Evaluation of City Ecological Vulnerability in Shanxi Province

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Abstract. Ecological vulnerability assessment is an important basis for comprehensive regional ecological sustainable assessment. Evaluating ecological vulnerability of Shanxi Province, a large coal mine province in China, is helpful for the restoration and construction of the ecological environment and sustainable cities. This paper establishes an ecological vulnerability evaluation index system based on ecological vulnerability research methods, calculates the weight of each indicator through the entropy weight method using the quantitative analysis to obtain the ecological vulnerability of each prefecture-level city, and evaluates the ecological vulnerability of Shanxi Province. The results show that Shanxi Province has a moderately fragile, fragile and extremely fragile land area of 77.39% of the total areas. Cities of Yangquan, Jincheng, and Luliang are in a mildly vulnerable grade. Cities of Taiyuan, Changzhi, Shuozhou and Linfen are at a moderate fragile level. Cities of Datong, Jinzhong, and Yuncheng are at a fragile level of strength. Xinzhou is at a very high level of fragility. Our results imply the status quo of the ecological environment in Shanxi Province is not optimistic.

1. Introduction

The ecological environment has been the basis for human survival and development. However, human activities have seriously affected the sustainable development of the ecological environment [1]. In recent years, the coordination between ecological environment construction and socio-economic development has become a common problem faced by China and the world. China has continuously strengthened the construction of ecological environment and increased investment in ecological environment governance. Ecological fragility is the result of the combined effects of internal factors and external disturbances of the ecology. Evaluating the regional ecological vulnerability can more clearly show the status of the ecosystem, and is helpful for the restoration and construction of the ecological environment [1, 2]. Shanxi Province is rich in mineral resources. It takes coal mining as its main industry and is a typical resource-based province. After a long period of resource mining, the amount of coal mine resources has been rapidly reduced, and the ecological environment has been severely damaged. Further, it has limited the pace of development due to intensive exploring of coal mines. Currently, the entire Shanxi Province is accelerating its transformation and becoming more sustainable. Moreover, Shanxi Province, as one of the provinces with obvious problems in China's ecological environment, has a strong research value and representativeness on the study of ecological vulnerability [2,3].
This study focuses on the ecological vulnerability of Shanxi Province. The main contents are as follows: First, the general situation of Shanxi Province is explained. Second, the ecological vulnerability analyses of Shanxi Province was performed. Third, the causes and characteristics of ecological vulnerability in Shanxi Province are illustrated. Fourth, the policy suggestions are given for improving ecological vulnerability.

2. Materials and methods

2.1. Study area.
Shanxi Province (34°34’-40°44’N, 110°14’-114°33’E) is located in the middle of the Yellow River Basin, on the Loess Plateau to the west of the North China Plain. The total area of the province is 156.7 thousand square kilometers, accounting for 1.6% of China's total area. Shanxi Province is a typical mountain plateau widely covered by loess. The area of mountains and hills accounts for 80.1% of the total area of the province, and the area of plains and river valleys accounts for 19.9% of the total area of the province. Most of the area is above 1500 meters above sea level. The highest point is Yedou Peak, the main peak of Wutai Mountain, with an altitude of 3061.1 meters, which is also the highest peak in North China. Shanxi Province has 11 prefecture-level cities, namely Taiyuan, Datong, Yangquan, Changzhi, Jincheng, Shuozhou, Jinzhong, Yuncheng, Xinzhou, Linfen, and Luliang.

2.2. Indicator selection
This study selected 17 specific indicators [4,5,6], the specific indicators are shown in Table 1. Among these 17 indicators, each indicator's response to vulnerability varied, and is divided into positive correlation indicators and negative correlation indicators. Positive correlation indicators represent the greater the ecological fragility, which are the more fragile the ecological environment, such as population density, natural population growth rate, groundwater quality value, and coal resource extraction, etc.; the negative correlation indicators represent the greater the ecological vulnerability, the weaker the ecological environment, such as forest coverage, per capita GDP, and ecological water consumption.

| Goal layer | Criterion layer | Elements layer | Index layer | Unit | Index properties | Weight |
|------------|-----------------|----------------|-------------|------|------------------|--------|
| Ecological pressure index | Ecological state index | Urban ecological vulnerability | Population density | people/km² | + | 0.0925 |
| Natural population growth rate | % | + | 0.0699 |
| Resource pressure | Coal resource extraction | million tons | + | 0.0551 |
| Economic state | GNPP | yuan | - | 0.0333 |
| Resource state | Water consumption per capita | stere | - | 0.0433 |
| Environmental state | Forest coverage rate | % | - | 0.0482 |
| Total area of crops | 1000 Ha | - | 0.0417 |
| Underground water quality score | point | + | 0.1828 |
| Days of standard air quality | day | - | 0.0383 |
| Production condition state | Proportion of primary industry | % | - | 0.0309 |
| Proportion of secondary industry | % | + | 0.0938 |
| Proportion of agricultural output value | % | - | 0.0275 |
| Economic response | Proportion of tertiary industry | % | - | 0.0512 |
| Investment in water conservancy, environment and public facilities management to GDP | % | - | 0.0656 |
| Input in scientific research, technical services and geological survey to GDP | % | - | 0.0383 |
| Ecological response | Annual afforestation area | ha. | - | 0.0367 |
| Ecological water consumption | Million square meters | - | 0.0530 |
2.3. Data sources and data processing
All data in this study mainly relates to the state of human economic and social development and the current status of the ecological environment in 11 cities in Shanxi Province. All were extracted in the Government Statistical Bulletin of Shanxi province. Because the 17 indicators have their own dimensions, the inconsistency between the dimensions and the magnitude of the indicators will cause the evaluation results to be inaccurate. Therefore, before the data is analyzed, the original data needs to be standardized. Due to the relative importance of these indicators, the weighted indicator was shown in Table 1. Further, to evaluate the ecological vulnerability in Shanxi province, in this study, quantitative analysis was used to evaluate the ecological fragility of cities in Shanxi Province [7]. The formula for calculating ecological fragility (G) is as follows:

\[
G = 1 - \frac{\sum_{i=1}^{n} P_i W_i}{\max \sum_{i=1}^{n} P_i W_i + \min \sum_{i=1}^{n} P_i W_i}
\]

Where \(P_i\) is the standardized value of each indicator, and \(W_i\) is the weight value of each indicator.

3. Result
Table 2 showed the ecological fragilities for all cities in Shanxi province. Yangquan has the smallest ecological vulnerability, with an ecological vulnerability of 0.32; Xinzhou has the largest ecological vulnerability, with an ecological vulnerability of 0.68.

Table 2. Ecological fragility of Shanxi Province

| Administrative unit | Taiyuan | Datong | Yangquan | Changzhi | Jincheng | Shuozhou | Jinzhong | Yuncheng | Xinzhou | Linfen | Luliang |
|---------------------|---------|--------|----------|----------|----------|----------|----------|----------|----------|--------|---------|
| Ecological vulnerability value | 0.53 | 0.60 | 0.32 | 0.51 | 0.45 | 0.50 | 0.59 | 0.57 | 0.68 | 0.53 | 0.33 |

Table 3. Ecological fragility classification table of Shanxi Province

| Level | Comprehensive evaluation grade | Ecological vulnerability | Administrative city | Area (km²) | Proportion of Shanxi Province total area (%) |
|-------|--------------------------------|--------------------------|---------------------|-------------|---------------------------------------------|
| I     | Mild fragile                   | G\leq0.45                | Yangquan, Jincheng, Luliang | 35084       | 22.26                                       |
| II    | Moderately vulnerable          | 0.45\leq G\leq0.55       | Taiyuan, Changzhi, Shuozhou, Linfen | 52103 | 33.06                                       |
| III   | Severe vulnerable              | 0.55\leq G\leq0.65       | Datong, Jinzhong, Yuncheng | 44690 | 28.36                                       |
| IV    | Extremely vulnerable           | G>0.65                   | Xinzhou             | 25180       | 15.98                                       |

Four grades of the magnitude of ecological vulnerability, i.e., mildly fragile, moderately vulnerable, severe vulnerable, and extremely vulnerable, were listed in Table 3. The ecological fragility of three cities in Shanxi Province is at mildly fragile level, namely Yangquan City, Jincheng City, and Luliang City, accounting for 22.26\% of the total area of Shanxi Province. Moderately vulnerable cities are Taiyuan City, Changzhi City, Shuozhou City, and Linfen City, accounting for 33.06\% of the total area of Shanxi Province. Severe vulnerable cities includes Datong City, Jinzhong City and Yuncheng City account for 28.36\% of the total area of Shanxi Province. Xinzhou City is the largest prefecture-level city in Shanxi Province, which accounts for 15.98\% of the total area of Shanxi Province. It was the city with extremely vulnerable grade. Figure 1 showed the distribution map of ecological vulnerability in Shanxi Province.
4. Discussion
Shanxi Province is a province with large mineral resources in China [2]. The high-intensity coal mining caused that the ecological environment is severely damaged, the soil in the mining area is deteriorated, and the vegetation landscape is missing with serious soil erosion. A large-scale collapse in the territory Land were caused by low land utilization. The rapid economic development has also caused the ecological environment to become increasingly fragile. Coordinating economic and social development and ecological environmental protection is still an important issue to be resolved, and achieving sustainable regional development is the primary task [4].

Due to the influence of geographical factors, the soil erosion in Shanxi Province has been one of the provinces with more serious soil erosion. The area of soil and water loss in the province reached 108,000 square kilometers, accounting for 69% of the total area of Shanxi Province. The abnormal fluctuations and the large seasonal precipitation factors have caused serious soil and water loss. These plays important impact on ecological vulnerability. In addition, Shanxi Province is one of the provinces with insufficient water resources in China. The main water resources are composed of surface water resources and groundwater resources. The main replenishment of water resources depends on regional precipitation. However, due to the geographical factors of Shanxi Province, the overall precipitation in

Figure 1. Distribution map of ecological vulnerability in Shanxi Province
Shanxi Province is seasonal [2]. Mostly concentrated in summer. The geographic monthly distribution of annual precipitation is extremely uneven, showing a downward trend from south to north and east to west. In 2017, the total water resources of Shanxi Province was 13.02 billion cubic meters, accounting for 0.45% of the country's total water resources. The amount of water resources ranks fifth among the provincial administrative regions in the country. The annual average precipitation is 579.5mm, which is lower than the national average. Due to the mineral industry as the dominance, the discharge of industrial wastewater has damaged water resources well. Further, some water resources have been contaminated due to the development of coal mines. The surface has been damaged, and there have been surface cracks and subsidence, causing water loss.

Furthermore, due to the development of mineral resources as the leading industry for several decades [2], the previous "destruction before treatment" caused the ecological environment of Shanxi Province to be damaged to varying degrees. The mining of coal mines causes the ground to collapse and collapse. The collapsed land is a serious geological disaster, and it will cause new geological disasters such as landslides and debris flows. Nationally, Shanxi Province has the largest and largest area of subsidence, accounting for more than two-thirds of the nation’s subsidence.

5. Conclusion
The overall status of the ecological environment in Shanxi Province is not optimistic. The fragile ecological environment has limited the pace of economic development in Shanxi Province. It is necessary to adjust the three major industrial structures, appropriately increase investment in the ecological environment, strengthen the management and construction of the ecological environment, restore the good state of the ecological environment, promote the overall transformation of provinces and cities, and ensure the unified development of Shanxi’s economy, society, and ecology.

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