Ecosystem Health Evaluation of Yima Coal-Mining Area based on Fuzzy Synthetic Evaluation Method

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Abstract: Evaluation of ecosystem health can help people realize the situation and developing trend of the ecological system of the area. An evaluation index system of ecosystem health of coal-mining area based on Pressure-Status-Response model was constructed. Then evaluation model based on fuzzy synthetic evaluation method was established. Finally ecosystem health condition of Yima Coal-Mining Area situated at Henan Province during 2005 and 2013 was evaluated. Results show that ecosystem of Yima Coal-Mining Area belongs to critically healthy grade in 2005, 2006, 2008 and 2009 and belongs to relatively unhealthy grade during other years. There is a tendency of gradual deterioration in ecosystem of Yima Coal-Mining Area with the exception of 2008 and 2009. The study can provide scientific guidance for the formulation of resource and environment management decisions and sustainable development strategies of the mining area.

1 INTRODUCTION

Coal-mining area is a typical community which is based on the development and utilization of coal resource to promote economic and social development of the region. Compared with general natural ecosystem, ecosystem of coal-mining area has its particularity. Firstly, almost all of the activities of coal-mining area are focused on the flow of coal resource. Therefore, ecosystem of coal-mining area has changed the attribute of natural ecosystem. Secondly, coal-mining area need not only import material flow and energy flow from the outside world but discharge wastes to the outside world. Therefore, ecosystem of coal-mining area is open, dependent, and non-autonomic. Thirdly, ecosystem of coal-mining area is affected by human activities and coal-exploiting and coal-utilizing. Therefore, ecosystem of coal-mining area is integrated, dynamic and non-linear. Ecosystem of coal-mining area has the characteristics of inevitability, irreversibility, heterogeneity, burstiness, hysteresis and complexity. Compared with general natural ecosystem, ecosystem of coal-mining area is more easily to be disturbed by changes in anthropogenic and environmental conditions. Therefore, ecosystem of coal-mining area is more fragile and complicated.

For a long time, coal-mining method in China is extensive and predatory. In the course of coal producing and processing, emissions including waste gas, waste water and waste residue pollute atmosphere, water, landscape and land resource around mines seriously. Therefore, ecological environment problem of coal-mining area is particularly prominent. Mainly ecological problems of coal-mining area are as follows. Firstly, air pollution of coal-mining area is serious. Sources of air pollution of coal-mining area mainly include gas and coal dust produced in the course of coal mining and transporting and harmful gases discharged by coal gangue and industrial production and residents around coal-miming areas. Secondly, water resource of coal-mining area is scarce and polluted seriously. Water resource in China is scarce and per capita water resource accounts for only one-fourth the world average. Water and distribution in China is unbalanced. Water quantity of North China and West China is less, while water quantity of South China and East China is much. On the contrary, coal quantity of North China and West China is much, while water quantity of South China and East China is less. We find that coal-rich regions are often water-deficient areas. According to statistics, 71 percent of coal-mining areas are suffering from water shortage, 40 percent of coal-mining areas are

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suffering from acute water shortage, and more than 80 percent of coal workers can not drink clean water. Water pollution around coal mining areas is mainly caused by coal mining and harmful substances discharged by coal gangue. Thirdly, land resource is damaged seriously. The reason lies in that coal-mining method under the shaft causes ground collapse, coal-mining method in the open damages lands, and solid wastes occupy lands. These ecological problems have endangered the sustainable development of coal-mining areas seriously.

D. Rapport (1989) and D. J. Schadffer (1988) proposed the concept of ecosystem health for the first time in the late 1980s. Many scholars have studied the concept of ecosystem health. D. Rapport defined ecosystem health as the stability and sustainability of an ecosystem, namely potential to recover after perturbation. Costanza (1992) thought that an ecosystem was healthy or had integrity if it was stable and sustainable. This to say, if the ecosystem was active and could maintain its organization and autonomy over a period of time and was resilient to stress while providing for human needs, the ecosystem was healthy. Some scholars extended the definition of ecosystem health and advanced that a health ecosystem should has the abilities to meet reasonable demands of human beings and to maintain and refresh ecosystem structure. The International Society for Ecosystem Health defined ecosystem health as a science to study the precautionary, diagnostic and prognostic characters of ecosystem management and the relation between ecosystem health and human health. Presently viewpoint of Constanza has been widely accepted by the scientific community. The concept of ecosystem health proposed by Constanza includes inner stability, free of disease, diversity or complexity, vigor, resilience and the balance among the elements.

A series of methods to assess ecosystem health have appeared, such as principle component analysis method, analytic hierarchy process method, foot print method, fuzzy comprehensive evaluation method, neural network method, landscape ecological structure method, etc. These assessment methods have different characters and apply to different situations. Therefore, the adoption of evaluation method depends on actual situations. As a mathematical method to deal with the fuzzy phenomena, fuzzy synthetic evaluation method describes the objects in quantity according to their attributes of “both A and B”. Ecosystem of coal-mining area is also fuzzy, because the borderline between health or sickness of the ecosystem is ambiguous. A more reasonable answer is that the ecosystem has some healthy elements as well as unhealthy ones, which means that the evaluation of the ecosystem health is a fuzzy aggregation. Consequently, evaluation model of ecosystem health based on fuzzy mathematics is more coincident with actual conditions. In addition, most of the studies aim at city, forest and watershed. Systematic studies on ecosystem health evaluation of coal-mining area are less. We set up an evaluation index system of ecosystem health of coal-mining area based on Pressure-Status-Response model, establish an evaluation model based on fuzzy synthetic evaluation method, and take Yima Coal-Mining Area as an example to carry out the analysis. The aim is to provide scientific guidance for the formulation of resource and environment management decisions and regional sustainable development strategies of the area.

2 RESEARCH METHOD

2.1 Construction of Evaluation Index System

Evaluation index system of ecosystem health of coal-mining area in this paper is based on PSR model proposed by David J. Rapport in 1979. The model is composed of pressure, status and response. Pressure represents the effect on environment around coal-mining areas caused by economic and social activities. Status represents environmental conditions and changes within a certain period of time. Response represents countermeasures taken by individuals and management departments to alleviate negative effect on environment and even better ecological environment of coal-mining areas as far as possible. Considering the realities of Yima Coal-Mining Area, following the principles of scientificity, measurability, availability, comprehensiveness and comparability and referring to concerned research findings, we set up an evaluation index system of ecosystem health of coal-mining area. The evaluation index system is composed of four layers. The first layer is goal layer, namely ecosystem health exponent of coal-mining area. The second layer is system layer, the third layer is element layer, and the fourth layer is index layer containing 37 indexes. Evaluation index system of coal-mining area is shown in Table 1.

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Table 1: Evaluation index system of ecosystem health of coal-mining area.

Goal layer	System layer	Element layer	Index layer
Ecosystem health exponent of coal-mining area	Pressure	Resource pressure	Per capita cultivated area (I_1), average soil erosion exponent (I_2), per capita water amount (I_3), consumption rate of coal reserves (I_4)
		Environment pressure	Emission intensity of industrial fumes per 10000 RMB of GDP (I_5), COD emission intensity per 10000 RMB of GDP (I_6), emission intensity of solid wastes per 10000RMB of GDP GDP (I_7), proportion of goaf area to coal-mining area (I_8)
		Social pressure	Natural growth rate of population (I_9), registered unemployment rate (I_{10}), Engel coefficient of residents (I_{11})
	Status	Economic status	Per capita GDP (I_{12}), proportion of tertiary occupation in GDP (I_{13})
		Energy status	Consumption proportion of raw coal (I_{14}), energy consumption per 10000 RMB of GDP (I_{15}), water consumption10000 RMB of GDP (I_{16})
		Resource status	Biological abundance exponent (I_{17}), forest coverage rate (I_{18}), greenery coverage rate (I_{19}), per capita public green area (I_{20}), soil organic matter content (I_{21}), proportion of soil erosion area to coal-mining area (I_{22})
		Environment status	Air pollution exponent (I_{23}), compliance rate of drinking water (I_{24}), regional environment mush (I_{25}), annual average of inhalable particles concentration (I_{26}), acid rain rate (I_{27}), natural disaster exponent (I_{28})
	Response	Economic response	Proportion of environmental investment in GDP (I_{29}), proportion of educational investment in GDP (I_{30})
		Environment response	Compliance rate of industrial waste water emission (I_{31}), recycle rate of industrial water (I_{32}), comprehensive utilization ratio of industrial solid wastes (I_{33}), comprehensive utilization of coal gangue (I_{34}), reclamation rate of subsidence land (I_{35})
		Social response	Average life expectancy (I_{36}), persons of higher academic degree per 10000 people (I_{37})

We divide ecosystem health level of coal-mining area into five grades, namely unhealthy grade, relatively unhealthy grade, critically healthy grade, relatively healthy grade and healthy grade. Then we determine critical values of evaluation indexes corresponding to the five grades, which is a key point in ecosystem health evaluation. We consult the suggested value of ecological city and environment protection model city commonly recognized as critical value of healthy grade and the international or national minimum value as critical value of unhealthy grade. By consulting concerned environmental protection experts, we determine critical values of other grades. Critical values of evaluation indexes corresponding to the five grades are shown in Table 2.

2.2 Setup of Evaluation Set

Based on evaluation evaluation indexes and objects, we set up the index set $X=(x_1, x_2, \ldots, x_n)$ and assessment set $V=(v_1, v_2, \ldots, v_5)$, where $v_1, v_2, \ldots, v_5$ represent unhealthy grade, relatively unhealthy grade, critically healthy grade, relatively healthy grade and healthy grade respectively.

2.3 Setup of Relatively Membership Degree Matrix

Relatively membership degree is used to compare the advantages and disadvantages of different things and its formula is different for a positive index (the bigger the index value, the more healthy the ecosystem) and a negative index (the bigger the index value, the more unhealthy the ecosystem) .

Firstly, calculation formula of relatively membership degree of a positive index is as follows ($s_{i,j}$ denotes critical value of the ith index corresponding the yth health grade, i=1,2,...,n; j=1,2,...,5).

If actual value of x_i is less than unhealthy grade, membership degree corresponding to unhealthy grade is 1 and membership degrees corresponding to other grades are 0. This means that if $x_i<s_{i,j}$,

$$r_{i1} = 1, r_{i2} = r_{i3} = r_{i4} = r_{i5} = 0 \tag{1}$$

If $s_{i,j} \le x_i \le s_{i,j+1}$,

$$r_{i,j+1} = (x_i - s_{i,j})/(s_{i,j+1} - s_{i,j}), r_{i,j} = 1 - r_{i,j+1} \tag{2}$$

If actual value of x_i is greater than healthy grade, membership degree corresponding to healthy grade is 1 and membership degrees corresponding to other grades are 0. This means that if $x_i>s_{i,j}$,

$$r_{i5} = 1, r_{i1} = r_{i2} = r_{i3} = r_{i4} = 0 \tag{3}$$

Secondly, calculation formula of a negative index is similar to the above.

If $x_i>s_{i,j}$,

$$r_{i1} = 1, r_{i2} = r_{i3} = r_{i4} = r_{i5} = 0 \tag{4}$$

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Table 2: Classification standard of indexes.

Index layer	Unit	Unhealthy grade	Relatively unhealthy grade	Critically healthy grade	Relatively healthy grade	Healthy grade
I_1	hm^2	0.02	0.03	0.05	0.08	0.1
I_2	$t/km^2·a$	5000	4000	3000	2000	1000
I_3	m^3	1000	3000	5000	7000	9000
I_4	%	70	60	45	30	25
I_5	kg	2	1.5	0.75	0.3	0.1
I_6	kg	6	5	3	2.25	1.5
I_7	kg	300	250	150	75	50
I_8	%	50	40	30	20	10
I_9	‰	11.2	9.6	8	5	4
I_{10}	%	4.2	3.6	3	2.5	1.2
I_{11}	%	50	40	35	30	25
I_{12}	10^4RMB	0.7	3	5	10	20
I_{13}	%	30	40	50	60	80
I_{14}	%	55	47.5	35	25	20
I_{15}	tce	1.5	1.25	0.75	0.3	0.1
I_{16}	m^3	300	225	175	75	50
I_{17}	—	25	35	55	75	80
I_{18}	%	30	35	40	45	50
I_{19}	%	20	25	30	40	50
I_{20}	m^2	7	10	12	16	18
I_{21}	%	0.7	1.5	3	4	5
I_{22}	%	15	12.5	8	4	2
I_{23}	—	3	2.5	1.6	0.9	0.6
I_{24}	%	80	85	92.5	97.5	100
I_{25}	db(A)	60	57.5	52.5	47.5	45
I_{26}	mg/m^3	0.15	0.12	0.10	0.06	0.04
I_{27}	%	30	25	10	5	0
I_{28}	—	0.8	0.6	0.4	0.2	0.1
I_{29}	%	1	1.5	2	3	5
I_{30}	%	1	1.5	2	3	5
I_{31}	%	80	85	92.5	97.5	100
I_{32}	%	20	30	50	70	80
I_{33}	%	30	50	70	90	100
I_{34}	%	40	60	70	80	90
I_{35}	%	10	20	35	50	70
I_{36}	Year	65	68	73	76	78
I_{37}	Person	300	450	650	1000	1200

If $s_{i,j+1} \le x_i \le s_{i,j}$,

$$r_{i,j+1} = (s_{i,j} - x_i)/(s_{i,j} - s_{i,j+1}), r_{i,j} = 1 - r_{i,j+1} \quad (5)$$

If $x_i < s_{i,j}$,

$$r_{i5} = 1, r_{i1} = r_{i2} = r_{i3} = r_{i4} = 0 \quad (6)$$

Then we obtain a relatively membership degree matrix:

$$R_h = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \quad (7)$$

Where r_{ij} is the relatively membership degree of x_i in X responding to the yth grade in V, $r_{i1} + r_{i2} + \cdots + r_{im} = 1$ (i=1,2,...,n; j=1,2,...,5).

2.4 Calculation of Indexes Weights

Methods to give indexes weights involve subjective and objective methods. The methods of the two category have their advantages and disadvantages. Objective methods don't consider the subjective intention of decision makers, while subjective methods are influenced by the subjective intention of decision makers to a large extent. Combining the two methods can make up their respective disadvantages. We use entropy method and AHP method to give indexes weights.

Steps of entropy method are as follows:

The first step is to establish original data matrix $X=(x_{ij})_{n\times m}$(n is number of evaluation objects and m is number of evaluation indexes). To alleviate the non-metrizability of indexes caused by different dimensions and units, the indexes must be non-dimensional-normalized. The formula of non-

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dimension-normalization is:

$$x_{ij}^{'} = \left(x_{ij} - \bar{x}_j\right) / \sigma_j \tag{8}$$

Where $x_{ij}^{'}$ is value of x_{ij} after non-dimension-normalization, $\bar{x}_j$ is mean value of the jth indexes, σ_j is standard deviation of the jth indexes.

The second step is to shift the axis in parallel to alleviate the negative values. The equation is:

$$x_{ij}^{''} = H + x_{ij}^{'} \tag{9}$$

Where $x_{ij}^{''}$ is the value of $x_{ij}^{'}$ after shift, H is the range of shift of axis.

The third step is to calculate the proportion of $x_{ij}^{''}$ according to the following formula:

$$R_{ij} = x_{ij}^{''} \Big/ \sum_{i=1}^{m} x_{ij}^{''} \tag{10}$$

The fourth step is to calculate entropy value of the jth indexes:

$$e_j = -\sum_{i=1}^{s} R_{ij} \ln R_{ij} \Big/ \ln s \tag{11}$$

The fifth step is to calculate otherness coefficient of the jth indexes:

$$g_j = 1 - e_j \tag{12}$$

The sixth step is to calculate the weighting of x_j:

$$w_j = g_j \Big/ \sum_{j=1}^{n} g_j = \left(1 - e_j\right) \Big/ \sum_{j=1}^{n} \left(1 - e_j\right) \tag{13}$$

According to the above steps, we obtain the set of indexes weights: $W_i^1(W_1, W_2, \ldots, W_n)$.

Because of space constraints, we don't elaborate the steps of AHP method. According to AHP method, we obtain the set of indexes weights: $W_i^2(W_1, W_2, \ldots, W_n)$.

Calculating the mean of $W_i^1(W_1, W_2, \ldots, W_n)$ and $W_i^2(W_1, W_2, \ldots, W_n)$, we obtain the final set of indexes weights: $W_i(W_1, W_2, \ldots, W_n)$.

2.5 Evaluation Model of Ecosystem Health of Coal-Mining Area

Evaluation model of ecosystem health of coal-mining area based on fuzzy mathematics is:

$$H = W_i \times R_h = \left(w_1, w_2, \cdots, w_n\right) \times \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} = \left(H_1, H_2, H_3, H_4, H_5\right) \tag{14}$$

H_1, H_2, H_3, H_4, H_5 represent membership degrees of ecosystem of coal-mining area corresponding to the five grades respectively, W_i is the set of indexes weights. According to maximum membership principle, we judge the grade of ecosystem of the coal-mining area.

3 CASE STUDY

Yima Coal-Mining Area is located at the juncture of Henan, Shanxi and Shaanxi Provinces. Yima Coal-Mining Area is rich in coal resource and has become an important energy base of China. During recent years, environmental problems have endangered the sustainable development of the area. Therefore, it is necessary to evaluate ecosystem health condition of Yima Coal-Mining Area. Coal fields of Yima Coal-Mining Area are distributed in Henan, Shanxi Province and Xinjiang Provinces. Taking Henan Province as an example, coal fields cover Yima City, Mianchi County, Shan County and Sanmenxia City. The distribution of coal fields around Yima Coal-Mining Area is widely dispersed. Therefore, it is very difficult to evaluate ecosystem conditions of all coal fields. We only take Changcun Mine and Qianqiu Mine situated at Yima City into account. Result is shown in Table 3.

According to maximum membership principle, we find that ecosystem of Yima Coal-Mining Area belongs to critically healthy grade in 2005, 2006, 2008 and 2009 (membership degree corresponding to critically healthy grade is 0.2924, 0.2756, 0.2884 and 0.2916 respectively) and belongs to relatively unhealthy grade in other years (membership degree corresponding to relatively unhealthy grade is 0.3182, 0.3364, 0.3508, 0.3628 and 0.3811 respectively). Results show that there is a tendency of gradual deterioration in ecosystem of Yima Coal-Mining Area during 2005 and 2013 with the` exception of 2008 and 2009. In addition, we find that membership degrees corresponding to relatively healthy grade and healthy grade show a tendency of gradual decrease, while membership degree corresponding to unhealthy grade shows a tendency of gradual increase.

4 CONCLUSIONS

The paper sets up an ecosystem health evaluation index system of coal-mining area and evaluates ecosystem health condition of Yima Coal-Mining

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Table 3: Result of ecosystem health evaluation of Yima coal-mining area.

Year	Membership degrees corresponding to each grade					Grade
	Unhealthy grade	Relatively unhealthy grade	Critically healthy grade	Relatively healthy grade	Healthy grade	
2005	0.1234	0.2526	0.2924	0.2247	0.1069	Critically healthy grade
2006	0.1686	0.2631	0.2765	0.2029	0.0889	Critically healthy grade
2007	0.1918	0.3182	0.2445	0.1739	0.0716	Relatively unhealthy grade
2008	0.1817	0.2657	0.2884	0.1704	0.0938	Critically healthy grade
2009	0.1732	0.2895	0.2916	0.1372	0.1085	Critically healthy grade
2010	0.2207	0.3364	0.2081	0.1523	0.0825	Relatively unhealthy grade
2011	0.2624	0.3508	0.1857	0.1303	0.0708	Relatively unhealthy grade
2012	0.2914	0.3628	0.1543	0.1174	0.0741	Relatively unhealthy grade
2013	0.3121	0.3811	0.1338	0.1021	0.0709	Relatively unhealthy grade

Area from 2005 to 2013 based on fuzzy synthetic evaluation method. Evaluation results conform to actual situations and can provide references for ecological safety management of the area.

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REFERENCES

Wang, G. C., Li, P. F., 2014. Study on the integrated ecosystem in coal mining area and its coupling mechanism. In *Ecological Economy* (in Chinese).

Rapport, D. J., 1981. What constitutes ecosystem health?. In *Perspectives Biology and Medicine*.

Schaeffer, D. J., Henricks, E. E., Kerster, H. W., 1988. Ecosystem health: measuring ecosystem health. In *Journal of Environment Management*.

Costanza, R., Norton, B. G., Haskell, B. D., 1992. *Ecosystem health: new goal for environmental management*, Island Press. Washington D. C., 1st edition.

Gao, C. B., Chen, X. G., Wei, Z. H., Peng, X. C., 2006. Application of entropy weight and fuzzy synthetic evaluation in urban ecological security assessment. In *Chinese Journal of Applied Ecology* (in Chinese).

Cheng, J. H., Chen, J., Yi, X. H., 2013. Research on evaluation indicators system of ecological civilization in mining China. In *China Population, Resources and Environment* (in Chinese).

Wang, G. C., Yan, X. Q., 2005. Study on indicator system of ecosystem health assessment in a typical mine area. In *Journal of China Coal Society* (in Chinese).

Zou, C. X., 2011. Research on evaluation index system of mine ecological environment quality. In *China Mining Magazine* (in Chinese).

Jerry, M. S., Mariano, B., Annalee, Y., 2001. Developing ecosystem health indicators in Centro Habana: a community-based approach. In *Ecosystem Health*.

Zhou, W. H., Wang, R. S., 2005. An entropy weight approach on the fuzzy synthetic assessment of Beijing urban ecosystem health. In *Acta Ecological Sinica* (in Chinese).

Qian, Y., Wang, L., Chen, J. F., 2008. Fuzzy comprehensive evaluation of urban ecosystem health in Urumqi. In *Research on Soil and Water Conservation* (in Chinese).

Qin, Q., Dai, W., Yang, Q., 2014. Security evaluation on ecological system of city based on entropy weight and fuzzy synthetic evaluation. In *Journal of Northwest Normal University (Natural Science)* (in Chinese).

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