Ecological Security Evaluation for Coal Mining Areas based on Fuzzy c-means Algorithm - An Empirical Study of China Coal Mine Company

Xiaoling Ke
School of Economics and Management, China University of Geosciences
China
kxlcug@163.com

Amal Mougharbel
Business Administration Department, International Technological University
United States
amougharbel@itu.edu

ABSTRACT: *Using P-S-R Model as a framework, this paper selects fifteen typical indicators for evaluating coal mine ecological security, including employee number, raw coal production, industrial waste water discharge and so on, constructs an ecological security evaluation model for coal mining areas based on fuzzy c-means algorithm, collects data of ecological security in a coal mining company in Zhengzhou from 2007 to 2013, processes the data in the evaluation model, and obtains results of ecological security in the recent seven years. In order to test the validity of the evaluative results obtained from the model, an important subsidiary's net assets per share data from 2007 to 2013 have been analyzed. Through test and analysis of the results of the model, a proposal to improve ecological security in the coal mining area has been put forward.*

Keywords: Ecological Security Evaluation, Fuzzy c-means Algorithm, Coal Mining Area, China

Received: 18 April 2017, Revised 21 May 2017, Accepted 28 May 2017

1. Introduction

Since the reform and opening up, China's rapid economic development leads to an increasing demand for resources. When petroleum and gas are relatively insufficient, coal is the main force in China's energy consumption and has a dominant position in the energy production and consumption structure. According to statistics, coal accounts for more than 70% in primary energy consumption in China. Continuous coal mining, when providing the impetus for economic development, also causes severe damages to ecological security of coal mining areas. It is estimated that around 11.6 billion cubic meters of methane are emitted from coal mining areas annually, which is nearly the capacity of China's Project "West Gas to the East"; 1.06 million hectares of forest and 263,000 hectares of grassland are destroyed annually. In addition, geological disasters caused by coal mining, such as collapses, landslides, mudslides and other natural disasters including floods and droughts in recent years continue, causing more than 50 billion Yuan economic loss every year [1]. All these negative consequences caused by coal mining have become a thorny issue, and it is a new problem how to better evaluate the ecological security of mining areas. Mine ecological security evaluation concerns residents around the mining area, environmental policies, and the realization of a "Beautiful China".

The concept of ecological security was put forward in 1989 by the International Institute of Applied Systems, and its meaning has been constantly debated by scholars from various countries. To sum up, there are two understandings of the concept. The broad concept of ecological security includes the security of nature, economy and the society, while the specific concept only refers to the security of nature and semi-natural ecological system[2].

The purpose of understanding ecological security is to better evaluate it, and index system is the basis of the evaluation. Some international organizations and institutions designed various ecological security evaluation index systems, such as the PSR Model (Pressure - State - Response) by the UNDP, the DSR model (Development - State - Response) by the United Nations Sustainable Development Commission. The European Environment Agency added Drive and Influence to the P-S-R model and came up with the D-P-S-I-R framework, and the EPA established a comprehensive evaluation index system of a river ecosystem, which includes chemical environment, physical environment, hydrological and biological conditions [3]. Chinese scholars have also done a lot of useful explorations in the area within the above frameworks. Zhang Nan proposed a DPSR (Driving forces - Pressure - State - Response) model based on the P-S-R model and the actual situations in Liaoning Province [4]; Huangbao Rong constructed an SOPAC index system which includes regional development, environmental pressure, ecological risk, etc.[5]

Evaluation methods of ecological security have developed significantly with the recent in-depth studies, and they fall into four categories: Ecological modeling, mathematical modeling, landscape modeling, and digital terrain modeling [6]. For example, Lzumi S. measured water PH value, air temperature, toxic elements in the soil, biomass and the size of biological populations to evaluate the security of the ecosystem [7]; Liuxi Tao and Zhu Xiang respectively applied fuzzy mathematics and AHP method and comprehensive index method for land reclamation and water environment in Changzhutan [8-9]. Digital terrain modeling is based on the 3S technology, and conducts dynamic monitoring, spatial analysis, and ecological risk assessment, such as Yang Cunjian's application of remote sensing technology to evaluate ecological security in lake areas [10].

FCM is a new clustering algorithm. By virtue of its own advantages, it has been researched and applied in various fields, especially in image processing, medical diagnosis, channel equalization, vector encoding and time-series design, and many achievements have been made, such as Zhang Xiaofeng's medical image segmentation research based on fuzzy clustering algorithm, Zhi Xiaobing's self-adaptive dimensionality reduction fuzzy clustering algorithm, Zhang Lijuan's categorization of comprehensive competitiveness of coal mine cities, Sun Chengliang's coal mining production process selection and prediction. Moreover, many scholars combine FCM with other methods to compensate for the weakness of FCM, or to make use of the strengths of these methods, which in turn promotes the development and refinement of FCM, such as Guo Haitao and Liu Liyuan's sonar image segmentation based on MAR and FCM clustering, Xu Peng's load forecasting method based on fuzzy clustering and RBF neural network, Zhang Wen's classification of mudslides based on principal component analysis and FCM, Wang Xinxin's analysis on supplier's trust factors based on FCM emulation and her proposal of a supplier trust evaluation model based on FCM [11-18].

The above research applied FCM algorithm in many areas of social life, which confirms that FCM algorithm is accurate in classification and evaluation and has a high potential in more areas. Currently, there are four main methods in the evaluation of ecological security, and FCM is not among them. Therefore, it is innovative to apply this method in the evaluation of ecological security. In addition, some scholars integrate new theories and methods from social sciences and made achievements, such as Qi Shuofeng's study of coal mine ecological security based on BP neural network, which also inspired this article[19].

2. Variable Design

Due to the particularity and complexity of coal mine ecological security system, its evaluation index system is also different from other types of ecological security evaluation index system. In order to avoid subjectivity and arbitrariness, this paper selects the P-S-R model (pressure - state - response) proposed by UNDP as a framework, and constructs an ecological security evaluation index system of coal mining areas. The index system is divided into three categories: ecological security pressures, ecological security status and ecological security response. Ecological security pressures is the pressure and threat produced in the coal mining process, which includes population pressures, pressures on natural resources and pollution pressure. Status refers to the specific situation of ecological security in a coal mining area within a period of time, including resource quality and environmental quality in the coal mining area. Response refers to the measures taken in response to the threats in the coal mining area, including the technological capacity and ecological investment.

The ecological security evaluation system and the classification of its various indices are shown in the following table:

Target	Categories	Indices
Ecolgocial security evaluation system	Ecological security pressure	Number of employees, raw coal production, water consumption
	Ecological security status	Industrial wastewater discharge, domestic wastewater discharge, solid waste area, sulfur dioxide emissions, energy consumption per ten thousand Yuan output value, rate of recovery
	Ecological security response	revenues, taxes, environmental protection investment, investment in waste management, industrial wastewater treatment rate, domestic wastewater treatment rate

Table 1. Table of ecological security evaluation system

Among them, the rate of recovery is the rate of total recovered minerals after the first mining. The smaller the rate, the severer the pollution to the environment is. Energy consumption per ten thousand Yuan output value is the energy consumed to produce ten thousand Yuan industrial output (ton of standard coal equivalent). The smaller the number, the better.

After field research and questionnaires, the research team collected data of fifteen evaluative indices in recent seven years from a coal enterprise in Zhengzhou. Due to the different units of each index, it is necessary to eliminate the dimensional relationships between them. First, the data are normalized. Sample data are scaled so that they fall within a specific range to make comparison possible. By using Stata to standardize the data, they are shown as follows:

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15
2013	-2.06	0.65	-0.23	0.99	0.56	0.57	-0.78	1.27	1.07	0.20	1.29	0.19	0.70	0.60	1.32
2012	-0.39	0.65	0.91	1.04	0.33	0.57	-0.77	0.96	0.50	0.90	0.98	1.01	0.49	0.60	0.90
2011	0.43	0.65	1.14	1.08	1.52	0.57	-0.45	0.01	0.57	1.17	0.70	1.03	1.48	0.60	0.61
2010	0.82	0.94	0.26	-0.33	0.50	0.81	-0.18	-0.30	0.98	0.66	-0.04	0.75	0.06	0.60	-0.56
2009	0.82	-0.16	0.54	-0.75	-0.83	0.38	-0.13	0.54	-1.26	-0.59	-0.83	-0.53	-0.31	0.48	-0.04
2008	0.18	-1.11	-1.27	-1.13	-0.76	-1.66	0.19	-1.34	-0.83	-0.79	-1.04	-1.12	-1.26	-1.22	-0.77
2007	0.20	-1.61	-1.35	-0.90	-1.33	-1.23	2.12	-1.14	-1.03	-1.54	-1.06	-1.33	-1.17	-1.68	-1.47

Table 2. Standardized data sheet

Note: Indices F1 to F15 are respectively: the number of employees, raw coal production, industrial wastewater discharge, domestic wastewater, production water consumption, solid waste area, sulfur dioxide emissions, the rate of recovery, energy consumption per ten thousand Yuan output value, revenue, environmental protection investment, tax, investment in waste management, industrial wastewater treatment rate, rate of sewage treatment.

3. Model Constructions

After the standardization of the original data, an FCM model is used to evaluate the ecological security of a coal enterprise in Zhengzhou, and the evaluation results are divided into three categories: best, good and bad.

3.1 Principles of the Model

Fuzzy c-means algorithm (FCM) is a clustering algorithm proposed by Bezdek in 1973. Its purpose is to achieve the highest similarity between samples clustered in the same category and the lowest similarity between samples in different categories. It is an improvement of the earlier Hard C-means Clustering (HCM), and the difference is that the concept of membership is added[20].

Membership describes the extent an object belongs to a group. Its value range is between [0, 1]. However, as set down by the rules of data standardization, the sum of memberships within a sample is 1, i.e.,

$$\sum_{i=1}^{c} u_{ij} = 1, \forall j = 1,\ldots,n \tag{1}$$

FCM divides n vectors x_i ($i = 1, 2,\ldots, n$) into c fuzzy sets, and works out the cluster center in each group, so that the non-similarity index is minimal. The objective function is:

$$J(U, c_1,\ldots,c_c) = \sum_{i=1}^{c} J_i = \sum_{i=1}^{c}\sum_{j}^{n} u_{ij}^m d_{ij}^2 \tag{2}$$

Here u_{ij} is between [0,1], c_i is the cluster center of the cluster set I, and $d_{ij} = \|c_i - x_j\|$ is the Euclidean distance from the i-th cluster center to the j-th data point, and $m \in [1, \infty)$ is a weighted index.

After all input parameters were differentiated, the necessary condition to make the objective function reach its minimum is: the calculation of cluster center C and segmentation matrix U:

$$c_i = \frac{\sum_{j=1}^{n} u_{ij}^m x_j}{\sum_{j=1}^{n} u_{ij}^m} \tag{3}$$

$$u_{ij} = \frac{1}{\sum_{k=1}^{c}\left(\frac{d_{ij}}{d_{kj}}\right)^{2/(m-1)}} \tag{4}$$

In summary, the FCM arithmetic process is shown below:

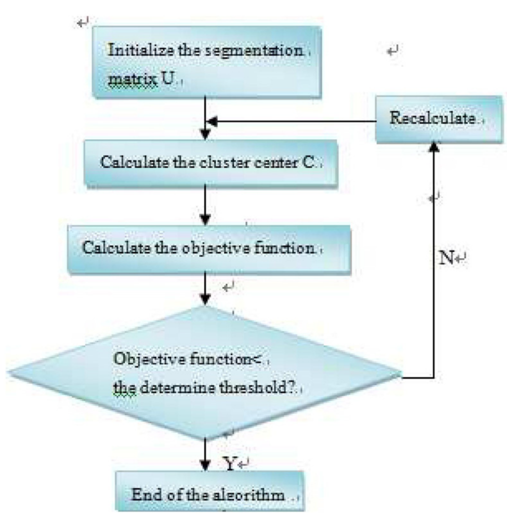

Figure 1. The FCM arithmetic process

3.2 FCM Arithmetic Operations

The weighted index m controls the fuzziness of clustering. The closer m is to 1, the more likely the clustering tends to mutate. A larger value of m will lead to a fuzzier clustering result and therefore makes it easier to reflect the gradual spatial change. But too large the value of *m* will cause too much overlapping between categories and an unclear clustering structure. Therefore, it should be balanced between fuzziness and clarity of the clustering structure. Valid values of m are generally between l-30, but some studies suggest the value of the best weighted index lies between the 1.5-2.5 [21]. After comparing different clustering results of the different values of m, it is found that 2 is an appropriate value, so in this study the weighted factor of *m* is 2.

The algorithm is input into Matlab for computing. After 110 times of iterative operation, the value of the objective function drops from 34.0262 to 14.0076 and arrived its least value. The operation is then terminated, and the objective function curve is shown below:

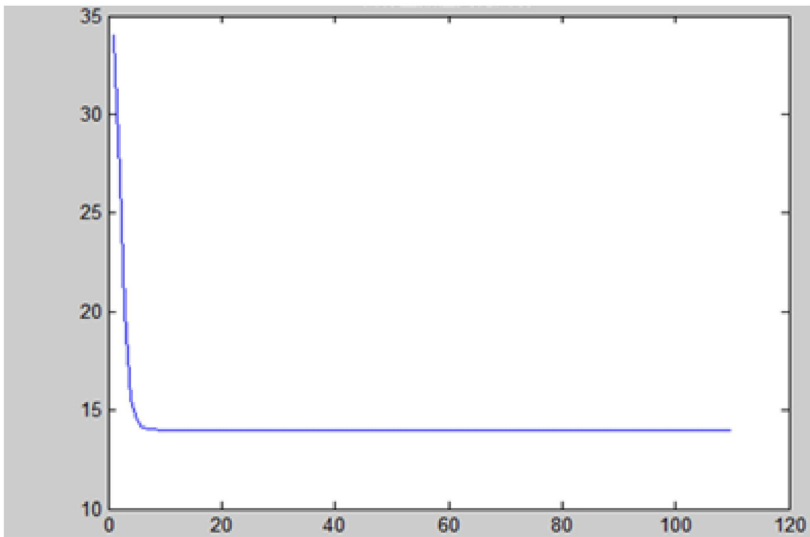

Figure 2. The curve of the objective function value change

By (3) and (4) the computing of FCM cluster center and the segmentation matrix U are known, and the results are shown below:

C = Columns 1 through 10

-0.6978	0.6325	0.5947	0.9918	0.6438	0.5616	-0.6843	0.8276	0.6616	0.7098
0.7267	0.5907	0.3885	-0.3247	0.1873	0.6539	-0.1960	-0.0033	0.3042	0.3189
0.2014	-1.3297	-1.2612	-0.9996	- 1.0344	-1.3841	1.1349	-1.1866	-0.9343	-1.1520

Columns 11 through 15

0.9721	0.7277	0.7615	0.6099	0.9404
-0.1882	0.3834	0.0617	0.5622	-0.2839
-1.0362	-1.2050	1.1848	-1.3977	-1.0925

U =

0.7848	0.9303	0.6633	0.1026	0.1953	0.0284	0.0237
0.1637	0.0602	0.2902	0.8693	0.5917	0.0518	0.0394
0.0514	0.0095	0.0465	0.0281	0.2130	0.9199	0.9369

Meanwhile, the distance Dist from various sample points to the cluster center is:

Dist = 1.9273 0.7370 2.0178 3.1217 4.5687 6.8142 7.9411

4.2195	2.8984	3.0506	1.0724	2.6235	5.0458	6.1540
7.5293	7.2871	7.6171	5.9603	4.3740	1.1969	1.2626

The segmentation matrix U describes the membership of each sample in different classes. A greater degree of membership indicates a higher similarity of the sample to the class, i.e., this sample falls into this class. The cluster center represents the average feature of each class, which can also be considered to represent this class. Cluster centers serve as the criteria to judge the quality of classification. The greater the value of the cluster center C, the better the indices are, i.e., a better ecological security. The distance from a sample point to a cluster center determines to which class the sample belongs. The smaller the distance is, the closer the sample is to that class, and vice versa.

The above calculation results show: samples 2013, 2012 and 2011 are in the same class, i.e., the best ecological security; samples 2010 and 2009 are in the middle class, indicating a good ecological security; samples 2008 and 2007 are in the worst class, indicating the worst ecological security.

In order to verify the validity of the above evaluation results, a major subsidiary of the coal company's net assets per share data between 2007-2013 were analyzed. A net asset per share is the ratio of the net assets to the number of shares, and the company's net assets are the general assets minus total liabilities. A net asset per share is a very important financial indicator for enterprises, and it reflects every share's net asset value. A high net asset value per share indicates a strong ability to earn profits, to resist risks, and a more likelihood and higher financial ability to respond to ecological security. Studying the change in net assets per share over the years can help infer changes in the operating conditions of the enterprise. The data were from the annual financial statements of listed companies and are shown below:

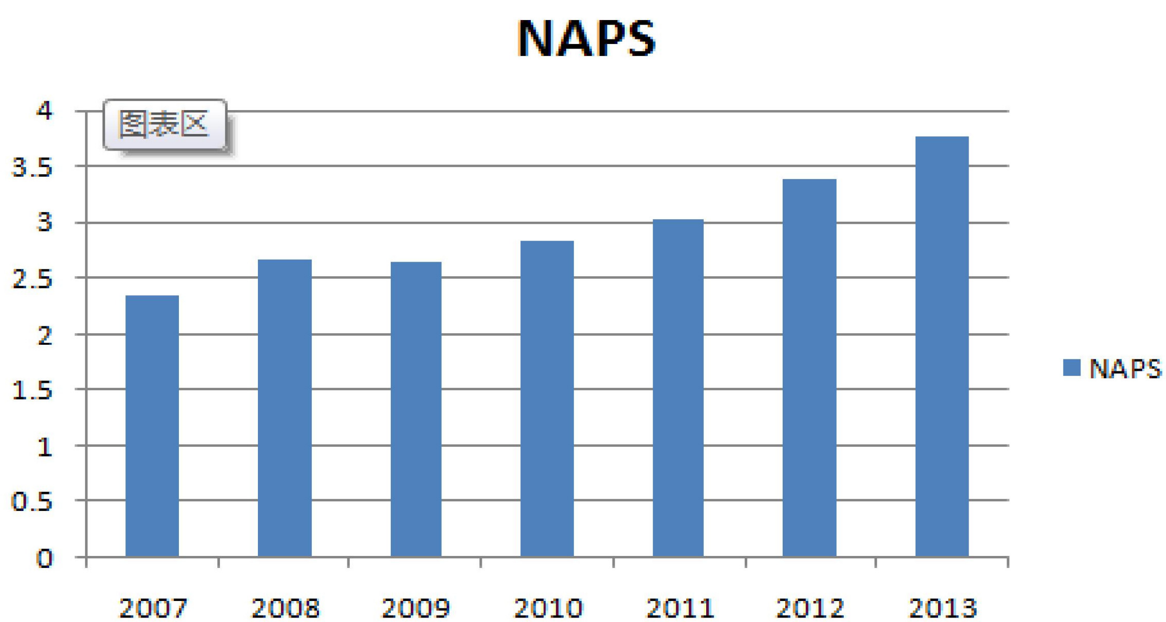

Figure 3. The subsidiary's net assets per share

The figure shows that, from 2007 to 2013, the net asset per share was rising. The net asset value per share in 2013 increased by 59.89% compared with that in 2007, with an average annual growth rate of nearly 8.5 percent. The company's overall competitiveness and the capacity for sustainable development were enhanced. The trend in net assets per share is consistent with the results, therefore verifying the evaluation results of the model.

4. Conclusions and Countermeasures

4.1 Results and Analysis

This paper applies P-S-R model as a framework and selects 15 representative indices for ecological security evaluation in coal mining areas. By using FCM an ecological security evaluation model in coal mining areas is constructed. Data from a coal enterprise in Zhengzhou in the recent seven years were input into the model and evaluation results were obtained: ecological security is best from 2011 to 2013, good from 2009 to 2010, and worst from 2007 to 2008. The validity of the results are tested by the net assets per share of an important subsidiary of the coal enterprise.

It is found that the ecological security pressure is higher in 2011, 2012 and 2013 than in the previous four years. The increase of the value of these indices indicates a better comprehensive competitiveness of the enterprise and at the same time a better ability to resist risks, and it also lays a good economic foundation for ecological security response. In terms of ecological security response, index values in 2011, 2012 and 2013, including waste management investment, industrial wastewater treatment rate, domestic water treatment rate, rate of recovery, environmental protection investment, revenues, taxes, are also higher than those between 2007 and 2010. The treatment of waste and pollutants greatly improved the ecological environment in the mining area, which leads to a better ecological security evaluation result.

However, some problems of ecological security are also found. In terms of ecological security status, industrial wastewater, domestic wastewater discharge, energy consumption per ten thousand Yuan output value, and solid waste area, are still not very satisfactory, and pollutant emissions are still rising. This is partly due to the fact that coal production and population are increasing, and that the company's efforts on pollutant emissions control are still not inadequate. It can be seen that the improvement of its ecological security is due to the decrease of pressure and more investment.

Accordingly, the enterprise was worst in terms of comprehensive strength and ecological security investment in 2007 and 2008, which affected the overall evaluation of its ecological security, while various indicators were in the middle in 2009 and 2010.

In order to show the above results more clearly, a representative index was selected from the three categories to reflect trends in recent years, as shown below:

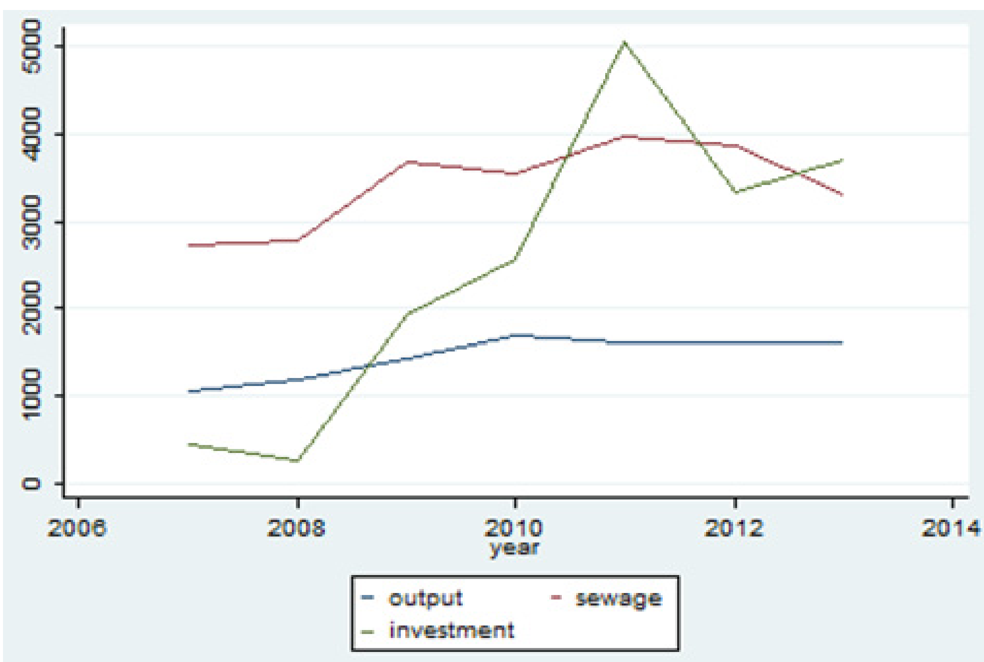

Figure 4. Change of index values

The horizontal axis is the year, the vertical axis is the indicators, the blue line represents coal production, the red line represents the discharge of industrial wastewater, and the green line represents waste management investment. The index change chart shows a gradual increase in coal production and industrial wastewater discharge, and the steep curve of waste management investment shows that the management places more emphasis on ecological security and has made improvements.

4.2 Strategies and Suggestions

In light of the above analysis, in order to improve the ecological situation in the coal mining area, the following measures are proposed:

(1) Recycle waste materials and reclaim wasteland. Solid waste in coal mining areas occupies a relatively large area. As of 2013, the coal company's solid waste area covered 336 acres. Solid waste not only occupies a lot of land area, but also makes it impossible to recycle some recyclable resources. It has been proved that solid waste, such as waste rock, flyash, is an important recyclable resource. Recycling wastes and land reclamation can not only promote environmental quality, but also build a recycling economy, reduce costs, and enhance the economic efficiency of enterprises.

(2) Develop clean coal technology. According to statistics, 90 percent of sulfur dioxide emission and 80 percent of soot are directly caused in the burning of coal [22]. Clean coal technologies include devices that increase the operational efficiency of a power plant and technologies that transform coal into clean fuel. The promotion of clean coal technologies can reduce emissions of sulfur dioxide, soot and other harmful pollutants, thereby changing the phenomenon of clustering chimneys and directly improving the ecological environment of mining areas.

(3) Optimize the industrial structure. Coal mining economy is mainly composed of the sale of raw coal, and has a low added value. It is important to develop the service sector so that the economic structure of mines are healthier and more resistant to economic downturns and the risk of falling coal prices. In addition, we should improve secondary conversion value of coal through a variety of measures, such as turning coal into electricity, the development of coal gasification technology.

(4) Ecological security publicity campaigns. We should raise workers' and residents' awareness of the importance of ecological security. The survey found that people's awareness of ecological protection was generally weak. The improvement of ecological security starts from the grassroots.

Acknowledgements

This work is supported by Research Foundation of Humanities and Social Sciences of Ministry of Education of China No. 13YJC630065, by the Fundamental Research Founds for National University, China University of Geosciences (Wuhan) No. CUGW110201, by the open foundation of Research Center of Resources and Environmental Economy in CUG No. 2011B011and by the open foundation for Research Center for Digital Business Management.

References

[1] Yan, Wang. (2009). Impact of coal mining on ecological environment and countermeasures [J] *Coal Science and Technology*, 37 (12): 125-128

[2] Duning, Xiao., Wenbo, Chen., Liang, Guofu. (2002). Basic concepts and research of ecological security [J] *Journal of Applied Ecology*, 13 (3): 354-358

[3] Wei, Zuo., Huizhen, Zhou., Qiao, Wang. (2003). Research of the framework of regional ecological security evaluation index system [J] Soil, 1: 2-7

[4] Nan, Zhang. (2009). Ecological evaluation model based on the concept of scientific development in Liaoning Province [D]. Dalian University of Technology master's degree thesis

[5] Baorong, Huang., Zhiyun, Ouyang., Zhang, Huizhi. (2009). Ecological vulnerability assessment in Hainan [J] *Journal of Applied Ecology*, 20 (3): 639-646

[6] Hong, Liu., Hui, Wang., Wei, Zhang. (2006). Review of ecological security evaluation[J] *Journal of Ecology*, 25 (1): 74-78

[7] Lzumi, S. (2004). Environmental security issues for semiconductors (research on scarce materials recycling) [J] .*Thin Solid Films*, 461 (1): 7-12

[8] Tao, Liuxi., Yan, Martin., Zhenqi, Hu. (2007). Ecological security evaluation in reclaimed mine land [J]. *Agricultural Engineering*, 23 (8): 102-106

[9] Zhu, Xiang., Huizhen, Zhou., Qiao, Wang. (2011). Win after ecological security evaluation Changzhutan [J] *Journal of Hunan*

University (Natural Science), 38 (1): 72-77

[10] Cunjian, Yang., Jingan, Chen. (2009). Using remote sensing and GIS to evaluate ecological security in Sichuan Province [J] *Journal of University of Electronic Science and Technology*, 38 (5): 700-706

[11] Xiaofeng, Zhang. (2014). Medical image segmentation based on fuzzy clustering algorithm [D]. *Shandong University Doctoral Dissertation*.

[12] Xiaobin, Zhi. (2013). Self-adaptive dimensionality reduction fuzzy clustering algorithm [D]. *Xi'an University of Electronic Science and Technology Ph.D. Dissertation*.

[13] Lijuan, Zhang., Guo, Chenxiao., Yaping, Zhang. (2013). Research of classification of coal cities based on variable weighted FCM clustering [J] *Journal of Harbin Normal University* (Natural Science), 29 (2): 20-23.

[14] Sun Chen Liang, Jiang, Houxu., Yuanhong, Shun. (2012). Selection in mining process based on fuzzy C clustering and matlab implementations [J] *World Technology Research and Development*, 34 (1): 58-61.

[15] Haitao, Guo., Liyuan, Liu., Yaxin, Zhao. (2013). Sonar image segmentation based on MAR and FCM clustering [J]. *Journal of Scientific Instrument*, 34 (10): 2322-2327.

[16] Peng, Xu. (2012). Load forecasting method based on fuzzy clustering and RBF neural network [D]. *Guangxi University* Master's Degree Thesis.

[17] Zhang, Jianping, Chen., Qinsheng, Wu. (2010). Application of the FCM method in mudslides classification based on principal component analysis [J] *Journal of Jilin University*, 40 (2): 368-372.

[18] Xinxin, Wang. (2011). Suppliers trust evaluation model based on FCM [J] *Intelligence Magazine*, 30 (6): 285-287.

[19] Shuofeng, Qi. (2013). Ecological security evaluation of coal mines based on BP neural network and its application [D]. *Taiyuan University of Technology* Master's Degree Thesis.

[20] Hongji, Li. (2005). Fundamentals of fuzzy mathematics and practical algorithm [M] Beijing: Science Press.

[21] Lin, Yang., Xing, Zhu., Baolin, Li. (2007). Obtain desired soil in soil mapping based on fuzzy C-means clustering [J]. Soil, 44 (5): 784-791.

[22] Chaoyang, Wei., Licheng, Zhang., Shujin, He. (1997). Ecological environment in China's coal mining areas and comprehensive countermeasures [J] *Geographical Science*, 52 (4): 300-307.

Author Biographies: Xiaoling Ke (1980-), Ph.D., is an associate professor at the School of Economics and Management , China University of Geosciences in China. Now she is a visiting scholar in USA. Her research interests are decisions under uncertainty and corporate sustainable development. In recent years, she began to pay attention to the sustainable development of resource-based enterprises. Some of her researches have been supported by government funding, such as Social Science and Humanities Funds of China Ministry of Education.