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# Application of GIS based ecological vulnerability evaluation in environmental impact assessment of master plan of coal mining area

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## Abstract

Coal accounts for more than 70% of total energy consumption in China. Kinds of ecological problems resulting from coal mining have become increasingly serious, which directly threaten regional ecological security and people's normal production and livelihood in some areas. Ecological vulnerability is the overall performance of the ecosystem change under mining development, thus evaluation of ecological vulnerability based on GIS in Fuxin mining master plan environmental impact assessment was presented in this article. According to ecological condition of Fuxin, the ecological vulnerability index was established synthetically reflecting ecological environmental status, ecological sensitivity and landscape spatial structure, including 9 indicators. The study area was divided into 247 grids, then the EVI value of each grid was calculated by comprehensive evaluation and the results were divided into 5 levels by Zonal Statistic analysis of ArcGIS. Combining the distribution of vulnerability classification with the important ecological function area and natural reserves in the scope of planning, the research area was plotted into five types of zone, i.e., appropriate exploitation zone, optimized exploitation zone, moderate exploitation zone, restrictive exploitation zone and forbidden exploitation zone. Several adjustment suggestions were put forward to optimize the layout of Fuxin mining area and guide the ecological protection during coal exploitation.

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## 1. Introduction

Along with the high-speed economic development, the demand of energy is increasing in China. Coal accounted for around seventy percent of total energy consumption [1]. At the same time, long-term coal exploitation has caused kinds of ecological problems, such as ground stripping, surface subsidence, ground water levels descending and soil erosion etc., which then induced great damages to water resource, vegetation and geological structure of mining area and resulted in ecological degradation [2]. In order to promote the coordinated development between coal resources exploitation and ecological protection, State Environment Protection Agency in China held a seminar on the ecological environment protection in coal development projects in April 2006 and indicated that propelling Plan Environmental Impact Assessment (PEIA) is urgent for environmental protection in coal industry, namely alleviating ecological destruction and environmental pollution in the source through reasonable planning [3]. As an inherent property of ecosystems in most mining area, ecological vulnerability is the overall performance of the evolutionary result of these ecosystems [4]. Ecological vulnerability should be adopted into the PEIA of mining areas, not only for a complement of environmental assessment theory, but also for the important theoretical and realistic implications for mining development layout, mining ecological environmental protection and realizing sustainable development and utilization in mining areas.

This concept of ecological vulnerability originated from ecological ecotone by Clements, which was further defined in the seventh SCOPE (Scientific Committee of Environmental Problems) Conference in 1989 [5]. Thence the study about ecological ecotone attracted more attentions. At present, the 3S technologies have been widely used in ecological vulnerability research [6], and an ecological vulnerability evaluation system which incorporates landscape theory or for special conditions has been established [7]. The beginning of relevant studies in China was late, most of which concerned the arid regions, rivers, mountains and wetland, etc. [8-12], while study on the ecological vulnerability of mining exploitation is insufficient. In PEIA of mining areas, aspects such as circular economy, environmental impacts and evaluation index system [13-16] have been discussed and studied by researchers. However, little insight has been derived with respect to the evaluation of ecological effects in PEIA of coal mine.

The aim of this study was to develop a systemic method of ecological vulnerability based on GIS to be used in environmental impact assessment of mining area planning. The method was applied to evaluate the ecological vulnerability of Fuxin, whereby regionalization the study area for different intensity of exploitation, then put forward the advice of optimized adjustment of planning.

## 2. Study area and outline of planning

Fuxin mining area is located in the mid-west part of Liaoning province, lying between  $40^{\circ} 46' N$ – $42^{\circ} 43' N$  and  $121^{\circ} 7' E$ – $123^{\circ} 17'$  with area about  $20096 \text{ km}^2$ , consists of two coalfields (Fuxin and Heishan) and two exploration areas (Zhangwu and Liaohe basin). The terrain in the west is higher than that of the east. It connects west with the western mountain and foothills area of Liaoning province, and the main mountain is Yiwulv Mountain, outspreaded from southwest toward northeast along Fuxin coalfield. The perennial coal exploitation in the underground and surface in Fuxin mining area has caused increasingly aggravated eco-environmental problems, such as surface subsidence, groundwater pollution, vegetation coverage reducing and soil erosion, etc. The north part of Fuxin mining area is contiguous with Horqin sandy land, which worsened the desertification problem in the area.

The study case is Fuxin Mining Area Development Master Plan in Liaoning province (modified) which belonged to Fuxin Mining Industry Group, while the planning period was 2008-2020. The total scale of exploitation was designed at  $18.20 \text{ Mt/a}$  and it would keep the balanced production for 20 years. The overall planning area includes eight existing coalmines (namely Wulong, Yima, Oolong, Haizhou

shaft, Qinghemen, Yiyou, Evergrande Company and Badaohao. While except the last one was in Heishan coalfield, the others were in Fuxin coalfield), two new planning mines (Fulin and Dongxin) and eight coal forecasting regions (namely Songjia, Jiucaitai, Xielintai, Leijia, the southern Badaohao, the western slope of Xialiaohe River and Banlamen ). The distribution of planning was shown in Fig. 1(a) in section 4.

### 3. Method of ecological vulnerability evaluation

#### 3.1. Ecological vulnerability indicator system

In PEIA, ecological vulnerability of mining area is the instability of inherent structure of ecosystem, which means that it has low resistance and high sensitivity to the exploitation of mineral resources and the recovery and regeneration abilities are poor after interference, resulting in irreversible changes in the structure and function of the ecological system. Combining the essence of mining's ecological vulnerability with the specific characteristics of ecological environment in Fuxin mining, the evaluation indicator system was established by incorporating 3 aspects and 9 indicators (see table 1). The weights of the indicators [17] were determined using AHP method, and the result has passed the consistency test.

Table 1. Ecological vulnerability indicator system in mining area.

Objective layer	Criterion layer	Weight	Index layer	Weight
Ecological Vulnerability Index(EVI)	Ecological Index(EI)	0.387	Slope	0.271
			NDVI index	0.483
			Groundwater	0.246
	Ecological Sensitivity Index (ESI)	0.410	Sensitivity of soil erosion	0.264
			Sensitivity of land desertification	0.523
			Sensitivity of soil salinization	0.211
			Isolation	0.397
	Landscape Structure Composite Index (LSCI)	0.203	Fractal Dimension	0.215
			Fragmentation	0.388

#### 3.2. Comprehensive evaluation

Every factor was attached to the professional layers by using GIS space analysis function, and then conducted the comprehensive evaluation based on the multiple factor weighted summation model. The comprehensive evaluation index model was described as follow:

$$A = \sum_{i=1}^n W_i \times C_i \quad (1)$$

where  $A$  is the total score of all factors;  $C_i$  is the score of factor  $i$ ;  $W_i$  is the weight of factor  $i$ .

#### 3.3. Ecological vulnerability classification

A systematic sampling was conducted by using grids to cover the whole region [18,19]. According to

the area and ecological characteristics of study region, it was divided into 247 grids with each size of 10 km×10 km. Using Zonal Statistic analysis of 9.2 ArcGIS, the EVI of each grid was calculated by the weighted superposition of EI, ESI and LSCI. The formula was as below:

$$EVI = \sum \frac{A_i}{A} (\alpha \times EI_i + \beta \times ESI_i + \gamma \times LSCI_i) \quad (2)$$

where  $EI_i$ ,  $ESI_i$  and  $LSCI_i$  are the values of EI, ESI and LSCI for the each basic unit in spatial analysis, respectively;  $\alpha$ ,  $\beta$  and  $\gamma$  are the weights of EI, ESI and LSCI, respectively.

The calculated EVI value of each grid was endowed to the geographical centre of grid as attribute value. Based on the grid system sampling, the Ordinary Kriging method of geographical statistics in ArcGIS was employed to interpolate mining eco-vulnerability index and the result was equidistantly divided into five levels, i.e. 1, 2, 3, 4, 5. The index was treated to be plane-shape and continuous ( see in Fig.1(a)).

### 3.4. Exploitation zoning of mining area

According to the results of ecological vulnerability evaluation, the superposition result of planning layout and vulnerability distribution was statistically analyzed by using overlay analysis function of GIS. Take the important ecological function area and legal protection zone into consideration, research area could be plotted into 5 kinds of zone: appropriate exploitation zone, optimized exploitation zone, moderate exploitation zone, restrictive exploitation zone, and forbidden exploitation zone.

## 4. Result and discussion

### 4.1. Distribution of ecological vulnerability classification

The result is shown in Fig.1(a). The Xialiaohe River Plain region was in lower vulnerability (1-3) because its flat terrain and good hydrothermal conditions, thus it was the main rice planting area of Liaoning province. However it faced the risk of soil salinization, but it was not serious. The higher vulnerability (4-5) area was located in Fuxin coalfield, Heishan coalfield and ZhangWu exploration region, which was due to its severe land desertification and soil erosion. The grading result was highly consistent with actual ecological situation in study area.

### 4.2. Overlapping analysis of the ecological vulnerability distribution and the planning layout

The spatial distribution of planning coalmines was overlapped with the grading result of eco-vulnerability, as shown in Fig.1(a). The results showed that the area where existing and planning coalmines were located had a high eco-vulnerability, which distributed in grade 4 and 5, but the area proportion is very small, occupying only 5.22% of whole planning area. This could indicate that the recent exploitation of mining have little effect on the whole vulnerability of the region. On the other hand, the large coal forecasting area was less vulnerable than the former area, mostly in level 3. Therefore, the continue exploitation in the future might exert great influence on overall vulnerability of the mining area.

### 4.3. Exploitation zoning of Fuxin mining

According to the classification results of ecological vulnerability, combining with the distribution of the main ecological function areas, urban planning scope and nature reserve zones in the mining area and

the characteristics of its function and vulnerability, Fuxin mining area was divided into 5 exploitation areas for the eco-function regionalization in the PEIA of Fuxin mining area, as shown in Fig.1 (b).

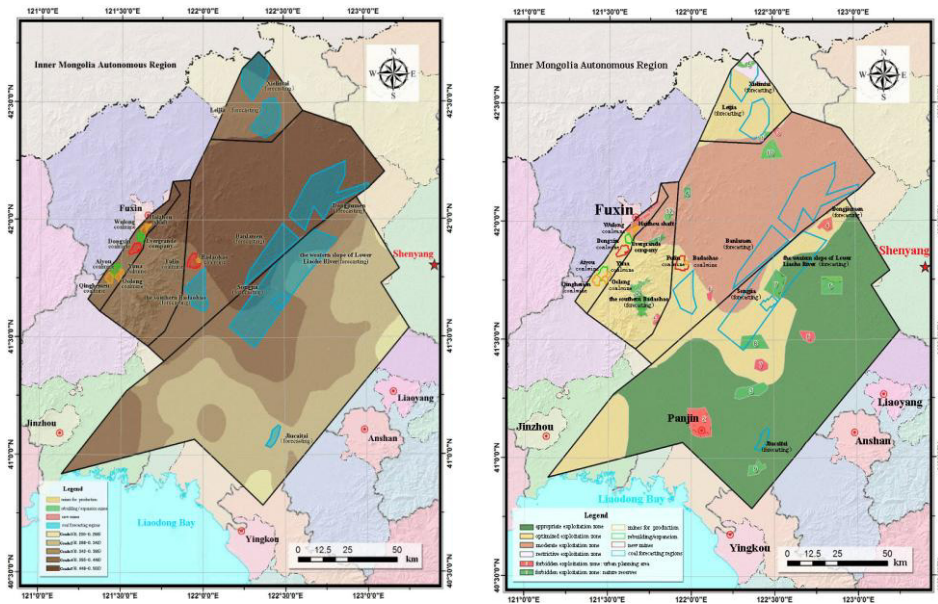


Fig. 1. (a) The superposition of planning layout and EVI classification result; (b) Exploitation zoning of Fuxin mining area

Appropriate exploitation zone was the area in vulnerability level 1–3 and not within the scope of the urban planning, nature reserves and forest parks. The coal mining activities in these areas have relatively small influence on eco-vulnerability of the mining area. However, it cannot be completely ignored because problems such as groundwater recession, surface subsidence, soil erosion, etc. which was caused by coal mining cannot be avoided generally, so it is still necessary to take measures for prevention.

Optimized exploitation zone was mostly in ecological vulnerability grade 4. The main area outspreads from two sides toward north along Yiwulv Mountain and a section of Liu river basin from Zhangwu to Xinmin. Recycling economy should be advocated in this zone, gangue should not a bit or as little as possible occupies the land. It is also necessary to strengthen the planting in ground industrial sites and their surrounding areas. Moreover, opencast mine should be forbidden in severe desertification area.

The region of ecological vulnerability grade 5 was divided as moderate exploitation zone, which is mainly located in Yiwujvshan area exclude Zhangwu northern areas. The ecological degradation in this zone is under high probability, therefore the mining intensity shall be restricted in the mining yield and range, and a comprehensive ecological management and recovery should be developed vigorously.

The northern Zhangwu exploration area was in the key construction region of "Three-North" Shelterbelt Program and faced the invasion of Horqin sandy Land. Therefore, it was restrictive exploitation zone. In principle, no mineral exploitation should be allowed and ecological recovery should be enhanced preferentially. However if the exploitation is demanded, a detailed investigation should be carried out in advance. Besides the exploitation planning and range should be strictly limited.

Finally, the urban planning scope, nature reserves and forest parks were regionalized as forbidden exploitation zone. In accordance with relevant state laws and regulations, exploitation of mineral resources is banned in these areas in order to avoid serious damages.



## 5. Conclusions

According to the zoning results of mining exploitation and planning content of Fuxin mining, several optimization and adjustment suggestions can be put forward. First, land reclamation and surface vegetation recovery should be promoted in the existing coalmines and new planning coalmines which are located in optimized exploitation zone, meanwhile the advanced technology of exploiting should also be adopted to reduce the ecological impact caused by mining. Secondly, stringent environmental protection measures should be implemented to reduce ecological destruction during resource exploitation in optimized exploitation zone. Thirdly, the scale and scope of exploitation in restrictive region should be strictly limited. At last, all types of resources exploration and exploitation activities should be prohibited in the western Xialiaohe River.

Overall, the results indicated the evaluation of ecological vulnerability in PEIA of mining area is necessary to guide the optimization and adjustment of plan. Therefore, ecological vulnerability evaluation based on GIS has significance to realize sustainable exploitation and utilization of coal resources by formulating and implementing an eco-friendly development plan.

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