INTEGRATED EVALUATION OF ECOLOGICAL SUSTAINABILITY OF A MINING AREA IN THE WESTERN REGION OF CHINA[1]

Yufen Hao[2], Zhenqi Hu and Jack R. Nawrot

Abstract: The ecological environment is extremely fragile in the western region of China, where the largest coal mining company in China is located. After mining, subsidence and massive loss of water resources occur in many areas. Plant mortality caused by lack of water, has made the fragile ecological environment deteriorate much more rapidly after 1986. Therefore, an investigation of eco-environmental sustainability in the mining area is imperative. Based on Remote Sensing (RS) and GIS, two typical mines were selected as study areas. Four types of spatial information (desertification, land use structure, water and soil erosion, and vegetation) for the ecological environment were extracted from remote sensing imagery for 5 periods (August 2, 1986, August 29, 1990, July 26, 1995, July 31, 2000, and July 24, 2006). The spatial information was used to construct an evaluation index system. Based on a grid of environmental data, the environmental index was used to develop and design an integrated evaluation model for evaluating sustainability of the ecological environment in the mining area. Four classes of ecological sustainability were identified by the model. The analyses identified variability in the environmental sustainability. The changes in loess areas were much greater than in sandy areas because subsidence in loess areas was more serious than that in sandy areas. Because most cropland occurs in loess areas, and the ecological environment of loess regions is extremely sensitive and vulnerable to desertification, negative effects of mining are a serious concern. Therefore, evaluation of the environmental sensitivity and sustainability of the mining area is indispensable. The results of this evaluation corresponded quite well with the actual environmental conditions, demonstrating that this model is scientifically sound and objective. Application of this model to other mines and mining regions within China can be used to evaluate potential impacts in environmentally sensitive areas.

Additional Keywords: coal mine, subsidence, erosion, Remote Sensing/GIS, integrated evaluation model.

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Introduction

Survival and development are the fundamental problems facing humans. In the western regions of China, these problems have become more prominent. The economic development of western China was slow, and the standard of living was low. In these regions, economic development consumes resources and damages the eco-environment. The extremely fragile eco-environment in the region has become the main obstacle for economic and social development.

Shendong mining area is located north of Shenmue County and west of Fugue County in Yule city, Shaanxi province, and south of Erin Hole County and southwest of Zhungeer County in Inner Mongolia province. The mining area is in the transitional zone of Maowusu Sandland and the hilly and gully area of the Loess Plateau (110°05′–118°14′E and 39 °17′–39°26′N). The mining area is about 80km from north to south and 15–55km from east to west along both banks of the Ulanmulun River. Soils west and southwest of the mining area are dominated by sand, filled with mobile, fixed and semi-fixed sands which produce fierce sandstorms. The southeast is mainly a loess hilly landform, characterized by hills and gullies with serious soil erosion. Scattered beaches, depressions and sporadic lakes of different sizes characterize the eco-environment in this extremely fragile area (Lu et al., 2000).

Shendong mining area has the most coal reserves, accounting for one-third of the total reserves in China. It is the first coal mining area in China whose yield exceeded 100 million tons per year. However, the eco-environment is quite fragile and sensitive to mining. Continual mining has resulted in subsidence and massive loss of water resources in many areas. Inadequate water supplies have increased plant mortality and the deterioration of the fragile eco-environment in recent years. This deterioration has become a great concern; therefore, the investigation of ecological sustainability in this mining area is imperative. Using 3S (Remote Sensing, RS; Geography Information System, GIS; Global Positioning System, GPS) technology, multi-source spatial information of the ecological environment was developed as evaluation indexes. Then the integrated evaluation model of ecological sustainability was designed based on raster layers (Xu and Zhao, 2006; Li et al., 2006). This model was used to evaluate the ecological sustainability of Shendong mining area. Through further analysis, we derived the spatial-temporal dynamic rules of ecological sustainability, and identified the reasons of the environmental change. Those analyses provided descriptions for problems areas and potential solutions that can contribute to healthy and sustainable development of the mining area.

Study Areas and Index System

Study Areas

Based on many site investigations in the Shendong mining area, and knowledge of the mining area's natural environment, we selected two typical mines (Huojitu mine in loess area, Bulianta mine in sandy area) as study areas (Fig. 1, Fig. 2, Fig. 3 and Fig. 4).

Huojitu mine, located between Shanxi province and Inner Mongolia province, is in Shenmue County, Shaanxi province (63 km^2). Huojitu began construction in 1993. In 2000 construction was completed and the standard production was reached (Table 1; Figs. 1and 2).

Table 1. Huojitu's coal production 1999-2004

Year	1999	2000	2001	2002	2003	2004
Coal(t) Produced	464,400	3,919,500	5,771,973	5,392,021	9,245,166	11,079,358

Figure 1. Vegetation and erosion in loess area

Figure 2. Subsidence and erosion in loess area

The 36.52km^2 Bulianta mine is located in Ejin Holo County, Inner Mongolia province. Construction was from the end of August 1990 to the end of 1993. Production is 690,000t per year. In 2001, after three technical transformations, production reached 8.0Mt (Figs. 3 and4).

Figure 3. Subsidence and erosion in sandy area

Figure 4. Vegetation and subsidence cracks in sandy area

Index System

Evaluation index selection. The selection of a suitable evaluation index is required to correctly evaluate regional eco-environmental situations. The establishment of an index system allows a scientific and systemic synthetic analysis of the subject. The selection of the index group should be based on the following principles (Alewell and Manderscheid, 1998; Geraghty, 1993):

(1) Be scientific: it must be reasonable in ecological significance and representative of the ecological sustainability in mining area;

(2) Be available: it must be suitable for the management and support the decisions of land reclamation and ecological reconstruction in the mining area;

(3) Be feasible in finance, technology and society: the eco-environment information can be obtained under the current level of the RS and GIS technology.

Based on qualitative analysis of the features of the eco-environment in the Shendong mining area, two kinds of evaluation indexes were chosen to represent the natural environment and landscape ecology. The evaluation indexes included 4 factors (Table2).

Index Weight. Different factors have different impact on eco-environment, so the weight of the evaluation factors should be confirmed. In this paper, the weight of different indicators is determined by the Analytic Hierarchy Process (AHP) (Ansdin et al., 1989). AHP is a simple systems analysis method, which allows the non-quantitative variables to be quantitatively analyzed. On one hand, it takes full account of experts' subjective judgment and makes a qualitative and quantitative analysis of research objects, determining the relative importance of factors by listening to the experts' advice. On the other hand, it regards the research objects as a system, analyzing the various complex factors layer by layer through the internal and external linkages of this system. The method focuses on assigning an appropriate factor weight to complex items; therefore, we call it multi-level weight analysis. Eco-environmental system is a complex system with multi-level, multi-factor, and is particularly suitable for AHP (Yang and Tang, 2002). Through analysis, the weights of different level-evaluation factors are identified in Table 2.

Table 2. Index and weight for ecological sustainability evaluation

Eco-environment Index	Primary (#1) Index	Secondary (#2) Index
Integrated evaluation of ecological sustainability (weight)	Landscape ecology（0.5）	Desertification（0.75）
		Land use (0.25）
	Natural environment（0.5）	Water and soil erosion（0.67）
		Vegetation coverage（0.33）

Integrated Evaluation Model Based on Grid

Data and Data Processing.

Collection of related information on the eco-environmental features in the Shendong mining area generated the basic data need for the model. The basic data used in the study included: RS image data, statistics, field survey data, DEM and slope-grade data, etc.

The ecological sustainability changes before mine construction, during the construction and the present should be integrally analyzed. Therefore, five Landsat TM images of August 2, 1986, August 29, 1990, July 26, 1995, July 31, 2000 and July 24, 2006 were chosen. ERDAS remote sensing image processing software was used to extract for land use, desertification, water and soil erosion, and vegetation coverage data.

Land use data processing. Mine land use classifications included: vegetation, water, and bare land (Fig. 5 and Fig. 6). After mining (1995), the acreage of water and vegetation of the Huojitu mine decreased indicating impacts to the ecological sustainability had occurred. The Bulianta mine bare land acreage was greatest in 1995, because water and vegetation were destroyed during construction. Mining impacted the ecological sustainability in both areas.

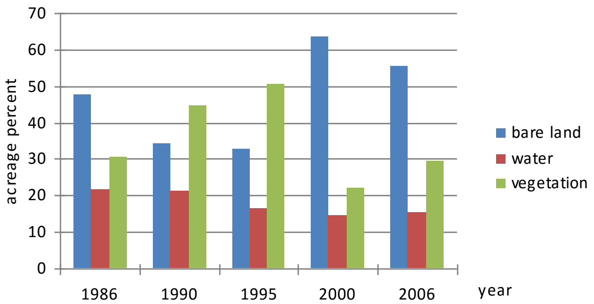

Figure 5. Huojitu land use structure

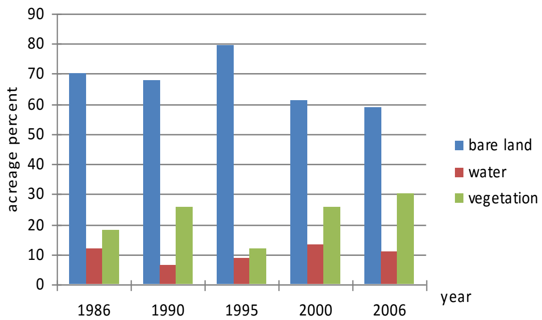

Figure 6. Bulianta land use structure

Desertification and water and soil erosion data processing. Mine desertification, water and soil erosion intensity were divided into five classes: stable area (class 1), micro-degree area (class 2), mild area (class 3), moderate area (class 4) and severe area (class 5) (Fig. 7, Fig. 8, Fig. 9 and Fig. 10). After mining (1995), increased desertification, and increased water and soil erosion at the Huojitu mine resulted in decreased ecological sustainability. Bulianta's desertification and water and soil erosion were most degraded in 1995, due to mine construction impacts on the ecological environment.

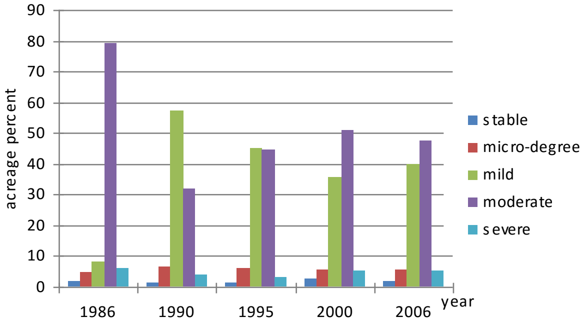

Figure 7. Huojitu desertification

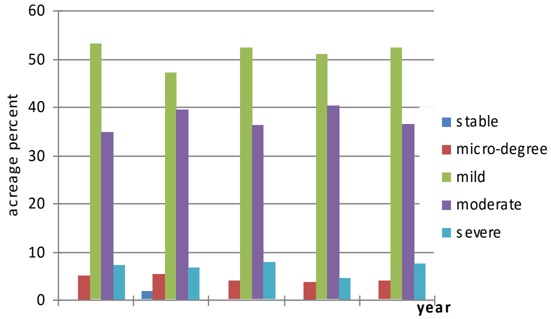

Figure 8. Bulianta desertification

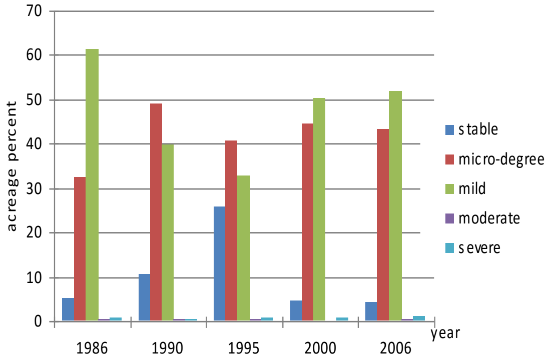

Figure 9. Huojitu water and soil erosion

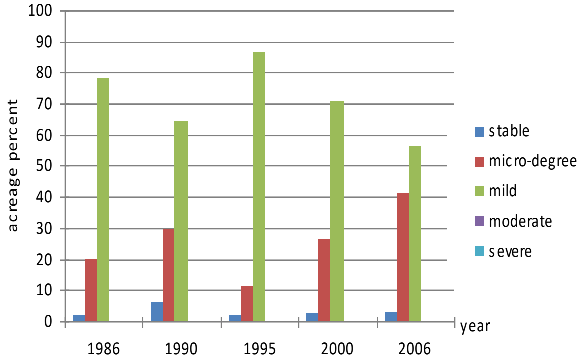

Figure 10. Bulianta water and soil erosion

Vegetation coverage data processing. Mine vegetation coverage was divided into five categories: 80–100% (class 1), 60–80% (class 2), 40– 60% (class 3), 20–40% (class 4), 0–20% (class 5) Fig. 11 and Fig. 12). Huojitu's vegetation coverage was worst in 1995, because mine construction destroyed most of the vegetation. Although vegetation recovered after 1995, the 60–100% vegetation cover class was almost zero, indicating that mining had seriously impacted vegetation. Bulianta's vegetation coverage was worst in 1995, but improved later.

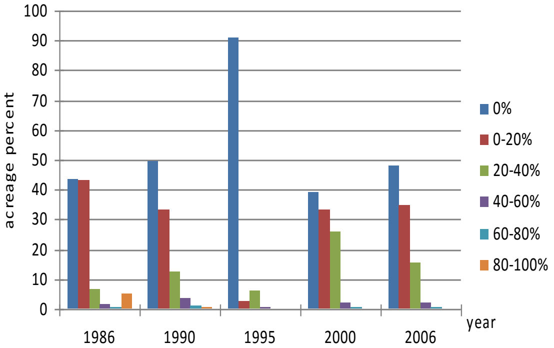

Figure 11. Huojitu vegetation coverage

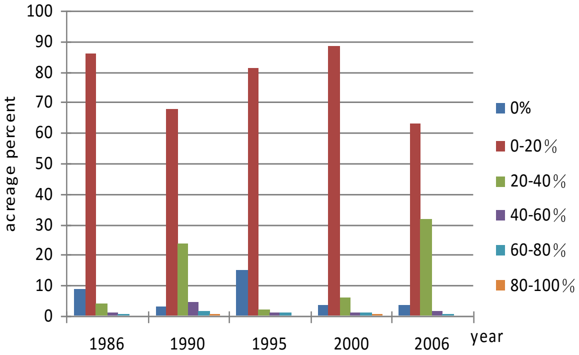

Figure 12. Bulianta vegetation coverage

Based on the survey of land use and the results of remote sensing interpretation, supported by GIS technology, areas of water were defined as the first grade of ecological sustainability (value=1). Vegetated areas were defined as the second grade (value=0.6). Bare lands were defined as the third grade (value=0.2).

Using the results of remote sensing interpretation supported by GIS technology, we analyzed the vector data of desertification, soil erosion and vegetation coverage. Class 1 was defined as the first level of ecological sustainability (value=1). Class 2 was defined as the second level (value=0.8). Class 3 was defined as the third level (value=0.6). Class 4 was defined as the fourth level (value=0.4). Class 5 was defined as the fifth level (value=0).

Evaluation Unit

Evaluation unit reflects a certain space and entities, including a series of factors that impact environmental quality. The division of units should have an objective reflection of the spatial differences in environmental quality; similar units should have the same basic attributes (Ma et al., 2004). The selection of the evaluation unit must be based on the methods used. Because we use RS and GIS technology in this paper, all the evaluation factors achieve quantitative and spatial expression. Therefore, we select a grid as the basic evaluation unit. A grid data format is more conducive to overlay analysis, algebra, and logic operations. The grid data format can also effectively avoid the appearance of many small patches of vector data in a multi-source spatial information overlay. Using GIS technology, multi-source spatial vector data, such as the geological environment, eco-environment and natural environment indicators, can be transformed into raster data. Each grid (30 m × 30m) is used to produce thematic raster data layers. Then using the spatial overlay function of GIS, each overlapping thematic data layer can produce the digital environment model.

Evaluation Method

All the thematic data of the study area were transformed from vector to raster. Through spatial overlay analysis with GIS, we can produce raster data documents displaying the thematic attributes of the various evaluation factors. The data table records each index value. Using a composite index evaluation method (also called synthetic weighted mark method); we can calculate the composite index of ecological sustainability in each grid. Synthetic evaluation results are indicated with the following formula:

$$F_n = \sum_{i=1}^{7} k_i w_i \qquad \textbf{(1)}$$

Where F_n is No. n unit (grid) integrated index of ecological sustainability; k_i is No. i index quantitative value in the unit; w_i is the index corresponding weight; n is the total number of evaluation unit. In this paper, the integrated index of ecological sustainability can point out the present situation of the ecological sustainability, defined as ESI (Ecological Sustainability Index). Higher ESI values represent enhanced ecological sustainability.

Results and Analysis

Results Classification and Analysis

The digital environmental model represents the spatial attribute data, using the grid as the basic unit, with each unit including all of the evaluation factor attributes. Therefore, the digital environmental model can evaluate the ecological sustainability for each grid unit, and calculate the ESI for each unit. The ESI value range is between 0 and 1. For comparative analysis, ESI values were divided into to 4 classes: severe problem (＜0.25), moderate problem (0.25≤～＜0.5), mild problem (0.5≤～＜0.75), and stable (≥0.75). The spatial distribution characteristic of each class reflects the regional differences of ecological sustainability. The

2006 classification results for the Huojitu and Bulianta mines are shown in Table 3, and Fig. 13 and 14.

Table 3. Classification results of an integrated evaluation of ecological sustainability for typical Shendong mines in 2006

Ecological Sustainability Class		Severe	Moderate	Mild	Stable
Huojitu	Area /ha	163.63	2422.71	3053.64	317.26
	Area percentage /%	2.75%	40.67%	51.26%	5.33%
Bulianta	Area /ha	146.99	1353.28	2712.08	342.27
	Area percentage /%	3.23%	29.71%	59.55%	7.51%

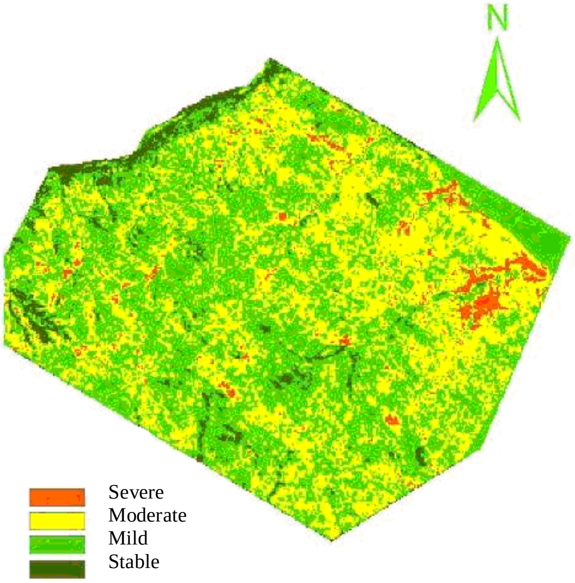

Figure 13. Classification results of the integrated evaluation of the ecological sustainability for Huojitu in 2006

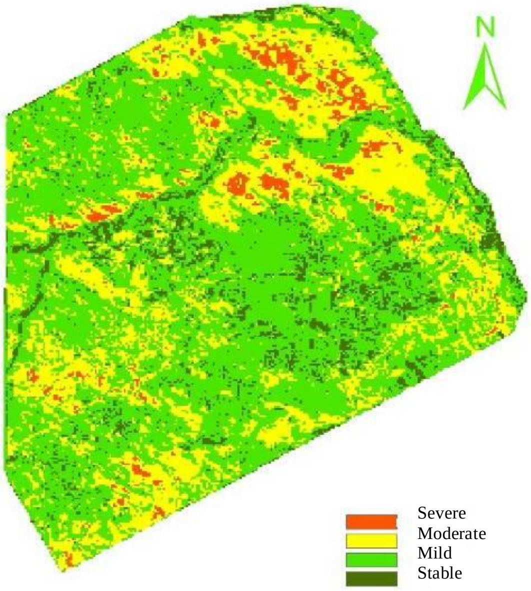

Figure 14. Classification results of the integrated evaluation of the ecological sustainability for Bulianta in 2006

In 2006, stable areas in the Huojitu mine and Bulianta mine, two typical mines in Shendong mining area, accounted for 5.33% and 7.51 % respectively. This demonstrates that only a small portion of the mining area was stable. A very small portion was classified as a severe problem (Huojitu 2.75%, Bulianta 3.23%). The majority of the mining area had mild to moderate ecological problems. Therefore more effort is needed to protect the ecological system of the mining area and improve ecological sustainability.

Temporal Change and Analysis

To interpret the temporal change of a mining area's ecological sustainability based on the evaluations of grids as the unit of analysis, it is necessary to respectively analyze two typical mines as a composite unit over time. It is conducive to analyze the ecological sustainability differences between periods, by incorporating the mining time-series evolution rule of ecological sustainability. The time-series composite indexes of ecological sustainability for two typical mines are assessed using the following formula

$$C_i = \frac{\sum A_i S_i}{\sum S_i} \tag{2}$$

Where C_i is No. i period integrated index of ecological sustainability; A_i is the integrated index quantitative value of ecological sustainability of each unit in this mine; S_i is the integrated index corresponding grid. Higher values of the integrated index of ecological sustainability indicate better ecological sustainability.

Huojitu's ecological sustainability improved from 1986 to 1995, but after 1995 ecological sustainability declined due to adverse effects of mining (Table 4). After 1995, the ecological sustainability continued to decline, indicating that the Huojitu mining area needs more reclamation work.

Table 4. Integrated indexes of ecological sustainability for typical Shendong mines during the period 1986 – 2006.

Time		1986	1990	1995	2000	2006
Integrated indexes of ecological sustainability	Huojitu	0.51	0.59	0.69	0.58	0.52
	Bulianta	0.49	0.54	0.48	0.49	0.55

Bulianta's ecological sustainability was severe in 1995 and 2000, during the peak of construction, when construction activities destroyed some ecological factors. The ecological sustainability improved in 2006, because Shendong company spent 500 million Chinese yuan for reclamation after 2000 (Qiao, 2006).

As a whole, the changes in loess areas were much greater than in sandy areas because subsidence in loess areas was more serious than that in sandy areas. Because most cropland occurs in loess areas, and the ecological environment of loess regions is extremely sensitive and vulnerable to desertification, negative effects of mining are a serious concern. Therefore, evaluation of the environmental sensitivity and sustainability of mining area are indispensable. The results of this evaluation corresponded quite well with the actual environmental conditions, demonstrating that this model is scientifically sound and objective. Application of this model to other mines and mining regions within China can be used to evaluate potential impacts in environmentally sensitive areas.

Conclusions

(1) Based on RS and GIS technology, the results of ecological sustainability evaluation in the Shengdong mining area corresponded very well with actual conditions. The results also provide a scientific basis for the design and planning and construction of mining areas, improvement of the ecological environment, and the development of a healthy society.

(2) Based on RS and GIS technology, from the time-series remote images, the spatio-temporal information of different eco-environment factors is extracted as evaluation indexes. Therefore the evaluation results can more accurately reflect the change of the ecological sustainability, and display ecological sustainability in a spatio-temporal context.

(3) This paper chooses a numerical integrated evaluation model for ecological sustainability of mining area based on a grid scale. The grid is the basic analysis unit for the spatial data, and the spatial attribute features of all thematic indexes were retained in each grid. The evaluation model can facilitate the numerical analysis of all of the thematic indexes which represent the spatial distribution; the generation of a quantitative expression of ecological sustainability for a mining region has a very practical application for mine planning and reclamation.

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