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Application of Analytic Hierarchy Process in Prospecting-Take Zijin Mountain in Fujian as an Example

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Abstract

Since the development of RS and GIS technology, its application in ore prospecting has attracted much attention. There are many previous studies with remarkable achievements. In this paper, the Zijinshan mining area in Fujian Province is selected as the research object, and the Landsat 8 image is used as the basic data to carry out structural interpretation and remote sensing alteration information extraction, and then the metallogenic target area is divided by means of GIS and analytic hierarchy process, which provides reference for further prospecting.

Keywords

Analytic Hierarchy Process; Prospecting; Fujian Zijinshan; Landsat8.

1. Introduction

1.1. Research Status of Comprehensive Information Prospecting of RS and GIS

Since the development of RS and GIS technology, people have given high hopes to its application in geological research and mineral exploration, and facts have proved that this method is feasible. In the process of metallogenic prediction and mineral exploration, a large number of remote sensing image data will be analyzed and interpreted by remote sensing technology, and then the multi-information comprehensive metallogenic prediction will be carried out by GIS. Asadi et al. applied GIS spatial model and weight of evidence model to prospecting in Takab area of Iran[1]. At present, the weight of evidence model is one of the most mainstream methods for prospecting through GIS, and its core theory is the theory of similarity and analogy, that is, when there is a mineral under a certain geological condition, there will be a certain probability that it will also exist under similar geological conditions. Based on Bayesian conditional probability, the model obtains the weights of evidence factors related to mineralization through mathematical calculation, and then obtains the posterior probability of a certain place containing minerals in space, and according to the posterior probability, various levels of metallogenic target areas can be delineated[2]. The evidence factors related to mineralization are specific geological conditions, such as structure, alteration anomaly of surrounding rock, geochemical anomaly of elements and magnetic anomaly. The biggest advantage of the weight of evidence method is to carry out research through the most intuitive form of expression, but it also has shortcomings. Using the weight of evidence method requires that all evidence factors are independent of the conditions of the predicted object, otherwise it will lead to errors in calculating the posterior probability. In order to overcome the influence of the limitation of mathematical methods on the accuracy of ore prospecting, Cheng Qiuming proposed to enhance the evidence right model in 2012 and relaxed the requirement of conditional independence[3]. Yan Bing and others introduced fractal theory into the evidence right model for the first time in 2012[4], which made the ore prospecting result more accurate, but it was followed by a more complicated and tedious process. Therefore, this paper proposes to calculate the weight of main

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metallogenic evidence factors in mineralization by analytic hierarchy process, and then make metallogenic probability map by ArcGIS superposition analysis module to complete the purpose of prospecting. This method has the advantages of simple steps and small workload while retaining the greatest advantage of weight of evidence method.

1.2. Research Content and Significance

This paper chooses Zijinshan mining area in Shanghang County, Longyan City, Fujian Province as the research area. The landform of the study area is high in the northwest and low in the southeast, generally steep in the northwest and gentle in the southeast, with slopes of 15°-40°, with strong weathering, poor bedrock exposure, developed vegetation and large coverage[5]. The strata in the study area are well developed, but the exposed strata are simple. Zijinshan Mountain is located on the west side of Mesozoic volcanic activity belt along the southeast coast, northwest of Hangzhou-Yunxiao deep fault zone and the northern edge of Hangzhou volcanic tectonic depression in the early Cretaceous controlled by it[6]. The faults in the study area are mainly NE-trending and NW-trending faults, and there are also small faults in the near North-South direction. Zijinshan area is suitable as a research area because of its complex structure and rich metallogenic factors. The location map of the study area is shown in Figure 1.

Firstly, collect and sort out the geological data of the study area and the previous research results to understand the geological survey of the study area; Landsat 8 OLI data is selected, and based on this remote sensing image, ENVI software is used for geological interpretation and alteration information extraction. According to the comprehensive analysis of the previous results, the geoscience database of the study area is established; ArcGIS software is used to analyze the established geoscience database, and the metallogenic target area of the study area is delineated based on analytic hierarchy process. Through the research results, we can carry out targeted prospecting, effectively improve the accuracy of prospecting, reduce the cost of prospecting and avoid invalid operations.

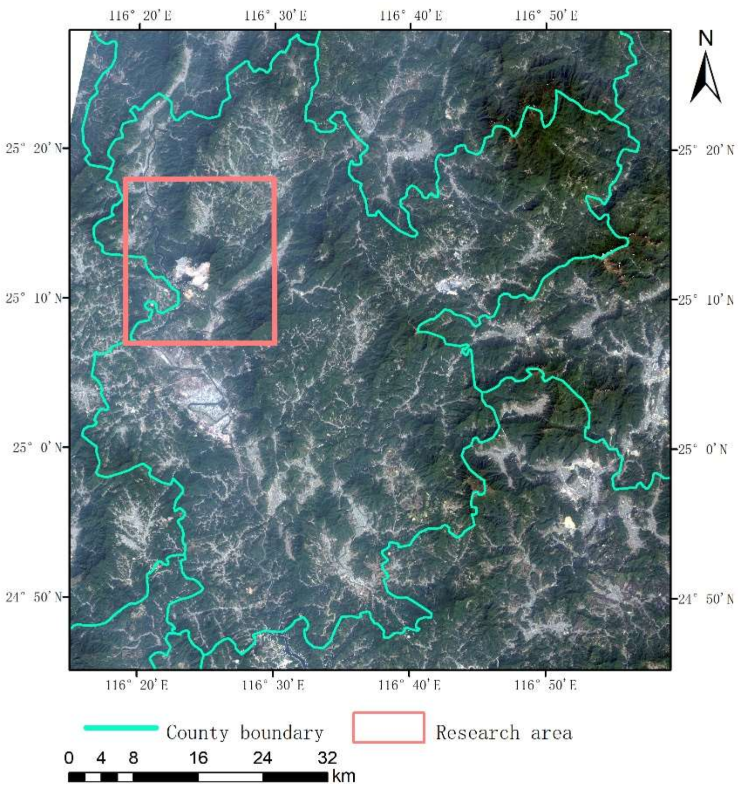

Figure 1. Location map of study area

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Compared with the previous use of ASTER satellite data combined with weight of evidence method to make metallogenic prediction, this paper chooses Landsat8 satellite data as the data source, which has the advantages of free and rich band combination. Compared with the weight of evidence method which is widely used at present, the analytic hierarchy process (AHP) has the advantages of being simple and easy to understand.

2. Remote Sensing Data Processing based on ENVI

2.1. Pre-processing of Remote Sensing Images

The selection of remote sensing images should meet the requirements of less cloud cover, strong layering of different features, good tone contrast and clear overall impact, and the band setting can meet the requirements of remote sensing geological interpretation and alteration information extraction[7]. Obtain the Landsat8 L1TP data of February 22nd, 2021 in the Geospatial Data Cloud, which has been corrected for terrain and geometry. The flow chart of image preprocessing is shown in Figure 2, in which Gram-Schmidt image fusion method is selected for image fusion. This fusion method has good image fidelity and is an efficient image fusion method. It has high spatial resolution while retaining spectral information, which is helpful for geological interpretation[8]. 25°7′N-25°18′N and 116°19′E-116°30′E are selected as the study areas, and the pretreatment results are shown in Figure 3.

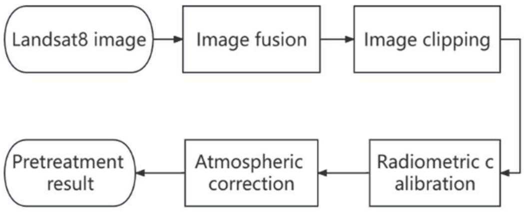

Figure 2. Pretreatment Flowchart

Figure 3. Pretreatment Results

Pretreatment is a necessary preparation before the formal extraction of metallogenic evidence factors, and the quality of pretreatment results is directly related to the extraction results of main metallogenic evidence factors. In this paper, we choose to extract two kinds of main evidence factors, namely structural information and surrounding rock alteration information, for research.

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2.2. Structural Interpretation

Remote sensing geological interpretation refers to the process of establishing marks and extracting geological information identified in remote sensing images[9]. Visual interpretation is used to interpret remote sensing images. Image enhancement is needed before visual interpretation of remote sensing images. 562 bands are combined in color synthesis, and the color of the image is clear. Gaussian image stretching method is selected by comparison. The enhanced image is shown in Figure 4.

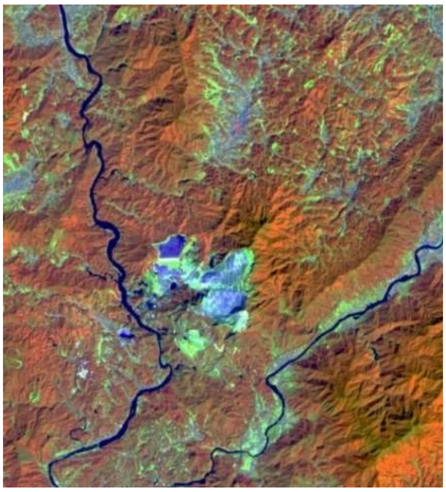

Figure 4. 562-band combined Gaussian stretching image

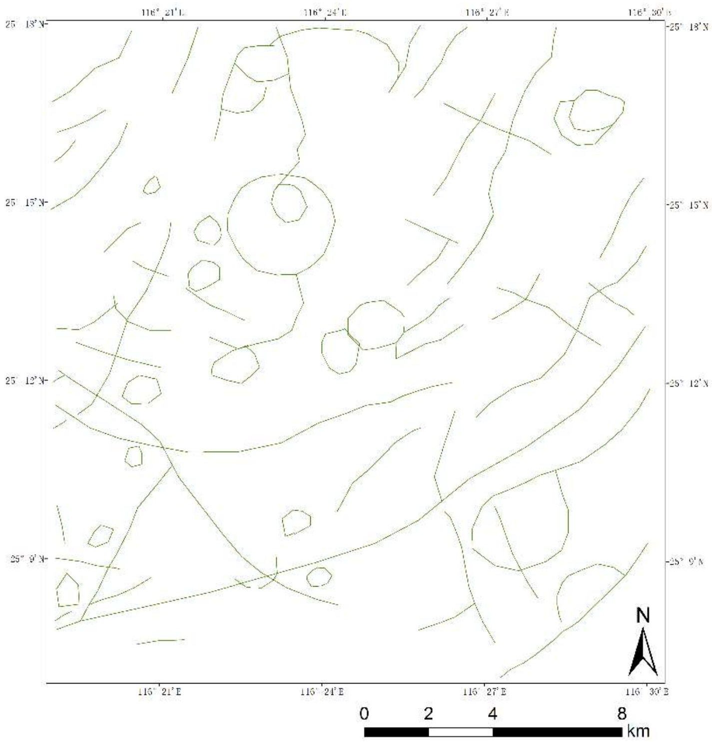

Figure 5. Structural Interpretation Diagram

According to the extraction and analysis of linear structures, most of the linear structures in the study area are NE-trending structures and NW-trending structures. These structures are long-extending, especially NE-trending structures, which are the embodiment of the Zhongliao-Jinshan foot fault zone and the main rock-controlling and ore-controlling fault zone in the study

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area. The NW-trending structures are the reflection of two parallel fault zones, Chishui-Shizhentan and Changshuxia-Xiaojinshan[10]. The ring structure in the study area is relatively developed, almost all of which are round and arc in shape, and the development has the characteristics of groups. The metallogenic types of copper-gold deposits in this area are mainly related to Yanshanian basic-intermediate-acidic and acidic magmatism, so we should pay attention to the interpretation of volcanic mechanism[11]. The linear and circular structures obtained by interpretation are abundant in quantity and good in quality, which is of research value. The structural interpretation results are shown in Figure 5.

2.3. Extraction of Alteration Information of Surrounding Rock

Mineralization and alteration information is a product directly related to mineralization, and it is quantitative remote sensing prospecting information[12]. The surrounding rocks of the deposit in Zijinshan area have been seriously altered, and all kinds of rocks exposed in the area have suffered from intense hydrothermal alteration, and the mineral composition and structure of the original rocks have undergone major changes[13]. The main types of wall rock alteration in Zijinshan area are pyritization, sericitization, silicification, etc. Usually, pyritization contains $Fe2+$ and $Fe3+$ ions, and sericitization contains hydroxyl and carbonate ions, so iron staining anomaly, hydroxyl anomaly and carbonate anomaly are extracted. Before the formal extraction, the third and sixth bands of Landsat 8 data are selected for band ratio operation, Band6/Band3, and the part with DN value less than 0.6 is taken as a mask, and then the water body in the remote sensing image is removed through the mask.

2.3.1. Extraction of Iron Dyeing Alteration Anomaly

Using the ratio method to process the 5th and 6th bands, we can extract the abnormal iron staining and alteration. Firstly, the band operation of Band6/Band5 is carried out; The image obtained by band operation is processed by 5×5 median filtering to reduce the interference such as isolated noise; The obtained images are statistically analyzed, and the low-level alteration area, middle-level alteration area and high-level alteration area are divided by density segmentation method. The obtained abnormal diagram of iron staining and alteration is shown in Figure 6.

2.3.2. Extraction of Abnormal Hydroxyl Alteration

Principal component analysis is used to extract hydroxyl alteration anomalies. Principal component analysis (PCA), also known as Karhunen-Loeve, compresses or reduces the dimension of data through feature selection and feature compression, and its ultimate goal is to make the information content between principal components not duplicate, reduce the amount of data and highlight useful information[14]. Select Band2, Band5, Band6 and Band7 for principal component analysis, and the results are shown in Table 1. It is found that the inversion of PC4 can meet the demand. PC4 band is extracted and inverted, and then filtering and density segmentation are also carried out. The obtained abnormal diagram of hydroxyl alteration is shown in Figure 7.

2.3.3. Extraction of Carbonate Alteration Anomalies

Table 1. Characteristic Vector of Band2567 Principal Component Analysis

Proper vector	B2	B5	B6	B7
PC1	0.209236	0.552561	0.632179	0.501245
PC2	0.181922	-0.819652	0.294090	0.456713
PC3	-0.937556	-0.066173	0.339575	0.036035
PC4	-0.210032	0.135901	-0.631307	0.734077

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Table 2. Characteristic Vector of Band3567 Principal Component Analysis

Proper vector	B3	B5	B6	B7
PC1	-0.313696	-0.515070	-0.621661	-0.499836
PC2	-0.239288	0.843171	-0.244259	-0.414899
PC3	0.899554	0.072971	-0.411048	-0.128520
PC4	-0.187454	0.135799	-0.620414	0.749337

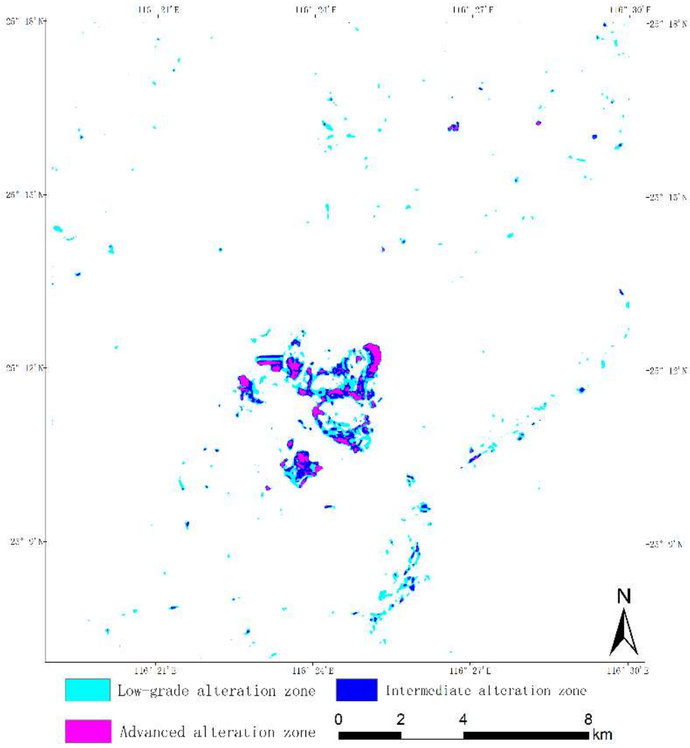

Figure 6. Abnormal Diagram of Iron Dyeing and Alteration

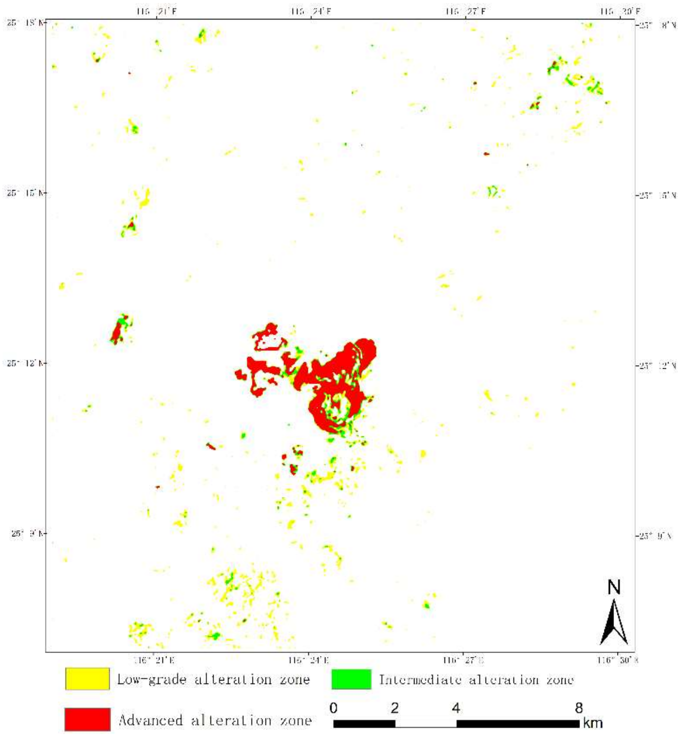

Figure 7. Abnormal Diagram of Hydroxyl Alteration

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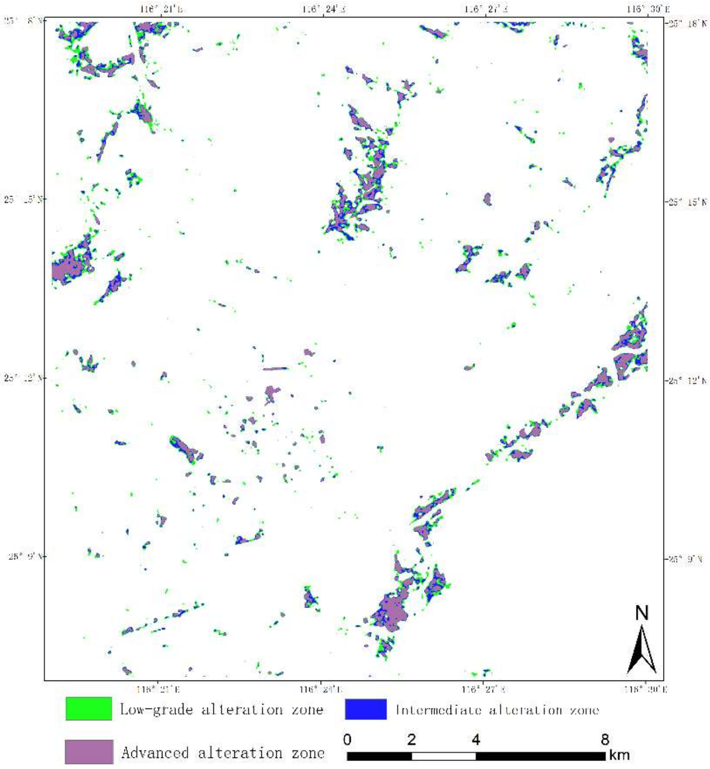

Figure 8. Abnormal Diagram of Carbonate Alteration

Principal component analysis is also used to extract carbonate alteration information, and four bands, Band3, Band5, Band6 and Band7, are selected for principal component analysis, and the obtained feature vectors are shown in Table 2. Analysis shows that PC4 meets the requirements. PC4 is extracted for filtering and density segmentation again. The obtained alteration anomaly map is shown in Figure 8.

3. Delineation of Metallogenic Target Area

According to the processed remote sensing images combined with geological maps, the metallogenic target area can be delineated according to geological theory.

In this paper, the analytic hierarchy process (AHP) is selected as the core, which is more flexible than the currently used evidence weight method. The weight of evidence method needs to analyze a large number of evidence factors, get the influence of each factor on mineralization, select the factors with great influence, and meet the conditional independence, and then calculate the areas with high metallogenic probability. Through the analytic hierarchy process, an appropriate number of metallogenic factors can be extracted according to the actual demand and personal ability, and the weight can be given after analysis and calculation, and then the metallogenic prediction can be made. Analytic hierarchy process (AHP) has the advantages of flexible application and simple steps, but it requires users to be familiar with the metallogenic mechanism and have a certain understanding of the study area.

3.1. AHP to Determine the Weight

Analytic Hierarchy Process (AHP) is a subjective evaluation method, which decomposes the elements related to decision-making into three levels: target level, criterion level and scheme level, and carries out qualitative and quantitative analysis on this basis. This method is generally used for index weighting and quantitative scheme selection. This study only needs to determine the index weight, so the target layer is determined as "the influence of various metallogenic factors on mineralization" and the criterion layer as "multiple metallogenic factors", and the scheme layer does not need to be considered.

Analytic Hierarchy Process (AHP) compares any two factors among multiple factors, gives the comparison coefficient of importance according to the importance, thus obtains the evaluation matrix, and obtains the importance proportion of each influencing factor of complex events through the operation of the matrix[15], namely the weight value. The evaluation matrix is shown in Figure 9, and the comparison coefficient of importance is shown in Table 3.

$$\boldsymbol{D} = \begin{bmatrix} \boldsymbol{a_{11}} & \boldsymbol{a_{12}} & \cdots & \boldsymbol{a_{1j}} \\ \boldsymbol{a_{21}} & \boldsymbol{a_{22}} & \cdots & \boldsymbol{a_{2j}} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{a_{i1}} & \boldsymbol{a_{i2}} & \cdots & \boldsymbol{a_{ij}} \end{bmatrix}$$

Figure 9. Evaluation Matrix

Table 3. Table of Importance Comparison

Comparison coefficient	meaning
1	i factor is as important as j factor
3	i factor is slightly more important than j factor
5	i factor is obviously more important than j factor
7	i factor is more important than j factor
9	i factor is much more important than j factor
2,4,6,8	The intermediate value of the above judgment
reciprocal	The ratio of the importance of i factor and j factor and the ratio of the importance of j factor are reciprocal

Coefficient.

According to the above standards, the fifth-order evaluation matrix is constructed, with the indexes of linear structure, annular structure, iron staining alteration, hydroxyl alteration and carbonate alteration, and the specific important comparison coefficients are shown in Table 4.

Table 4. Fifth-order Evaluation Matrix

index	Linear structure	Annular structure	Carbonate alteration	Iron staining alteration	Hydroxyl alteration
Linear structure	1	0.333	3	2	3
Annular structure	3	1	5	3	2
Carbonate alteration	0.333	0.2	1	0.25	0.333
Iron staining alteration	0.5	0.333	4	1	0.5
Hydroxyl alteration	0.333	0.5	3	2	1

The following are the calculation steps.

1) Calculate the product of the elements in each row of the matrix.

$$M_i = \prod_{j=1}^{n} a_{ij}, i = 1,2,3, \dots, n \tag{1}$$

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2) Calculate the nth root of Mj.

$$\overline{W_i} = \sqrt[n]{M_i} \tag{2}$$

3) Standardize $\overline{W}$i, where W is the feature vector.

$$W_i = \frac{\overline{W_i}}{\sum_{j=1}^{n} \overline{W_j}} \tag{3}$$

4) Calculate the maximum characteristic root.

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} \tag{4}$$

5) Consistency verification. CR is the consistency ratio, CI is the consistency index, and RI is the randomness index, which can be obtained by looking up the table. The value of RI is shown in Table 5. When CR<0.1, the consistency test is qualified.

$$CI = \frac{\lambda_{max}}{n-1}, CR = \frac{CI}{RI} \tag{5}$$

Table 5. RI Value Table

Order	1	2	3	4	5	6	7	8	9
Value	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

The results obtained by completing the above steps are shown in Table 6, and the consistency test is qualified and the obtained results are reliable.

Table 6. Analytic Hierarchy Process Results

Item	Proper vector	Weight value	Maximum characteristic root	CI
Linear structure	1.203	24.067	5.343	0.086
Annular structure	1.972	39.44		
Carbonate alteration	0.291	5.812		
Iron staining alteration	0.282	13.64		
Hydroxyl alteration	0.852	17.041		

3.2. Delineation of Metallogenic Target Area based on ArcGIS

Based on the weight values obtained by analytic hierarchy process, the metallogenic prediction map can be made by using the superposition analysis module in ArcGIS. In the analytic hierarchy process, the weights of different influencing factors are realized by weighted superposition of raster data, and finally the evaluation results are formed[16].

Because the linear structure and the ring structure are line elements, a 400-meter buffer zone is made for the linear structure and the ring structure as the influence range of the structure, and the area elements are obtained, which can be converted into raster data for weighted superposition analysis. The tool used in drawing is the weighted sum in ArcGIS toolbox. Based on the weighted value of each factor, the weighted value of each pixel is calculated, and the image is obtained according to this value. Through the statistical analysis of the obtained images, the density is segmented with the standard of mean + k·standard deviation, and the k value is taken as 2 and 3 respectively, and three ranges are obtained, namely 0-0.59, 0.59-0.79 and > 0.79, corresponding to low probability area, medium probability area and high probability area respectively. According to the obtained map, combined with geological map and geological theory, the metallogenic target area is delineated, and the result is shown in Figure 10.

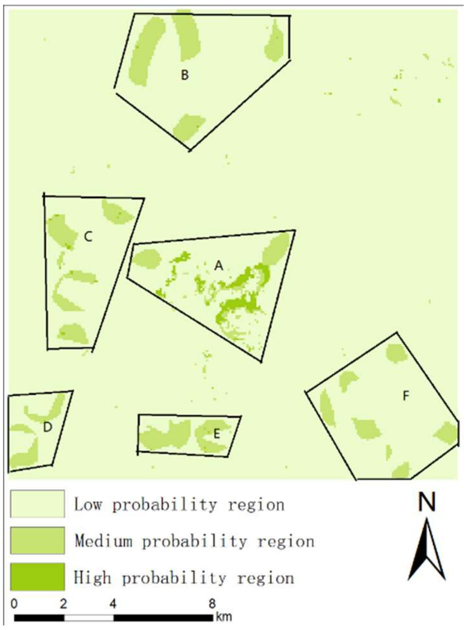

Figure 10. Metallogenic Prediction Map

Six metallogenic target areas are delineated in the figure. Area A is a mining area, which is a known metallogenic area, and the other five areas are expected metallogenic areas, which provides some reference for subsequent exploration. Area A can reflect that the method adopted in this study is more accurate, and can be applied to prospecting, delineating the scope for subsequent more detailed prospecting, thus reducing the prospecting cost.

4. Conclusion

Based on the remote sensing image, this study takes the analytic hierarchy process as the core, and defines the metallogenic target area accurately by means of RS and GIS, which provides some reference for subsequent exploration. The method used in this paper is simple and flexible. Compared with the weight of evidence method, the method in this paper can make a result in a shorter time and obviously reduce the consumption of manpower and material resources. Compared with the facts, it can be confirmed that this method has qualified accuracy, but the researchers who operate it are required to have enough professional ability to determine the importance comparison coefficient.

There are some problems in this study. First, the field verification is not carried out because of the conditions. Secondly, affected by the environment of the study area, the vegetation coverage area in the study area is large, which interferes with the processing and information extraction of remote sensing images.

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