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Full Length Research Paper

Biological reclamation of the Lu'an mining territory in China: An incorporated model

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Variances in the natural-environmental and artificial factors of the mining industry and of mining production were analyzed to achieve scientifically the ecological restoration of the Lu'an mining land system. The eco-environmental pressure of the evaluation index system was established. Each unit of land system was exposed to a different eco-environmental pressure, which resulted in differences in land eco-function performance. The land system can be categorized into the productive, protective, consumptive, and mixed land types based on eco-environmental performance. The Lu'an mining area was divided into four regions, namely, the uncultivated land consumptive zone (23.33 km^2, 4.09%), the wetland and mining subsidence protective zone (109.23 km^2, 19.16%), the flatland productive zone (373.89 km^2, 65.57%), and the artificial mixed zone (63.76 km^2, 11.18%), and a total of eleven eco-function types. The regions' area ratios were 6.50, 19.16, 8.77, and 65.57%, respectively. Productive and consumptive land was oversized, whereas mixed and protective land was very small, indicating an undesirable land use system. Based on the analysis, an integrated model involving 19 models (e.g, shrub and grassland rehabilitation, steep slope protection, ecological village building model, etc.) was proposed for the development of the local eco-environment based on the eco-function type of mining land.

Key words: Mining area, ecological division, eco-function type, eco-environmental pressure, China.

INTRODUCTION

Human activities have significantly affected most ecosystems of the earth (Vejre et al., 2010; Anand et al., 2010). Substantial alterations in the terrestrial biosphere have occurred because of the rapid expansion of the human population, unabated economic development, and associated processes such as deforestation, environmental pollution, and contamination (Parrota and Knowles, 2001; Bradshaw, 1997). The expansion of industrialization entails massive energy generation for which huge quantities of coal need to be extracted through mining, causing extensive landscape destruction (Wang et al., 2009; Demirel et al., 2011). In China, the estimated wasteland produced by mining activities alone is ca. 20,000 ha annually. This value is expected to exceed 33,000 ha in the near future (Miao and Marrs, 2000). Therefore, the restoration of mined land should be given priority in the exploitation of minerals; mining causes the destruction of natural ecosystems through the removal of soil and vegetation and their burial beneath waste disposal sites (Pammenter and Berjak, 2000). In practice, the restoration of mined land can largely be considered as ecosystem reconstruction. However, the lack of post-restoration monitoring and research has meant few opportunities to improve the theory and practice of ecological restoration in mining (Cook and Johnson, 2002). Further, mine area land reclamation and ecological restoration research spans numerous fields, such as mining, geology, geography, land use, environment, landscape, ecosystem, agriculture and forestry, biology, soil science, and social economy, among others, so the amount of information involved is huge (Fellet et al., 2011; Zhan and Sun, 2011; Chang et al., 2009). Therefore, the proposal of a scientific and integrated model of restoration for mining areas involves great challenges. The Lu'an mining area is located in the middle of the Shanxi province. Mining areas consist of different land use units, which are the result of long-term mining and other human activities that disturb the local environment. Each unit is exposed to different forms of ecological pressure and shows differences in ecological performance (Nichols et al., 2008; Liu and Ma, 2011). Land eco-function appraisal, which is based on the ecological performance of land units, is used for optimal land use selection, ecological design, and pre-management.

Both natural factors (topography, soil, vegetation, hydrology, and other elements of nature) and artificial factors (resource consumption, environmental pollution, and scale of production) are duly considered in the development of appraisal indices (Marchini et al., 2008; Jorgensen and Svirezhev, 2004; Yu and Bi, 2011). In this paper, the land system of the Lu'an mining area is categorized into four types according to the ecological function performance of the unit: productive type, protective type, consumptive type, and mixed type (Li et al., 2002; Zhang et al., 1999). An integrated model of restoration is correspondingly proposed to release the restoration and development of the local eco-environment.

MATERIALS AND METHODS

Study area description

The Lu'an mining area (35° 50′ N5 ′ N–36° 33′ N, 11 112°32′E–113° 16′ E, 900 m to 1,100 m altitude) is located west of Mt. Taihang across five counties: Changzhi, Xiangyuan, Tunliu, Lucheng, and Zhangzi of Shanxi Province in China (Figure 1). The topography from north and west to south and east shows a changing trend for hilly to valley plain. Its climate is temperate and semi-humid, with a mean annual temperature of 10.4ºC, annual precipitation of 583.9 mm, and annual evaporation of 1731.84 mm. The soils of the mining land are mainly loess soil, brown soil, drab soil, and meadow soil. The vegetation is of the warm temperate deciduous broad-leaved forest zone, the coverage of which is only 8% (Wang and Ma, 2009). About six large coal mines (e.g, Wangzhuang, Sima, Wuyang, etc.) are operational in the area. Some measures such as the use of coal gangue and fly ash-filled ditch, coal gangue rehabilitation, and land reclamation after mining have been undertaken by local mining companies in recent years. However, the entire land system of the mining area remains under heavy eco-environmental pressure, which is the cause of long-term and over-explored coal mining, pollution, and soil erosion (Wang et al., 2007).

Appraisal index system

The eco-environmental pressure of the mining land system comprises mining and related activities of industries, which are responsible for the degradation of land and the environment. It comprises multi-causal and multi-dimensional factors (Fan et al., 2007). Based on variations in the natural environment, mining activities, and related industries production (topography, water and heat distribution, soil, residential and mining settlements, gangue and solid waste, etc.), the eco-environmental pressure in the Lu'an mine land is divided into four categories: natural resources pressure, A_1; resource consumption pressure, A_2; environmental pollution pressure, A_3; and production scale pressure, A_4 (Table 1).

Data analysis

ArcGIS 9.3 and Erdas 8.4 tools were used for the data analysis and eco-function division. The methods used in this study were overlap, buffering, and statistical analysis. Satellite images, topography and land use data, water resources bulletin, and a statistical yearbook were also employed.

Calculation of eco-environmental pressure

Weights of factors

In the calculation of the eco-environmental pressure in the Lu'an mining system, the weights of factors were assigned using AHP method combined with advice from experts.

Calculation of factors

All factor values were determined using standardized processing (Formulas 1 and 2):

$$E_i = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (1)$$

$$E_i = 1 - \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (2)$$

Where, E_i is the index value of factor *B,* whereas in *i* year, X_i is the value of factor *B* in *i* year. X_{min} is the minimum value of factor *B* in five years, whereas X_{max} is the maximum value of factor *B* in five years. Formula 1 is for positive factors, whereas Formula 2 is for negative factors.

For the point pressures of production scale A4, its effects on land units show a certain declining trend (exponential decline or linear decline) as the distance increases. In this paper, the index values were calculated with an exponential decline (Formulas 3 and 4):

$$f_i = M_i^{1-r} \quad (r=dc/d) \quad (3)$$

Where, f_i is the value of point pressure *i*'s effect on the land unit, M_i is the production scale pressure index *i, dc* is the distance between the center of the point pressure to the land unit for evaluation, and *d*

Table 1. Eco-environmental pressure in the Lu’an mining area.

Overall goal	Criteria	Criteria weights	Sub-criteria	Sub-criteria weights
Total environmental pressure in the land system of the Luan mining area (P)	Natural environmental pressure (A1)	0.25	Precipitation/A11	0.11
			Average annual temperature/A12	0.08
			Soil erosion module/A13	0.09
			Terrain index/A14	0.17
			N, P, K of soil/A15	0.21
			Natural vegetation coverage/A16	0.15
			Total water resources of the mining area/A17	0.19
	Resource consumption pressure (A2)	0.2	Total water consumption/A21	0.30
			Fresh water consumption/A22	0.15
			Total fuel coal consumption/A23	0.35
			Total fuel oil consumption/A24	0.20
	Environmental pollution pressure (A3)	0.35	Water pollution index/A31	0.23
			Soil pollution index/A32	0.21
			Air pollution index/A33 Surface	0.24
			subsidence index/A34	0.32
	Production scale pressure (A4)	0.2	Annual GDP output of mining/A41	0.31
			Annual output capacity of coal/A42	0.30
			Total population of mining settlements/A43	0.20
			Total amount of gangue and solid waste/A44	0.19

is the influencing radius of the production scale pressure index i. A land unit is affected by several point pressures, which is calculated using Formula 4:

$$F = \sum_{i=1}^{n} f_i \quad (4)$$

Where, F is the total value of the effect of point pressures on the land unit, n is the number of point pressures, and f_i is the value of the effect of point pressures i on the land unit.

RESULTS AND DISCUSSION

Eco-function type division based on eco-environmental pressure

Each land unit showed a different eco-function in its exterior, such as output energy and minerals, environmental protection, consumed biological matters, and a mixture of different functions caused by different types of eco-environmental pressure (Zhang et al., 1999). Hence, the eco-function type division of the mining area can be based on its eco-environmental pressure.

Resources consumption pressure (A2), environmental pollution pressure (A3), and production scale pressure (A4) were combined under artificial production pressure (B1). The land system can be categorized into four groups: productive type, protective type, consumptive type, and mixed type (Table 2).

The productive and mixed land system was substantially affected by artificial disturbance and not so much by natural environmental pressure. However, in the protective and consumptive land system, natural environmental pressure was the main restrictive factor.

Eco-function of the Lu’an mining land system

The Lu’an mining land system was divided into four ecological zones and eleven eco-function types (Figure 1B). The areas of the uncultivated land consumptive zone and wetland and mining subsidence zone were 23.33 and 109.23 km^2, which accounted for 4.09 and 19.16% of the total mining land, respectively. Those of the flatland productive zone and artificial mixed zone were 373.89 km^2 and 63.76 km^2, which comprised 65.57% and

Table 2. Environmental pressure and division of the ecological function zone in the Lu'an mining area.

Pressure index	Productive land system	Protective land system	Consumptive land system	Mixed land system
Natural environmental pressure (A1)	<0.4	0.6 to 0.8	>0.8	0.4 to 0.6
Artificial pressure (B1)	0.4 to 0.6	0.2 to 0.4	<0.2 or >0.8	0.6 to 0.8

Artificial pressure B1＝ (Resources consumption pressure A2 × 0.2 + Environmental pollution pressure A3 × 0.35) Production scale pressure A4 × 0.2)/0.75°.

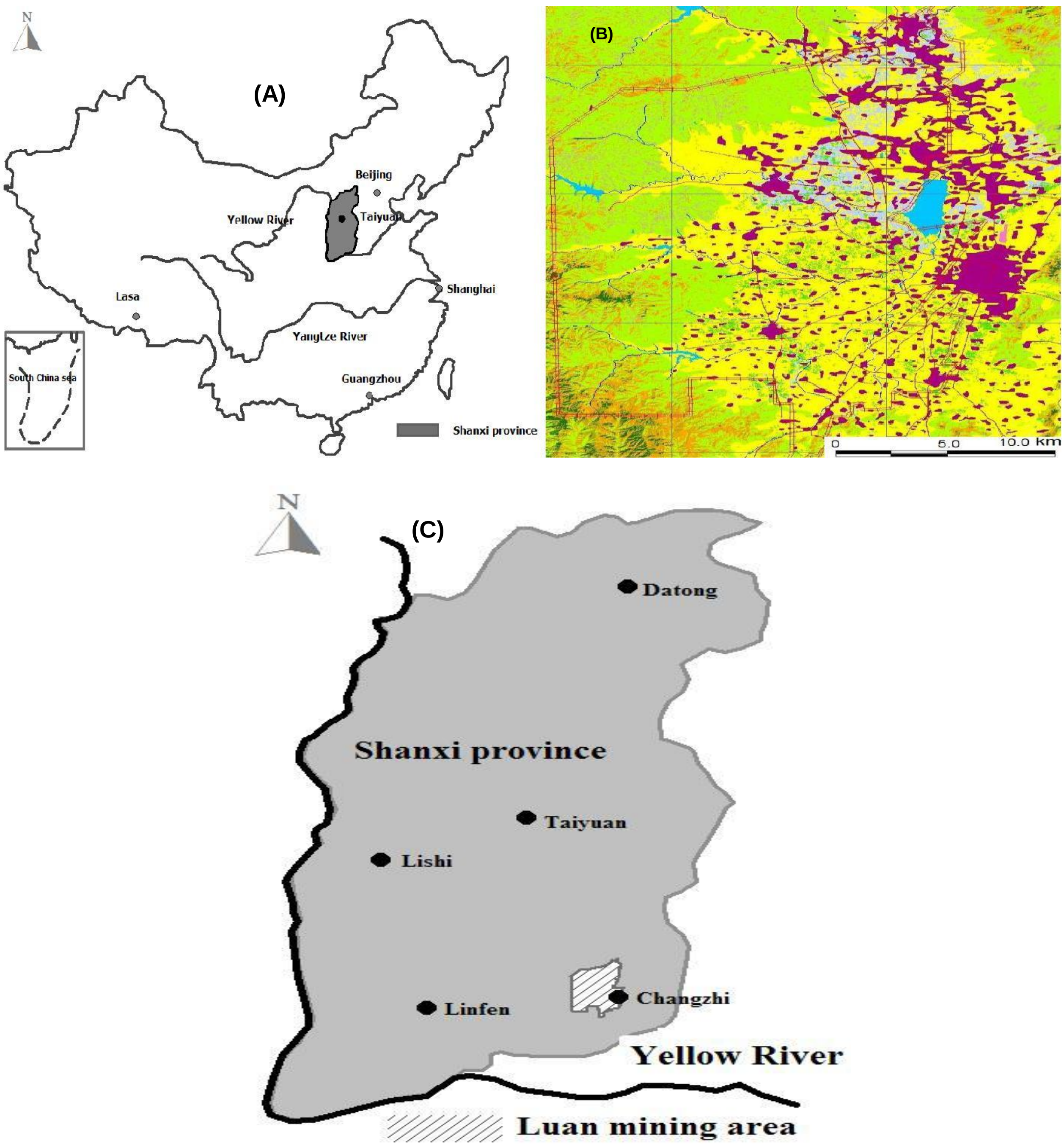

Figure 1. Location of the study region. (a), (b), and (c) represent China, Shanxi province, and the Lu'an mining area, respectively.

11.18% of the total mining land, respectively. The entire mining area was over-exploited with large tracks of productive and artificial mixed land, indicating that land use in the Lu'an mining area was undesirable. Therefore, more eco-environmental restoration strategies should be launched for further environmental protection of the area.

Ecological restoration models of the Lu'an mining land system

An integrated land system restoration model should fully take into account the existing mining activities in the area and its environmental features, especially eco-function performance. Under the framework of four ecological zones and eleven eco-function types, nineteen models (e.g, steep slope protection model, protected agriculture model, ecological village building model, etc.) were integrated for the ecological restoration of the Lu'an mining land system (Figure 1C).

Uncultivated land consumptive zone

The region comprised uncultivated land consumptive type (17.51 km^2) and steep slope protective type (5.82 km^2). The site conditions were harsh, dominated by natural environmental pressure. The restoration methods were mainly focused on rational rehabilitation and protection of existing vegetation. Four models (shrub and grassland rehabilitation model; steep slope protection model; optimization model of shrub, grass, and terraces; and soil and water conservation model) were used for the rehabilitation and protection of the local environment. Small-scale afforestation, slurry spray technology, and drought- and barren-resistant plant selection were adopted in the models (Fan and Liu, 2006). Vegetation restoration should involve a bidding strategy, change the use rights to uncultivated land, and mobilize various elements of the society for eco-environmental reconstruction. Investment systems may shift from national and collective investment to diversify patterns, states, collectives, individuals, and companies.

Wetland and mining subsidence protective zone

Three eco-function types can be found in the ecological zone: mining wasteland consumptive type, mining subsidence protective type, and wetland protective type. A series of economic and eco-environmental social issues, such as heavy pollution, soil erosion, and coal gangue caused by mining activities, was concentrated in this ecological zone. Six models (e.g, wetland landscape reconstruction, plant purification model, gangue comprehensive utilization patterns, etc.) were mainly related to wasteland, mining subsidence, and gangue comprehensive treatment. Full use of water was provided in mining subsidence, reconstruction of an artificial lake, and wetland landscape for tourism. Meanwhile, the coal gangue filling technique and vegetation rehabilitation can reduce the environmental effects of gangue, and subsidence plots can be controlled well.

Comprehensive utilization and development of artificial mixed and flatland productive zones

The region is the core of the productive zone, which has flat topography, convenient transportation, and abundant natural resources. It is a very complex land system interacting with long-term mining and agriculture activities (He et al., 1996). Eco-environmental construction should focus on the cycles of the mining industry and the development of the local eco-economy. Hence, artificial mixed and flatland productive zones were viewed holistically for ecological restoration. The region has two ecological zones and six eco-function types. Artificial pressure dominated the region. Nine models (e.g, protected agriculture model, ecological village building model, and ecological tourism model, etc.) were proposed for sustainable development. Ensuring the smooth material and energy flow of the different eco-functions of land units is important as mining itself is a multi-dimensional, complex eco- economic system that involves resources, the environment, economy, and society. The optimization of ecological restoration strategies was focused on the achievement of a productive layout and eco-economic benefits.

Conclusions

An evaluation index system of the eco-environmental pressure in the Lu'an mining area was established in this paper. According to eco-environmental pressure and eco-function performance, the mining land unit can be grouped into four types: productive, protective, consumptive, and mixed type. The Lu'an mining area was divided into eleven eco-function types. The overall land use was considered undesirable with overexploited natural resources. Nineteen models of ecological restoration (e.g, steep slope protection model, protected agriculture model, ecological village building model, etc) were integrated in the Lu'an mining land system for the sustainable development of the local economy, society, and eco-environment. The results offer a valuable reference for the ecological restoration of other mining areas in China.

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