Risk Assessment of Geological Hazards of Qinling-Daba Mountain Area in Shaanxi Province Based on FAHP and GIS

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Abstract: The paper herein selects nine disaster risk factors to build an evaluation index system by means of the fuzzy analytic hierarchy process (FAHP). Based on ArcGIS software, the risk assessment and regionalization of geological disasters in Qinling-Daba mountain area in Shaanxi province are carried out while the geological disaster points are used for verification. The results show that: 1) The conditions to trigger geological disasters in Qinling-Daba mountain area of Shaanxi are the slope 15°~45°, topographic relief degree more than 200m, perennial average rainfall about 950mm~1200mm, vegetation coverage less than 60%, distance from river network less than 2km, distance from fault less than 4km and the density of seismic points about 0.15-1.36 /100 km2. 2) The risk levels of geological disasters in Qinling-Daba mountain area of Shaanxi province are divided into several grades as extremely low risk area, low risk area, medium risk area, high risk area and extremely high-risk area, accounting for 8.63%, 14.56%, 31.56%, 31.91% and 13.34% of the area respectively. 3) Relevant verification shows that the risk zoning accuracy is high, which can provide a scientific basis for disaster prevention and reduction in Qinling-Daba mountain area of Shaanxi province.

Geological disasters refer to geological events that damage human life, property and living environment when the change of geological body reaches a certain degree under the action of internal and external geological forces [1]. With the continuous development of China's economy, human activities have intensified, resulting in more and more tension between human and land and leading to more and more frequent geological disasters that cause a large number of casualties and economic losses [2,3]. Geological hazard assessment is both a major link in the work of disaster prevention and reduction and an important reference for regional economic development and infrastructure construction [4,5]. At present, the most common risk assessment methods of geological hazards include evidence weight method [6], Logistic regression model [7], information content model [8], analytic hierarchy process [9], etc. However, these methods are commonly used to evaluate the risk of geological hazards in small areas with less risk assessment of geological hazards in large areas and small scales [10].

Qinling-Daba mountain area in Shaanxi province is China's geological hazard prone area and landslide, collapse, debris flow and other geological disasters in the area are widely developing, posing a great threat to the local people's life and property. According to incomplete statistics, geological disasters threaten 52,241 households, 281,771 people and 229,527 houses in Qinling-Daba mountain area of Shaanxi province, with an economic loss of 4.452 billion yuan. Therefore, it is of great significance to scientifically carry out the risk assessment of geological hazards in Qinling-Daba mountain area of Shaanxi province, determine the inducing conditions of geological hazards, compile the zoning map of geological hazards and divide the hazard intensity, which plays an important role in evaluation of the damage loss degree of geological hazards, and planning, deployment and implementation of the prevention and control of geological hazards.

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1. Overview of Study Area

Located between 105°29 'E~111°15' E, 31°42 'N~34°33' N, Qinling-Daba mountain area of Shaanxi province covers an area of 85089.7 km2. The terrain of this area is rugged and undulating with high mountains and deep valleys, serious rock breakage and weathering, developed active fault zones and complex geological structure. Taibai Mountain, the highest peak in the region, is 3771 m above sea level. Qinling-Daba mountain area of Shaanxi province spans two climate zones. North of Qinling mountains is a warm temperate continental monsoon climate zone. It is cold and dry in winter and hot and rainy in summer. The south of Qinling mountains is a subtropical humid monsoon climate zone with four distinct seasons and abundant rainfall. The average annual temperature is 5~17℃, the average annual precipitation is 600~1250mm, the frost-free period is 160~275 days and the accumulated temperature is ≥10℃ 1937 ~4951℃ in the zone.

According to statistics, there are 7,861 geological disasters in Qinling-Daba mountain area of Shaanxi province that are mainly landslides, collapses and debris flows. Among them, 6,817 are landslides, accounting for 86.6% of the total number of geological disasters while 539 are collapses and 434 are debris flows. However, ground collapse, cracks and unstable slopes are less developed, accounting for only 1% of the total number of geological disasters (Table 1). In terms of spatial distribution, geological disasters are generally distributed along large geomorphic boundaries, major fault zones and river valleys and also concentrated near towns and settlements (Figure 1).

Table 1 Statistics of geo-hazards types

statistics	hazard type						
	landslide	collapse	debris flow	surface collapse	ground fracture	unstable slope	total
number（place）	6817	539	434	43	42	6	7861
proportion（%）	86.6	6.8	5.5	0.5	0.5	0.1	100

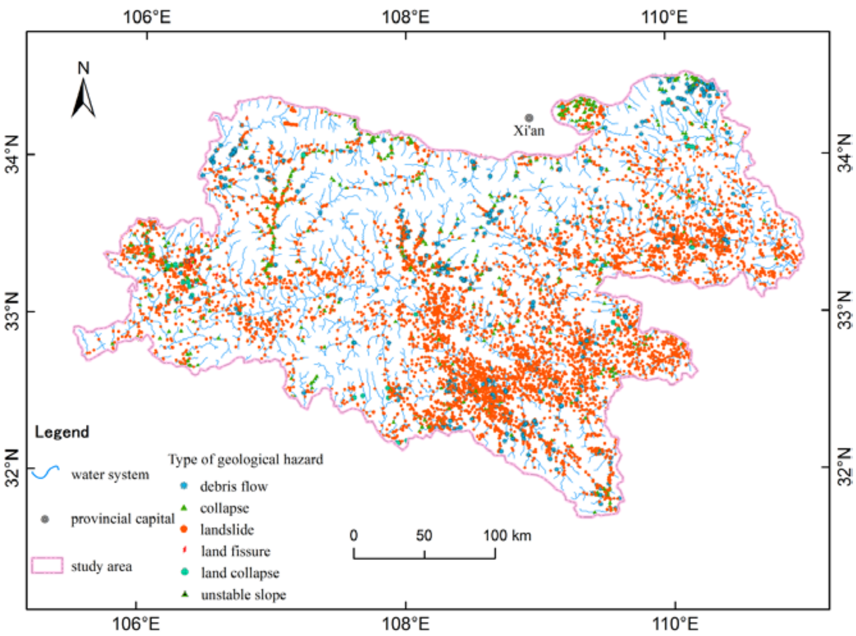

Fig.1 Types and spatial distribution of geological disasters in Qinling-Daba Mountains of Shaanxi Province

2. Data Source from Method

2.1 Data Sources

The datum used in this paper mainly include digital elevation model (DEM), vegetation, perennial average precipitation, fault, river network, earthquake catalog, geological disaster points and other data sets. DEM data is grid data with 30m resolution, which comes from ASTER GDEM data set of geospatial data cloud (http://www.gscloud.cn) and thus generates slope and topographic relief data in ArcGIS10.2. Vegetation data came from resource and environment data cloud (http://www.resdc.cn) and China annual vegetation index (NDVI) spatial distribution data set. Precipitation data is obtained from the average monthly precipitation data from 1959 to 2015 in the research areas and the surrounding meteorological stations of Shaanxi Provincial Meteorological Bureau and China meteorological science data sharing service (http://cdc.cma.gov.com). Fault data comes from the national geological data information network's (http://www.drc.cgs.gov.cn) 1:2,500,000 geological map; River network data is extracted from SWAT hydrological model based on DEM. Seismic data comes from the national earthquake science data sharing center (http://data.earthquake.cn); The data of geological disaster points comes from the field survey data of land and resources bureau at all levels in the research area.

2.2 Research Methods

2.2.1 FAHP

Fuzzy analytic hierarchy process is a comprehensive evaluation method combining fuzzy comprehensive evaluation method and analytic hierarchy process. It is improved from analytic hierarchy process and is an effective, multi-objective and multi-standard decision-making method [11], which is mainly applicable to the decision making without quantitative expression of influence factors. Its principle is to build problems and factors for the target layer, criterion layer and solution.

Then the judgment matrix of the influence of the lower layer on the upper layer is constructed according to the experts' rating and then the weight of the relative importance of the lower layer factors to the upper layer is calculated. Later the fuzzy evaluation is carried out according to the membership grade of each factor to finally obtain the overall evaluation result. Fuzzy analytic hierarchy process mainly includes the following four steps:

（1）The risk assessment model of geological hazards is constructed by stratifying the influencing factors. In this paper, four types and nine risk factors of geological hazards are selected to construct a three-level risk evaluation index system of "A target layer-B criterion layer-C indicator layer" (Table 2) to evaluate the risk of geological hazards in Qinling-Daba mountain area of Shaanxi province. The specific calculation formula can be seen in the reference [13].

（2）Constructing fuzzy judgment matrix. In the matrix, the comparison values of different indexes at the same level are given with scales ranging from 0.1 to 0.9 (Table 3).

（3）The fuzzy judgment consistent matrix $\mathrm{R} = \left(\mathrm{r_{ij}}\right)_{\mathrm{n\times n}}$ is constructed and the weights of each factor are calculated. The judgment matrix $\mathrm{r_i}$： is summed as follows:

$$r_i = \sum_{k=1}^{n} r_{ik} \tag{1}$$

Then the elements of the fuzzy consistent matrix are:

$$r_{ij} = \frac{(r_i - r_j)}{2n} + 0.5 \tag{2}$$

The weight of each index can be calculated from the above fuzzy judgment consistent matrix and the formula is as follows:

$$w_i = \frac{1}{n} - \frac{1}{2a} + \frac{\sum_{j=1}^{n} r_{ij}}{na}, (i = 1, 2, \cdots, n) \tag{3}$$

Among the formula: the parameter a satisfies $a \geqslant (n-1)/2$.

（4）Fuzzy judgment consistency matrix consistency test. According to the compatibility index formula (4), the compatibility index I between the fuzzy consistency matrix and its characteristic matrix is obtained. When the compatibility index $I \leqslant 0.1$ is obtained, the fuzzy consistency matrix is considered consistent.

$$I = \frac{1}{n^2} \sum_{i=1}^{n} \sum_{j=1}^{n} \left| a_{ij} - b_{ij} - 1 \right| \tag{4}$$

By testing, the consistency coefficients between the fuzzy judgment consistency matrices corresponding to the fuzzy judgment consistency matrices constructed in this paper are all less than 0.1, so it can be considered that the fuzzy judgment matrix constructed in this paper conforms to the consistency.

evaluation index			I Very low（1 point）	II low（2 point）	III medium（3 point）	IV higher（4 point）	V Very high（5 point）	weight	ranking
A Risk assessment of geological hazards	B1 terrain factor	C1 slope（°）	<5，>70	5~10，45~70	10~15	15~25	25~45	0.167	2
		C2 topographic relief degree（m）	0~50	50~100	100~200	200~300	>300	0.138	3
	B2 Climate and vegetation factors	C3 average annual precipitation（mm）	<750	750~850	850~950	950~1050	1050~1200	0.082	7
		C4 vegetation coverage（%）	>80	80~70	70~60	60~50	＜50	0.109	4
	B3 hydrological factor	C5 distance from river network（km）	＞4	3~4	2~3	1~2	<1	0.094	6
		C6 topographic wetness index	0.7~4	4~8	8~12	12~16	16~26	0.069	8
	B4 Tectonic factor	C7 distance from fault（km）	＞8	6~8	4~6	2~4	<2	0.191	1
		C8 ground motion peak acceleration（g）	<0.05	0.05~0.1	0.1~0.15	0.15~0.2	0.2~0.3	0.054	9
		C9 seismic point density（node/100km2）	<0.05	0.05~0.1	0.1~0.15	0.15~0.2	0.2~1.36	0.096	5

Table 2 Evaluation system for geological disasters

Table.3 Fuzzy judgment matrix scale and its meaning*

scale	definition	instructions
0.5	equal importance	The two factors are equally important
0.6	slightly more important	Compared with two factors, one factor is slightly more important than the other
0.7	Obviously important	Compared with two factors, one factor is obviously more important than the other
0.8	much more important	Compared with two factors, one factor is much more important than the other
0.9	Extremely important	Compared with two factors, one factor is extremely more important than the other
0.1、0.2 0.3、0.4	opposition	If r_{ij} is judged by comparing factor a_j with factor a_j, then $r_{ji} = 1 - r_{ij}$ is judged by comparing factor a_j with factor a_i.

*a_i、a_j representing different factors； r_{ij} is a measure of how important a_i is to a_j

2.2.2 Risk Assessment Model

Using raster calculator functions of ArcGIS10.2 software, according to formula (5), the risk rating layers of each factor are superimposed and analyzed and the risk rating layers of geological hazards in the study area are obtained, which refers to the risk index B. Then use formula (6) on normalized processing to get the normalized threat level index $B_{归一化}$. Use the natural breakpoint method to divide $B_{归一化}$ into five levels: Very low risk area (0~0.16), low risk area (0.16~0.33), medium risk area (0.33~0.46), high risk area (0.46~0.61), very high risk area (0.61~1). The larger the value of $B_{归一化}$, the higher the risk of geological hazard can be while the smaller the value of $B_{归一化}$ is, the lower the risk will be. The advantage of the natural break point method is that it can achieve the maximum variance between categories and the minimum variance within categories by identifying the classification interval to obtain the optimal classification results.

$$B = \sum W_i Y_i \tag{5}$$

$$B_{归一化} = \frac{B - \mathrm{Min}(B)}{\mathrm{Max}(B) - \mathrm{Min}(B)} \tag{6}$$

In formula (5) and (6) : B is the risk grade index; W_i is the comprehensive weight of each factor; Y_i will grade each influence factor; $B_{归一化}$ is the normalized risk grade index; $\mathrm{Min}(B)$ is to minimize the layer overlay; $\mathrm{Max}(B)$ is to maximize the layer overlay result.

3. Result and Analysis

3.1 Univariate Risk Analysis

According to the risk assessment system of geological hazards (Table 2), a single factor risk level map of geological hazards in Qinling-Daba mountain area of Shaanxi province is generated in ArcGIS10.2 (Figure 2). The risk level will be divided into five categories from low to high: I, II, III, IV and V. The lower the risk level is, the worse the disaster pregnant ability will be, while the higher the risk level is, the stronger the disaster pregnant ability will be. The results show that the conditions for geological hazards in Qinling-Daba mountain area of Shaanxi province are as follows: slope 15°~45°, topographic relief degree greater than 200m, perennial average rainfall 950mm~1200mm, vegetation coverage less than 60%, distance from river network less than 2km, distance from fault less than 4km and seismic point density 0.15-1.36 /100km2. In a word, regions with high topographic fluctuation, high rainfall, low vegetation coverage, close to river network and fault, and high density of seismic points have high risk of geological disasters.

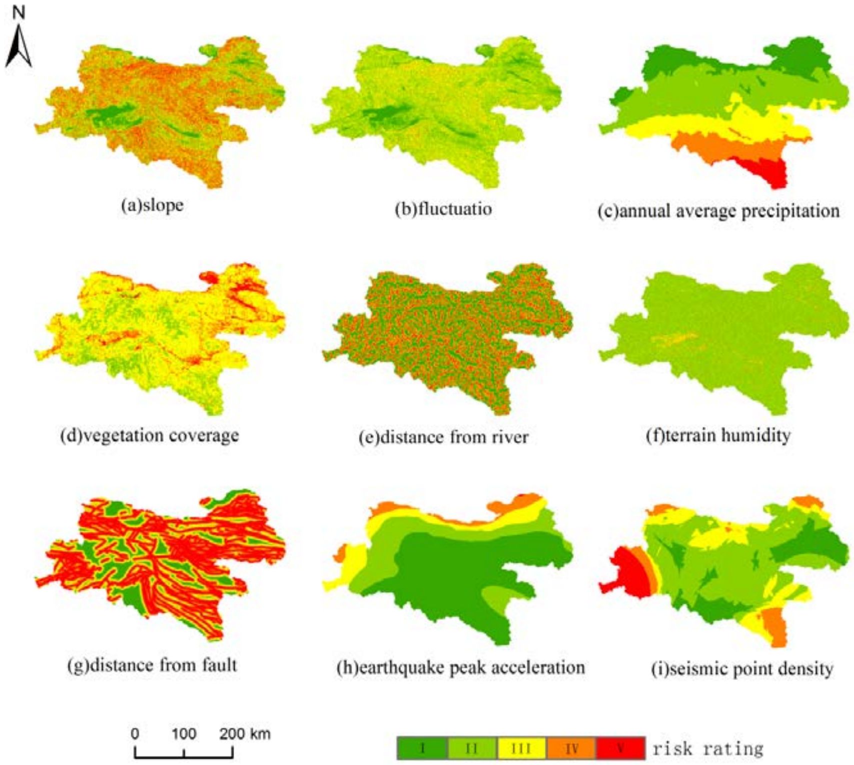

Fig.2 Single factor risk level of geological disasters in Qinling-Daba Mountains of Shaanxi Province

3.2 Multifactorial Risk Analysis

According to the weight of each factor in Table 2, multi-factor superposition analysis is carried out in ArcGIS10.2 by using formula (5), and the sub-map of the risk level of geological disasters in Qinling-Daba mountain area of Shaanxi province (Figure 3) is obtained. The hazard levels of geological hazards in Qinling-Daba mountain area show a normal distribution trend from low to high. The hazard levels of geological hazards in this area are mainly medium and high, the area and proportion of extremely high-risk area and low risk area are equal, and the area and proportion of extremely low risk area are less. The area and proportion of each grade of hazard area can be shown as: extremely high hazard area (area 11347.9 km2, proportion 13.34%), high hazard area (area 27151.6 km2, proportion 31.91%), medium hazard area (area 26858.8 km2, proportion 31.56%), low hazard area (area 12386.7 km2, proportion 14.56%), extremely low hazard area (area 7344.7 km2, proportion 8.63%).

Extremely high and high danger zone concentrate in three areas: (1) the central north of watershed in Qinling mountains, including Zhouzhi county, Huyi area, Changan area and Lantian county and other counties; (2) Qinling-Daba mountain area in the southwest, including Lueyang county, Ningqiang county and other counties; (3) the Qinling-Daba mountain area in the southeast includes Xunyang county, Ankang city, Baihe county, Pingli county, Zhenping county, Langao county, Ziyang county and Zhenba county, etc. This area is also a centralized distribution area of the geological hazard area in Qinling-Daba mountain area.

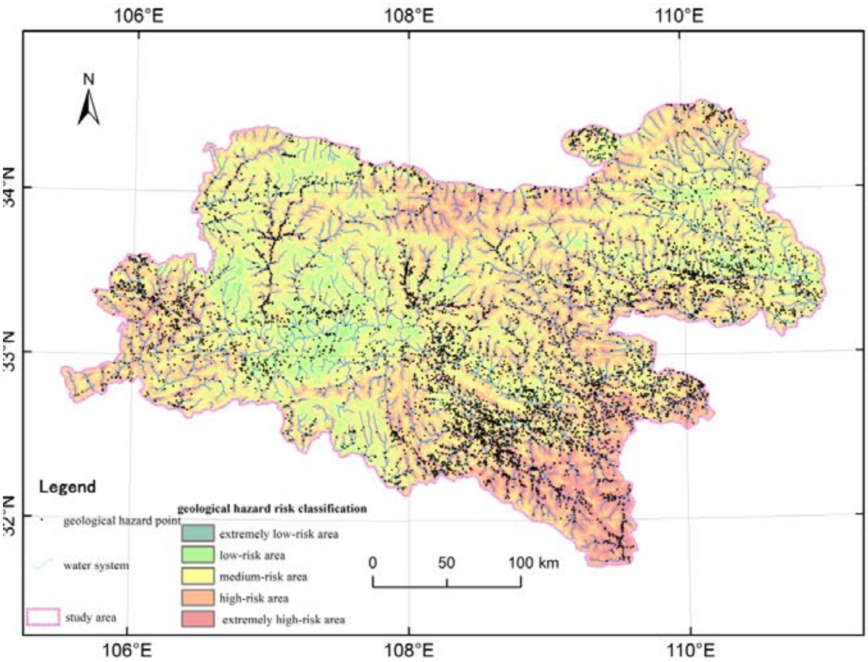

Fig.3 Risk grade division and result verification of geological disasters in Qinling-Daba Mountains of Shaanxi Province

In terms of the county scale, the ten counties with the largest areas of extremely high-risk areas and high-risk areas are Xunyang county, Zhenan county, Ningqiang county, Hanbin district, Lueyang county, Shanyang county, Ningshan county, Zhenba county, Pingli county and Ziyang county. The ten counties with the lowest area of extremely high-risk area and the least area of high-risk area are in order from low to high: Baqiao district, Linwei district, Qishan county, Hantai district, Chencang district, Lintong district, Tongguan county, Weibin district, Chenggu county and Mei county.

3.3 Dangerous Partition Result Verification

To explore the relationship between the result of geological hazard zoning in Qinling-Daba mountain area of Shaanxi province and the actual geological hazard, 7,861 geological hazard points in Qinling-Daba mountain area of Shaanxi province are imported into the hazard zoning map, and the number of geological hazard points in each grade of hazard area was counted by method of "spatial analysis toolbox → extraction analysis → value extraction to point" in ArcGIS10.2. Results shows:

The number of geological hazards distributed in the extremely low risk area, the low risk area, the medium risk area, the high-risk area and the extremely high-risk area is 12 (0.15%), 376 (4.78%), 1840 (23.41%), 4018 (51.12%) and 1615 (20.54) respectively. The geological hazards are mainly distributed in the extremely high-risk area and the extremely high-risk area (5633, 71.66%), which indicates that the actual spatial distribution of the geological hazards is highly consistent with the risk classification. Therefore, we can think that this study can provide an important reference for infrastructure construction and economic development planning in Qinling-Daba mountain area of Shaanxi province.

4. Conclusion

This article selects nine risk factors including slope, degree of ups and downs, average annual precipitation and other as the main elements. Based on fuzzy analytic hierarchy process, the weights are calculated respectively by means of ArcGIS platform to conduct evaluation of geological hazard risk of Qinling-Daba mountain area in Shaanxi province and complete the geologic disaster danger division. Based on the actual geological disaster points, the following conclusions are drawn:

（1）The conditions that may trigger geological disasters in Qinling-Daba mountain area of Shaanxi province are as follows: slope 15°~45°, topographic relief degree greater than 200m, perennial average rainfall 950mm~1200mm, vegetation coverage less than 60%, distance from river network less than 2km, distance from fault less than 4km and seismic point density 0.15-1.36 /100 km2.

（2）The risk level of geological hazards in Qinling-Daba mountain area of Shaanxi province is divided into extremely low risk area, low risk area, medium risk area, high risk area and extremely high-risk area. The area and proportion of each risk area are as follows: Very low risk area (area 7344.7 km2, proportion 8.63%), low risk area (area 12386.7 km2, proportion 14.56%), medium risk area (area 26858.8 km2, proportion 31.56%), high risk area (area 27151.6 km2, proportion 31.91%), very high risk area (area 11347.9 km2, proportion 13.34%).

（3）The result shows that only 4.93% of the geological hazards are distributed in the very low risk area and the extremely low-risk area, while 71.66% of the geological hazards are distributed in the high-risk area and the extremely high-risk area. This indicates that the regionalization can reflect the actual distribution of geological hazards with high accuracy and is able to provide scientific basis for disaster prevention and reduction in Qinling-Daba mountain area of Shaanxi province.

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