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Yang Yu[1,3], Denghong Wang[1], Juanqin Gao[1,2], Lijun Liu[1,2] and Feng Yu[1,2]

[1] MNR Key Laboratory of Metallogeny and Mineral Assessment, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China;
[2] China University of Geosciences, Beijing 100083, China.

[3] Email: yuyang_cags@sina.com

Abstract. An environmental impact assessment was performed to evaluate the environmental impact of ion-adsorption type rare earth (iRee) mining in Southern Jiangxi Province, China. Based on the research of essential factors for mining environment systems, an evaluation index system for surface water quality was established, and a special assessment model was built based on principal component analysis and fuzzy theory. On the basis of evaluating the water quality, a fuzzy comprehensive judgment model was established to conduct a comprehensive evaluation of the local mining area's geological environmental quality. Four factors such as physical geography (A), basic geology (B), mining development coverage (C), and environmental influences (D) were selected and combined with field data and measurement results. These factors were used to establish an index system using an expert system and objectivity to determine the weight of the factors. A comprehensive evaluation model for the geological environmental impact of different types of iRee mines (light and heavy rare earth mines) was established based on a support vector machine (SVM) model. The results indicate that the monitoring and governance model successfully assesses the environmental impact of typical iRee mining areas by classifying the environmental quality into four levels. The model has a strong applied value as it provides help for geo-environmental management, helps with the exploitation of iRee mineral resources, protects the geological environments and helps restoring and reconstructing mine environments.

1. Introduction

There are many environmental factors involved in the exploitation of ion-adsorption type rare earth mining (iRee) [1-14]. The main environmental concern regarding iRee mining is usually not the iRee itself but the common mineral processing reagents. These reagents occur not only in the mining, dissolution and migration, but also in the precipitation process. The comprehensive evaluation of environmental quality in iRee mining areas is a multi-level, multi-objective and multi-factor engineering problem. A previous study used the evidence law [15], BP-based neural network and GIS method, to evaluate and grade the geological environment of iRee. However, these indicators do not include surface water pollution. Surface water pollution caused by iRee mining is considered to be the top priority within different types of environmental pollution [16]. Therefore, the comprehensive assessment of the environment for such mines should take into account indicators of water pollution based on microanalysis.

Support vector machine (SVM) is a general learning method in the neural network evaluation domain and it is widely used in the environmental quality assessment of lake water eutrophication, soil environmental quality, soil heavy metal pollution, ambient air quality and mining environments [17-26]. These studies have yielded some objective and practical results. Given a set of training examples, each marked as belonging to one or the other of two categories, an SVM training algorithm builds a model that assigns new examples to one category or the other, making it a non-probabilistic binary linear classifier. Furthermore, it is easy to combine SVM with ENVI and ArcGIS tools, which was suitable for environmental applications.

Based on the survey of the environmental situation of the iRee mining in southern Jiangxi Province, this paper examines the water environment quality evaluation model of the iRee mining and evaluates the water quality. The evaluation index system for surface water environmental quality was established by selecting 13 secondary indicators (Figure 1) and a special assessment model was built based on principal component analysis and fuzzy theory. On this basis, the water quality grading results were used as one of the 13 secondary indicators, and the environmental monitoring and management model of iRee mining areas was established using SVM. A comprehensive evaluation of the local mining area environmental quality was carried out.

2. Construction of environmental monitoring and evaluation index system for iRee

The factors affecting the environmental quality because of the development of iRee mining are diverse. The mine's ecological environment depends not only on the mining activity itself, but also on a variety of factors closely related to the geology of the mining area, the topography and hydro-geological conditions. Based on the results of the environmental research of the iRee mining in Southern Jiangxi Province, four main factors (the natural geography A, the basic geology B, the mining development coverage C and the environmental impact D) were used as the criterion layer, corresponding to 13 secondary variable indicators, and were used to establish the environmental monitoring and evaluation index system. The data for each variable index were quantified by the fractional method. Due to the fact that the surface water pollution caused by mining in the study area was the most important factor of environmental pollution, the mine environment evaluation index system of Li Dong et al. [27] was optimized and improved. The degree of water resource deterioration, evaluated by microcosmic analysis was added. According to the degree of influence of the evaluation factor, the evaluation index value was quantified into three ranks: I (evaluation score of 1 point), II (evaluation score of 2 points), III (evaluation score of 3 points), as illustrated in Figure 1.

3. Environmental monitoring and evaluation factor information extraction

The basic data of the study area used in this study include: Landsat TM multi-spectral remote sensing images of first period (30 meters resolution, shot in October 2013, covering Longnan, Xunwu, Anyuan three counties, whereas some images are from a small part of Longnan County shot in November 2013), a basic geological map of the study area (1:200,000), Digital Elevation Model (DEM) data of the study area (30 meters resolution), administrative map of the study area; the boundary data of REE mining rights, 31 sampling sites in the study area (Figure 2a and Figure 2b), water quality monitoring data for six periods (data of leaching wastewater, tributaries at closed mines, downstream drainage of the mining area, upstream drainage of the mining area, well water of the residents and water quality data from the water network of from Longnan, Xunwu and Anyuan counties), and environment and society-economy data of the study area. The basic data are pre-processed by ENVI and ArcGIS software, including multi-spectral remote sensing image projection conversion, geometric correction and re-sampling. Then the information extraction of the basic geological map is carried out by means of human-computer interaction interpretation, obtaining the vector data of all kinds of rock mass distributions. Types of rock mass distributions on 1000 meters resolution were obtained by transforming vector data into raster data mutually, which were conducted by using the toolbox of ArcGIS 9.2. According to the coordinates of water quality sampling sites, ArcGIS space tools are used for generating vector files that can be overlaid with other spatial layers.

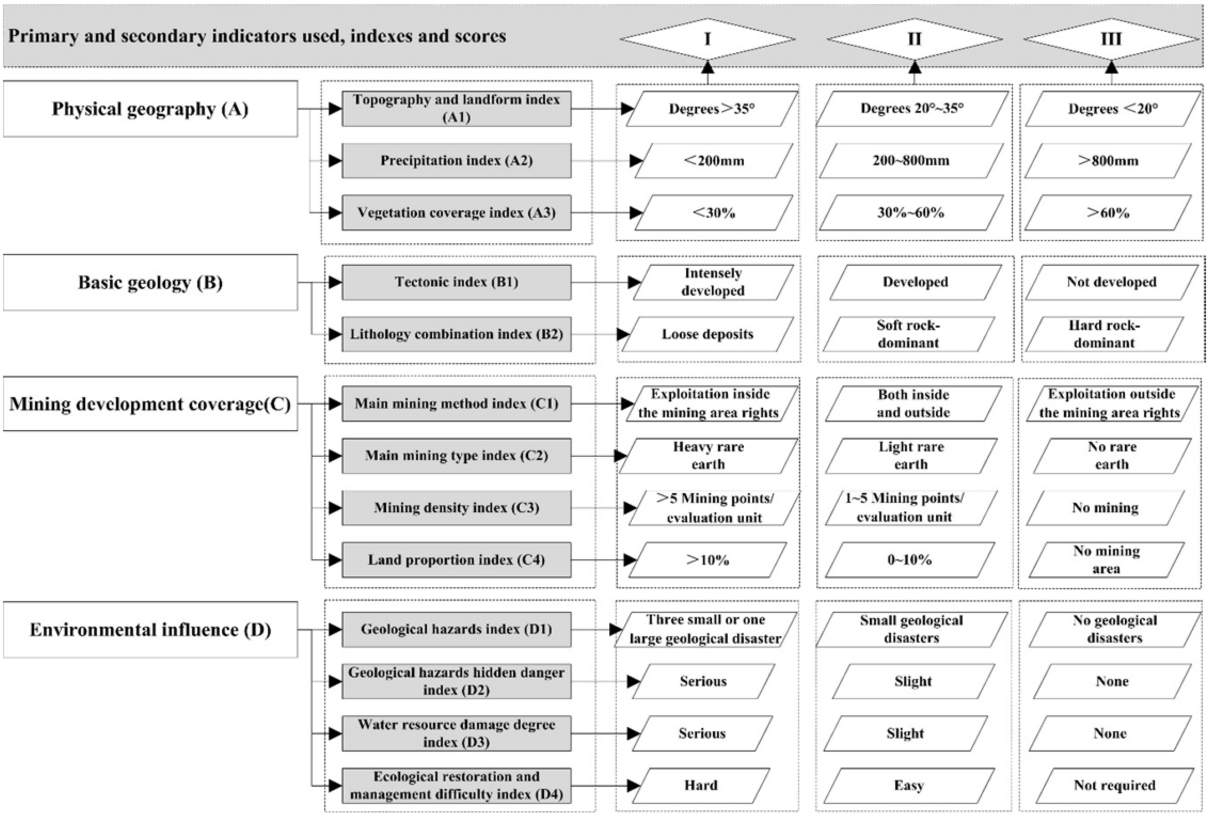

Figure 1. A flowchart regarding the primary and secondary indicators used, indexes and scores.

3.1. Natural geography (A) evaluation factor extraction and analysis

*3.1.1. Topography and landform index A1.*Using the Topographic Modelling tool of the ENVI software, the average elevation of each unit in the study area was calculated by entering the digital elevation data. Evaluation units were sampled at 1000m×1000m. According to the slope threshold of 35 degrees and 20 degrees, the evaluation units were assigned a value of 1, 2 or 3. The result was illustrated in Figure 2c.

3.1.2. Precipitation index A2. According to the statistical yearbook, the average annual precipitation of Longnan, Xunwu and Anyuan counties is above 1600mm. Based on the evaluation system, the precipitation index of all the evaluation units in the study area was 3 (> 800mm).

3.1.3. Vegetation coverage index A3. Firstly, vegetation indices were calculated based on Band 3 and Band 4 of Landsat TM images, and the degree of vegetation coverage was extracted according to NDVI based on the transformation model. Through linear transformation, the vegetation indices of each evaluation unit was calculated as the corresponding vegetation coverage value. On the basis of this, all evaluation units were assigned the value 1, 2 and 3 based on the vegetation coverage (1 for a coverage of < 30%, 2 for 30% to 60%, and 3 for > 60%), as illustrated in Figure 2d.

3.2. Basic geological (B) evaluation factor extraction and analysis

Tectonic index (B1): Based on the 1: 200,000 geological map, the evaluation units were assigned a value of 1, 2 or 3 based on intensely developed, developed or not developed arguments in the ArcGIS spatial data processing tools, as illustrated in Figure 2e.

Lithology combination index (B2): Interpreting the results based on the basic geological map, field investigation and remote sensing images through the ArcGIS spatial data processing tools, the evaluation units were assigned values of 1, 2 or 3 according to loose deposits, soft rock-dominant or hard rock-dominant, as illustrated in Figure 2f.

3.3. Mining development coverage (C) evaluation factor extraction and analysis
Main mining method index (C1): The exploitation of the rare earth elements in the study area involves open-pit mining. Therefore, an evaluation unit is assigned 1 when exploitation occurs inside the mining area rights, while the evaluation unit is assigned 3 when exploitation occurs outside the mining area rights. If the evaluation unit includes two mining methods, we determine the evaluation unit score on the basis of area proportion by different mining method. Main mining type index (C2): heavy rare earth was assigned 1, light rare earth was assigned 2 and no rare earth was assigned 3, as illustrated in Figure 2g. Mining density index (C3): based on the mining rights and field research data, evaluation units were graded with 1, 2 or 3 points according to: more than 5 mining points / evaluation unit, 1-5 mining points / evaluation unit or no mining in the evaluation unit. Land proportion index (C4): based on the mining rights and field research data, all evaluation units were assigned the value 1, 2 or 3 based on the mining area (1 for > 10%, 2 for 0 to 10%, and 3 for no mining area), as illustrated in Figure 2h.

3.4. Environmental influence (D) evaluation factor extraction and analysis

3.4.1. Geological hazards index D1. Based on field work and related geological hazard data of collapse, landslide and debris flow, the assessement of danger in the study area was estimated with a gray correlation method. All evaluation units were assigned the value 1, 2 or 3 based on the geological hazards danger assessment (1 for three small or one large geological disaster, 2 for 1 to 2 small geological disasters, and 3 for no geological disasters), as illustrated in Figure 2i.

3.4.2. Geological hazards hidden danger index D2. If the slope is less than 40 degrees and the vegetation coverage is less than 20%, geological disasters such as landslides and debris flows are very likely to happen. The evaluation units were assigned 1 point in this case. A low probability for disaster was considered as a slope of less than 15 degrees and more than 60% of vegetation coverage, in which case the evaluation unit was assigned 3 points. Other cases are slight geological hazard hidden danger areas and were assigned 2 points, as illustrated in Figure 2j.

3.4.3. Water resource damage degree index D3. 31 samples were collected in six periods: spring and autumn of 2012, spring and summer of 2013 and autumn of 2014 and 2015. S-type Principle component analysis (PCA) was employed to accomplish chemical analysis of non-dimensional index data for surrounding iRee mining areas. SPSS software was used for calculating covariance and correlation matrices. According to the results, a first main component was selected with a principal component variance contribution of $\geqslant$ 85% with chromium, arsenic, copper, zinc, lead, cadmium, selenium, nitrate, nitrite, ammonia, chloride, fluoride, sulphate as 13 indicator vectors combined in the factor set U. The reduced semi trapezoidal distribution method was selected to construct membership function by which the fuzzy performance matrix was established. The weight coefficient of each factor was calculated by the excessive pollution contribution method.

Based on fuzzy theory, subordination function was ascertained, fuzzy performance matrix was established, making use of multi- hierarchical fuzzy transformation appraised to surface water quality by programming in Excel VBA platform. On the basis of surface water environment standard (from I to V), estimation subclass (estimation subclass V) was established and the fuzzy comprehensive judgment model was constructed, including confirming gene subclass, estimation subclass and evaluation matrix (U, V, R). This provided a new way to evaluate surface water quality around the iRee mining area. According to the calculation of the fuzzy correlation matrix, the pollution of surface water and the water quality can be determined by membership grade rule. According to the calculation of divisors set U and evaluation set V, the water quality from different time stages at sampling sites can be divided into five grades: grade I (excellent), grade II (good), grade III (medium), grade IV (bad), grade V (very bad). On this basis, the degree of deterioration of the water resources at the sampling site which had twice or more times a grade of class V was assigned 1 point. The areas that did not exceed the level of IV were assigned 3 points and other regions were assigned 2 points, as illustrated in Figure 2k. Using the vector data of the river system, the results of the evaluation of the upstream and downstream evaluation units of the water system were obtained from the linear interpolation by GIS spatial analysis.

3.4.4. Ecological restoration and management difficulty index D4. Currently, all of the iRee mining areas are using open-pit mining approaches. It is very difficult to perform ecological recovery in diggings exploitation, so the evaluation units inside the mining area rights were assigned 1 point; while the evaluation units outside the mining area rights were assigned 3 points, as illustrated in Figure 2g.

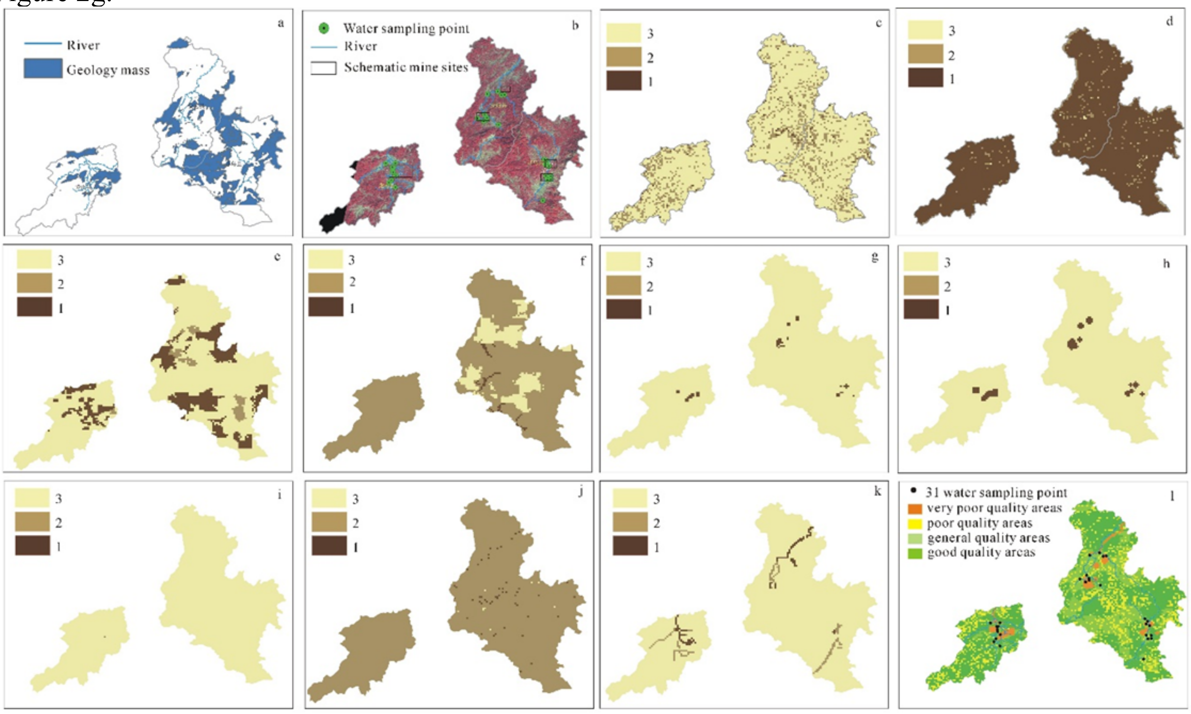

Figure 2. Sketch map of rock mass distribution in study area (a), Water sampling point distribution map (b), Results of topography and landform index A1 (c), Results of vegetation coverage index A3 (d), Results of tectonic index (B1) (e), Results of lithology combination index (B2) (f), Results of geological hazards hidden danger index C1, main mining type index (C2) and ecological restoration and management difficulty index D4 (g), Results of mining density index C3 and land proportion index (C4) (h), Results of geological hazards index D1 (i), Results of geological hazards hidden danger index D2 (j), Results of water resource damage degree index D3 (k), Discrimination of the iRee mining environmental quality (j).

4. Evaluation of the environmental quality of mines in the study area by the SVM model

A support vector machine model (SVM) [27-29] was used as the basic function to establish the iRee rare earth mining environmental evaluation model. The evaluation of the environmental quality of the iRee mining areas is an example of learning and training, which should take into account typicality and comprehensiveness. Based on the iRee 1: 200,000 regional geological map, terrain map, Google Earth map of mining development status, remote sensing interpretation data and the results of water quality analysis, we selected 110 units of very poor environmental area, poor environmental area, general environmental area and good environmental area as training samples, of which 31 samples were used for the verification of the evaluation results of the classification.

Using SVM classification tools in the ENVI software package to the pre-processed 13 iRee mining evaluation layers as the input vector, the SVM classification model parameter can be set (Gamma in Kernel Function (γ) is set to 0.071; Penalty Parameter is set to 100; Pyramid Levels is set to 0; Classification Probability Threshold is set to 0). It is important to carefully select enough training samples (110 samples which include mining areas and non-mining areas) for each category that should be recognized in the taxonomy. The spatial distribution of the environmental assessment results of the iRee mines will be obtained by using 79 units with a priori knowledge as the training samples to calculate the evaluation scores of each unit in the study area. The results include the spatial distribution of the very poor environmental quality areas, the poor quality areas, general quality areas and good quality areas, as illustrated in Figure 2l.

The classification accuracy of iRee mine environmental assessment method based on SVM was calculated by statistically evaluating results of 31 verification units with a priori knowledge (including very poor quality areas, the poor quality areas, general quality areas and good quality areas). Of the 31 cases, 10 samples are considered as very poor quality area, 8 samples were considered poor quality areas, 6 samples were general quality areas and 7 samples were good quality areas. The classification evaluation error is 19%. The iRee mining environmental quality problems are mainly concentrated in the mining area, surrounding areas of the mine and downstream river around mines were less affected. It can be seen that the tailings water, leachate and leaching water in the mining process are the main pollution sources that produce more serious environmental ecological problems. The good quality areas are mainly distributed in the regions far from the mining areas, have small slopes and higher vegetation coverage.

5. Conclusions

The environmental quality of the upper reaches of the study area is generally better than that of other regions. The areas with serious environmental quality problems are mainly distributed around the mining areas, especially in the areas affected by the wastewater discharge around the mining areas and near the tributaries. Based on the research results, it is suggested that the treatment of pollution sources can be divided into different regions and different types. The treatment can be combined with plant methods and physical chemistry methods. It is suggested to set and implement the environmental protection index threshold of in situ leaching green mining.

The results indicated that the monitoring and governance model realizes the environmental impact assessment aim by classifying the environmental quality of typical iRee mining areas into four levels. The model has a strong applied value by providing help for exploiting iRee mineral resources, protecting geological environment, restoring and reconstructing mine environments and helps geo-environmental management. The data of field and laboratory analyses were extracted and quantified by using an expert system and objectivity to determine the weight of the environmental effect of different types of mines (light and heavy rare earth mines) based on SVM. Using this monitoring model, the mine environment of iRee areas in the southern part of Jiangxi province was monitored and evaluated from 2012 to 2016. The results show that the model can classify the environmental quality of typical iRee in southern part of Jiangxi province into four levels with different sources of pollution, putting forward governance suggestions and providing a scientific basis for the coordinated development of rare earth resources and environmental protection.

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