk assessment model combined with relevant theories.

b) We consider unique meteorological, hydrological, topographic, and geological conditions in Changji, along with its geomorphic zoning, slope, aspect, regional height difference, engineering geological rock group, land cover type, distance from roads, nuclear density of water systems, and snow line distribution. These factors are utilized in assessing the geological disaster risk in the study area through an evidence weight model. According to the development and distribution law of geological disasters in the study area, the assessment indexes are preliminarily selected. The ArcGIS multifactor analysis tool is employed to analyze the correlation between these indexes, establishing a scientific assessment index system.

Acknowledgments

This research was supported by Open Fund of Xinjiang Key Laboratory of Geological Disaster Prevention and Control grant (No. XKLGP2022K06)

References

1 Lan Z. X., Zheng B., Liao D. W., et al. Risk assessment of geological hazards in Dayu Town, Sandu County, Guizhou Province based on information quantity method and slope unit [J]. Groundwater, 2023, 45 (05): 160-163.

2 Mo Y.F., Pan H.J., Deng Y.W. Evaluation of Geological Disaster Susceptibility in the Southern Part of Beiliu City Based on Evidence Weight Method[J]. Energy and Environmental Protection, 2022, 44(07): 1-8. DOI: 10.19389/j.cnki.1003-0506.2022.07.001.

3 Xue W.Y., Gao M., Zhu Y.S. Evaluation of collapse susceptibility based on ArcGIS and evidence weight method[J]. Nonferrous Metals World, 2019(13):154-156.

4 Chen Debo. Research on the susceptibility evaluation method of geological hazards in Tonghua County, Jilin Province [D]. Jilin University, 2023. DOI: 10.27162/d.cnki.gjlin.2023.005873.

5 Ricardo L ,Miguel L ,Julia C G .Marine Gas Hydrate Geohazard Assessment on the European Continental Margins. The Impact of Critical Knowledge Gaps[J].Applied Sciences,2021,11(6):2865-2865.

6 Hu Y., Zhang Z. Z., Lin S. H. Evaluation of landslide susceptibility in Ili Valley of Xinjiang based on the coupling of weight of evidence and logistic regression [J]. Acta Engineering Geology, 2023, 31 (04): 1350-1363.

7 Chen K., Chen L. F., Zhang Z. Z., et al. Study on risk assessment of geological hazards in Xinjiang based on empirical investigation [J]. Acta Engineering Geology, 2023, 31 (04): 1156-1166.

8 Ren T.Based on GIS, the geological disaster risk assessment of Pingshan County [D]. Hebei Geology University, 2022. DOI: 10.27752/2022.000046.

9 Pathak D .Geohazard assessment along the road alignment using remote sensing and GIS: Case study of Taplejung-Olangchunggola-Nangma road section, Taplejung district, east Nepal[J].Journ

https://doi.org/10.1051/e3sconf/202452004003

10 Song Yuan, Jiang Nan, Zhang Enbo, et al. Evaluation of landslide susceptibility in Xingshan County, Hubei Province based on the weight of evidence method[J]. Geology and Resources, 2023,32(03):352-359+289. DOI:10.13686/j.cnki.dzyzy.2023.03.012.