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Original Research

Construction of Ecological Security Pattern Based on Ecological Sensitivity Assessment in Jining City, China

Zhou Yao[1,3]*, Chang Jiang[1,3], Chen Zong-Cheng[2,3], Zhou Shi-Yuan[1], Zheng Guo-Dong[2,3]**

[1]Institute of Architecture and Urban Planning, China University of Mining and Technology, Xuzhou, 221116, China
[2]Shandong Provincial Lunan Geology and Exploration Institute (Shandong Provincial Bureau of Geology and Mineral Resources No.2 Geological Brigade), Jining, 272100, China
[3]Technology Innovation Center of Restoration and Reclamation in Mining Induced Subsidence Land, Ministry of Natural Resources, Jining, 272100, China

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Abstract

The coal mining activities and urbanization of China's coal resource-based cities have caused many ecological and environmental problems that cannot be ignored, seriously threatening regional ecological security. Constructing ecological security patterns (ESP) is an effective way to balance ecological protection, coal mining activities and urbanization. This study aims to take Jining City as an example, and propose a new ecological sensitivity assessment (ESA) method based on a combination of qualitative and quantitative analysis, and then propose a new ESP construction method based on ESA, including the method of determining ecological source patches and their grades through ESA and patch connectivity evaluation, the method of extracting ecological corridors based on the minimum cumulative resistance (MCR) model, and the method of determining the grade of ecologically sensitive areas based on ESA, and then constructing ESP and "two core, three corridors and multiple points" ecological network planning. And then guide the urban development through ESP and ecological network planning.

Keywords: Ecological Security Pattern (ESP), Ecological Sensitivity Assessment (ESA), Jining City

Introduction

As an important non-renewable natural resource, coal has a great impetus to the rapid development of China's national economy and industrialization. However, coal mining inevitably poses a threat to ecological security that cannot be ignored [1-4]. Ecological security is usually defined as a state in which the structure and function of an ecosystem are complete, healthy, and stable enough to protect species and human habitats, protect the migration of wild animals, and provide human beings with sufficient ecological services to

*e-mail: 3310bj@163.com
**e-mail: kssthj@163.com

support human life and socioeconomic activities [5-7]. However, in coal resource-based cities, serious ecological and environmental problems frequently occur, such as landscape fragmentation, decreased connectivity, land desertification and salinization, groundwater table decline, soil erosion, vegetation degradation, biodiversity loss, and land subsidence [2, 7-8]. In 2015, coal resources once accounted for about 70% of China's energy consumption, and coal production from large coal bases accounted for 93% of China's energy consumption [3, 8-9]. Large-scale coal mining activities not only bring economic development, but are also one of the main reasons for the degradation of ecosystem health [2, 10].

Ecological security pattern (ESP) is an important tool for maintaining the normal function of the ecosystem and ensuring ecological security [5, 11-13]. It can be understood that the ecological security pattern (ESP) is one of the tools to maintain and ensure ecosystem health (EH). There are many tools or methods to maintain and ensure ecosystem health (EH). ESP is undoubtedly one of the important methods. The ecological security pattern was constructed to identify the "ecological source patch-ecological corridor" spatial pattern, which consists of key elements involved in maintaining ecological processes [6, 11, 14], such as ecological source patches and ecological corridors. ESP are ecological networks constructed based on landscapes and taking into account landscape patterns and ecological processes and functions [10-11, 14]. Optimizing ESP aims to quantify the levels of relatively important ecological source patches and ecological corridors. And it can achieve effective land space planning and management, maximize the ecological security of coal resource-based cities, maintain the integrity of the ecosystem structure and process, and then promote ecosystem health.

The concept of ESP originated from urban ecological planning [14]. It shares an ultimate goal with ecological networks, green infrastructure and urban growth boundaries [6]. All of these approaches focus on resource conservation and ecological network construction, and are considered important tools for maintaining ecosystem health. ESP is to maintain important ecological processes and functions by protecting important ecological patches and corridors, thereby maintaining ecosystem health [5, 11, 14]. ESP can not only meet the theoretical requirements of ecological security research on the rational regulation of ecological processes, but also serve as a passive adaptive way to manage the bottom-line ecological security role of natural ecosystems [6]. ESP is mainly composed of three steps: identifying ecological source patches, constructing ecological resistance surfaces and extracting ecological corridors.

The first step is to identify ecological source patches and evaluate their grades. Ecological source patches are an important part of ESP, supplying ecosystem functions, promoting ecosystem dynamic processes and ensuring ecosystem structural integrity [6, 10], providing good multiple ecosystem services. There are two main methods for identifying ecologically sourced patches. One is to directly select nature reserves, scenic areas, large areas of ecological land and species habitats as ecological source patches [15-16]. Another approach is a more quantitative and practical approach. Ecological source patches are identified by evaluating the importance of regional ecological patches, landscape connectivity and service value from the perspectives of ecological suitability, ecological sensitivity, ecological risk, etc [6, 12-13, 17]. However, the current ecological source patch determination methods mainly adopt a purpose-oriented evaluation system. It is not a complete system, and there are subjective problems in its determination, such as the use of the PSR framework for subjective selection of evaluation indicators, the lack of quantitative tests to verify its rationality, and the subjective method of using AHP to determine weights. These can lead to biased judgment, the principal component analysis method can determine the indicators and weights, but it still lacks the connection with the final goal, and the results will still have errors. Based on previous research, this paper proposes a new method for identifying ecological source patches, that is, aiming at ecosystem health, using PSR framework to qualitatively analyze the influencing factors affecting ecosystem health, and then using spatial econometrics to quantitatively test the driving force factors to obtain the important driving factors and their weights that affect ecosystem health. Based on this, ecological sensitivity assessment is established, and then ecological source patches are identified. This qualitative and quantitative method overcomes the shortcomings of relying only on qualitative analysis before, and has a great improvement. The evaluation of ecological source patch level generally adopts the landscape connectivity evaluation, namely Inter Index of Connectivity (IIC) and Probability of Connectivity (PC).

The second step is to construct the ecological resistance surface. Ecological resistance surfaces represent landscape units or habitat patches that vary in ease or the level of disturbance a species will encounter when moving between them. This can effectively describe the impact of landscape heterogeneity on ecological processes [6, 18]. The most widely used method is the ecological resistance coefficient based on land-use type. Using land-use types, topographic factors and habitat quality to determine ecological drag coefficients [13, 19]. Although this method is universal, it is necessary to consider the actual local conditions in the setting of the ecological resistance coefficient. For example, in coal resource-based cities, coal mining activities have formed a large number of coal mining subsidence areas, the heavy coal mining subsidence area will accumulate water, and then form a water and land ecosystem. Generally, the water area has a certain resistance value. However, in this case, the water area will become a potential corridor for water and land ecological patches, and the resistance value of water should be set small, similar to the resistance value of grass.

The final step is to extract ecological corridors. Ecological corridors are the transmission of ecological flows, ecological processes and ecological functions within an area [6]. They can be extracted using a variety of methods [13, 16, 20], but the minimum cumulative resistance model (MCR) is the most commonly used. The theory of MCR model was applied to calculate the cost required for species to migrate from source to destination. It can not only express the potential possibility and trend of species movement, but also simulate the paths formed by different ecological flows across different landscape surfaces through MCR surface [6, 21-22]. At the same time, it also takes into account the heterogeneity and connectivity of the landscape and models the corridor orientation [6, 12, 23].

Ecosystem health (EH), which is based on ecosystem services and ecological functions and aims to meet human production and living needs, provides theoretical goals and practical basis for ESP. This clarifies the objectives of ESP optimization from an ecological perspective: first, identify key ecological patches, maintain process stability, and protect ecological security; Second, on the basis of ensuring ecosystem health, evaluate the grades of important urban ecological source patches, strengthen high-quality ecological space, and promote the optimization of urban ecological functions.

The purpose of this research is to explore the method of constructing ecological security pattern based on ecological sensitivity assessment, taking Jining City, Shandong Province, China as an example. To this end, consider the following core issues: 1. Construct a new ecological sensitivity assessment method based on the combination of qualitative and quantitative analysis. 2. Based on ecological sensitivity assessment, combined with landscape connectivity evaluation and MCR model, a new method of ecological security pattern is constructed, including the method of determining the ecological corridor level, the method of determining the ecological patch level and the method of determining the ecological sensitive area level. 3. Discuss ecological network planning. 4. Discuss the urban development strategy of Jining based on ecological security pattern and ecological network planning.

Methods

Study Area and Data

Jining City (34°25'~35°55' N, 115°54'~117°06' E) is located in Shandong Province, China. It is a medium-sized city developed by relying on coal resources. It is currently in the stage of a mature coal resource city, with coal-bearing area accounting for 45% of the city's total area. The city's coal reserves are 15 billion tons, accounting for 53.8% of Shandong Province, and it is one of China's 14 major coal bases. The large-scale subsided land has brought a series of ecological and social problems, resulting in the abandonment of many rural and mining areas. Now the subsided land in Jining City is developing at a rate of more than 2,000 ha per year, and most of the subsided land is concentrated in Jining Metropolitan Area (JMA). With the expansion of the city, the coal mining area has changed from the original suburban area to the urban area, which

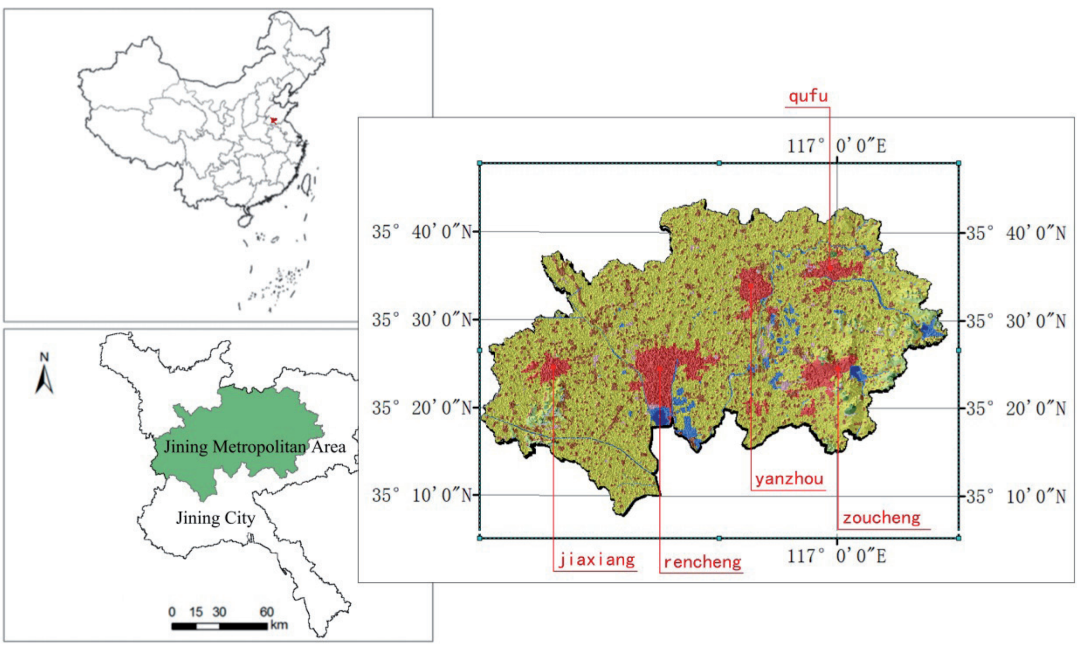

Fig. 1. Jining Metropolitan Area (JMA).

severely restricts the expansion of the city and faces the dilemma of no land available. JMA contains five county-level cities: Jiaxiang, Rencheng, Yanzhou, Qufu and Zoucheng. The total area of the metropolitan area is 355125 ha (Fig. 1). The current permanent population of the metropolitan area is 3.93 million (Data as of the end of 2020).

The main data used in this paper are: land-use and NDVI data in the JMA in 2020. Land-use data are extracted from Landsat (8) OLI remote sensing images (30-meter resolution) in 2020. These images were downloaded from the United States Geological Survey (USGS) (http://landsat.usgs.gov/index.php). Firstly, the OLI image is preprocessed, based on the resource and environmental science and data center platform of the Chinese Academy of Sciences, through the different images of the spring, summer and autumn of the year, human-computer interaction interpretation, field sampling surveys and high-precision images are used to verify the images, and finally, the synthesis is performed, and the overall accuracy is about 85%, and the maximum likelihood method was used for classification on the ENVI5.3 platform, and finally the land-use type database of each period in the JMA was obtained. According to research needs, the land-use types of JMA are divided into cultivated land, forest land, water area, grassland, urban and unused land (Fig. 2).

Research Framework

The construction of ESP is mainly divided into the following five steps (Fig. 3):

(1) Ecological sensitivity assessment

First, the dependent variable, that is, the ecosystem health value, is obtained through ecosystem health assessment. The independent variables were obtained by qualitative analysis of spatial drivers of ecosystem health (EH) through the PSR framework. Then based on the spatial econometrics method, stata software is used to quantitatively analyze and test the independent variables for the dependent variables. It was found that not all indicators were spatially correlated with ecosystem health, and the insignificant indicators were excluded to obtain the results of quantitative analysis (Table 5). Based on the 6 indicators and their weights (correlation coefficients) that are related to ecosystem health (EH) passed by the quantitative test (significance test), the data of the 6 indicators are superimposed, and the superimposed results (ecological sensitivity assessment) are used as the basis for the selection of ecological source patches.

(2) Identification and grade assessment of ecological source patches

Based on the ecological sensitivity assessment and classification, compared with the land-use type map, according to the previous research results and the ecological environment characteristics of JMA, the area threshold (greater than 50 hectares) was set to select the ecological source patches. On the basis of the identified ecological source patches, and referring to the previous research results and practical experience [24], the landscape connectivity parameters were selected and Conefor 2.6 software was used to evaluate the connectivity of ecological source patches. According to the evaluation results, ecological patches were classified into grades in stages.

(3) Identification and classification of ecological corridors

Through the determination of resistance factors and coefficients, a spatial resistance surface is constructed based on ArcGIS, and a potential ecological corridor with the lowest flow cost is generated according to the minimum cumulative resistance model (MCR) according to the spatial resistance surface. Combined with the grade of ecological patches, the ecological corridors are summarized and graded.

(4) Classification of ecologically sensitive areas

According to the ecological sensitivity assessment, the ecologically sensitive areas are classified into grades outside the ecological restraint area.

(5) Construction of ecological security pattern

According to the grades of ecological patches and corridors, and the grades of ecologically sensitive areas,

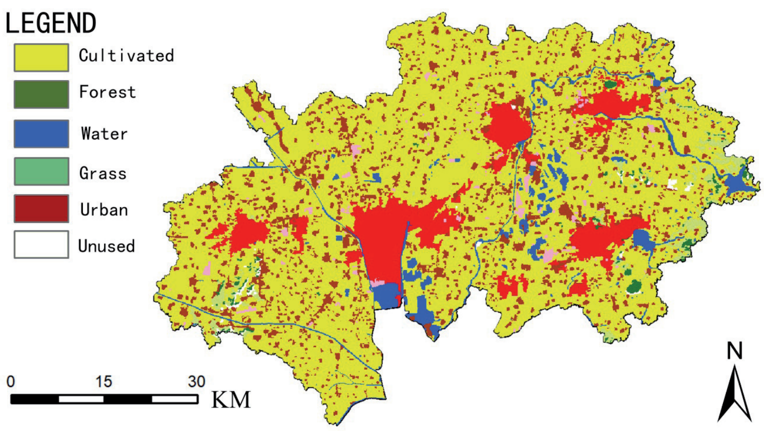

Fig. 2. Land-use maps of JMA in 2020.

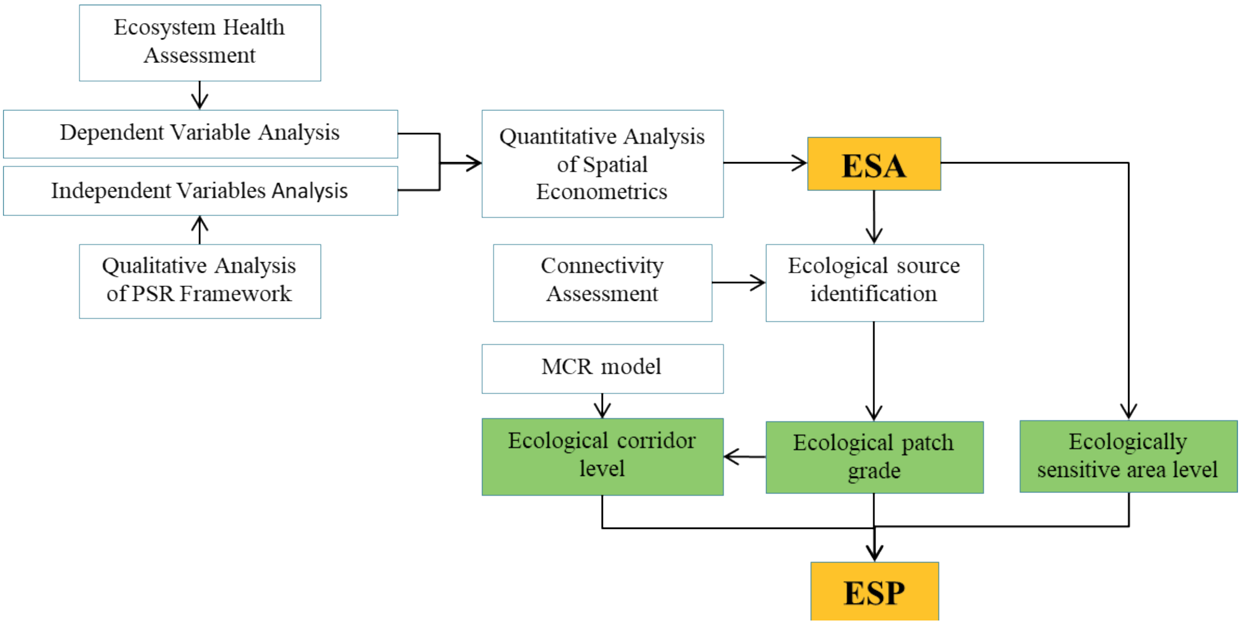

Fig 3. ESP construction method.

the ecological security pattern and ecological network planning are constructed in stages (short-term and long-term), and then urban development is guided.

Ecological Sensitivity Assessment

Ecological sensitivity assessment is to use quantitative evaluation methods to analyze the natural ecological stability in the region, and then optimize ESP [25]. The ecological sensitivity overlay analysis theory can be traced back to the ecological planning method proposed by McHarg (McHarg, 1969), an example can be traced back to Sinton D's dissertation in 1997 [26]. As a result, related research at home and abroad continues. However, the selection of evaluation indicators usually adopts subjective methods, such as various frameworks such as nature-society-ecology, PSR, etc. There are certain advantages, but the lack of objective verification links will inevitably bring errors [27]. Based on previous research, this study attempts to obtain indicators and their weights by adding objective verification links.

The spatial driving force of ecosystem health (EH) is qualitatively analyzed through the PSR framework, and the results of the qualitative analysis are quantitatively analyzed and tested through spatial econometric methods, and it is found that not all indicators are spatially related to ecosystem health, remove the insignificant indicators, and get the results of quantitative analysis (Table 6). This result is the basis of ecological sensitivity assessment.

Dependent and Independent Variables

The dependent variable and independent variable data in this study were extracted by the grid method, and the grid of the study area was calculated using the grid method in ArcGIS software (the grid size was 2×2 km, and a total of 1017 grids were generated in the study area). In this study, 2×2 km window was used to calculate the dependent variable (EH) and independent variable values in JMA. The window size is appropriate because it represents an appropriate distance to reflect the unique spatial characteristics of JMA landscape pattern. To demonstrate the 2×2 km window, we also tested several other window sizes.

Dependent Variable

In previous studies, three indicators were always used in traditional EH: vitality, organization, resilience, and ecosystem services were not always mentioned as indicators, not even at the landscape scale [28]. However, it is well known that human well-being can actually be improved by improving ecosystem services [29], so it is necessary to ensure coupling between human and natural systems. Recently, some related scholars [30-31] extended the framework to "vitality-organization-resilience-ecosystem services". The author recognizes the new framework system and adopts the new framework system in this study, that is, the evaluation of ecosystem health (EH) from two aspects of ecosystem physical health (EPH) and ecosystem services (ES). The formula can be expressed as:

$$EH = \sqrt[2]{EPH \times ES} \tag{1}$$

where EH = ecosystem health, EPH = ecosystem physical health, ES = ecosystem's services.

Ecosystem health values are obtained in three steps.

The first step is to extract the relevant data by dividing the land-use into a grid. Then, Fragstats4.2 software is used to calculate the relevant landscape index. Finally, the VOR model is used to evaluate ecosystem physical health (EPH). The VOR model is divided into ecosystem vigor, ecosystem organization and ecosystem resilience.

The second step is to improve the evaluation method of ecosystem service value in the study area based on land-use data, estimate the service value.

In the third step, the ecosystem health (EH) value is calculated through the previous calculation results of ecosystem physical health (EPH) and ecosystem service (ES) and formula (1) (the grid size is 2×2 km, a total of 1017 grid), use the data normalization formula to normalize the values in Excel (0-1) to obtain ecosystem health (EH) values (1017).

Independent Variable

The selection of independent variables usually adopts the "pressure-state-response (PSR)" framework for qualitative classification. Recently, some scholars have expanded the selection of independent variables from different aspects, such as subjective and objective aesthetic indicators [32], human body heat comfort and temperature indicators [33]. and has been explored in terms of 3D city models [34]. This study focuses on the relationship between independent variables and dependent variables (ecosystem health), so subjective and objective aesthetic indicators are not discussed for the time being. Due to the small area of the study area, the fluctuation of temperature and precipitation is not large, so it will not be discussed for the time being. Considering the characteristics of coal resource-based cities, the range of coal mining subsidence areas, the distance from industrial and mining land, and the distance to wetland park in coal mining subsidence area have been added. At the same time, other indicators are also strongly affected by coal mining activities, such as transportation framework, population density and lakes. Therefore, the selection of independent variables in this study can represent the characteristics of coal resource-based cities, so the "pressure-state-response (PSR)" framework is still used to qualitatively classify the spatial driving forces affecting the evolution of ecosystem health.

The PSR framework proposed by the United Nations Agency for Economic Cooperation and Development (OECD) and the Environment Programme (UNEP) has been widely used in previous studies. First proposed by Rapport and Friend (1979), its main purpose is to analyze the relationship between ecosystem pressure, status and response, and this method has been widely used in ecosystem health assessment [35]. In this study, we employed a "stress-state-response (PSR)" framework to qualitatively categorize the spatial drivers affecting the evolution of ecosystem health. This framework is often used to reflect the interactions between humans and the environment in order to classify and evaluate the spatial driving forces that affect the evolution of ecosystem health by considering both human disturbance and protection of ecosystem health (Table 1). The values of each independent variable were obtained by the grid method (the grid size was 2×2 km, with a total of 1017 values).

Pressure Factors (P)

"Pressure" represents external pressure on ecosystem health (EH). The external pressure on the ecosystem health (EH) of coal resource-based cities is mainly the influence of coal resource mining and its socio-economic factors. Due to the cyclical nature of resource development, the development of coal resource-based cities has cyclical characteristics. In the rapid development stage of coal resource-based cities, coal mining greatly promoted the development of the city; after entering the mature development stage, the development slowed down, diversified industrial development began to appear, and the ecological environment resistance gradually increased; in the recession stage, the coal industry declined , resource depletion and deterioration of the ecological environment have become huge obstacles [36]. If the industrial structure cannot be adjusted in time in the mature development stage, it will show a decline trend; but before the decline of resources, by digging new economic growth points and support points, it can avoid the risk of the city disappearing after the resources are exploited [37]. As a typical mature coal resource-based city, coal resource mining activities and urbanization have a dual impact on the ecological environment and land-use structure of JMA, which in turn affects ecosystem health (EH) and human well-being. Therefore, from the aspect of pressure, land-use change (P1), distance to coal mining subsidence area with accumulated water (P2), distance to coal mining subsidence area (P3), distance to national highway, provincial highway, railway and city center (P4, P5, P6, P7), distance to industrial and mining land (P8), distance to rural settlements (P9), and population density (P10) are selected. This is of great significance to analyze the change law of ecosystem health (EH) in JMA.

(1) Land-use change

Land-use change is affected by human production and life, and will have an impact on ecosystems health [38]. Jining is not only a coal resource-based city, but also an important agricultural production base. Agricultural production is affected by both urbanization and coal mining activities. Therefore, this study gives priority to changes in cultivated land, forest land, grassland and water areas (including accumulated water in coal mining subsidence areas) in land-use types, and uses the order of the ecosystem service (ES) equivalent factor scores to pay for the land-use grades value.

(2) Influence of coal mining activities

Excessive coal mining will bring serious ecological and social problems to cities, such as ground subsidence and air pollution. Among them, coal mining subsidence is the biggest problem facing coal resource-based cities at present, which in turn poses a serious threat to the local society, economy and ecological environment. The dynamic changes of coal mining subsidence areas in coal resource-based cities and their industrial and mining land are important factors that affect the changes of ecosystem health. Therefore, this paper selects the distance to coal mining subsidence area with accumulated water (P2), the distance to the coal mining subsidence area (P3), and the distance to the industrial and mining land (P8) as the factors that influence the change of ecosystem health (EH) by coal mining activities.

(3) Traffic factors

As an important factor influencing the spatial evolution of urban land-use, transportation affects changes in ecosystem health (EH). The transportation network is the basic skeleton of the city, which is oriented to the development of the city, and at the same time, it also causes many negative impacts on the ecosystem. In this paper, distances from national highways, provincial highways, railways, and urban centers (P4, P5, P6, and P7) are selected as the factors that affect the changes in ecosystem health, and the relationship among them is discussed.

(4) Demographic factors

Demographic factors influence human demand for various ecosystem services, and one of the drivers of demand for the ecosystem's ability to provide these services. Humans need to obtain necessary material resources from natural ecosystems, so the rapid population growth will directly affect factors such as land-use change. Therefore, the distance from rural settlements (P9) and population density (P10) were selected as the factors affecting the changes of ecosystem health by population factors.

Status Factors (S)

"State" represents the natural state of ecosystem health (EH). According to the main problems faced by the study area, this study mainly focuses on the natural geographical state.

The natural geographical state includes natural geographical conditions such as topography, vegetation, climate and hydrology. Among them, topographic factors are mainly reflected in DEM (S2), slope (S3) and aspect (S4). Vegetation factors are mainly reflected in NDVI (S1). The hydrological factors are mainly reflected in the distance from the river (S5), and the distance from the lake and wetland (S6). Climate factors mainly include changes in precipitation and temperature, but the study area is small, and the fluctuation range of temperature and precipitation is small, with consistent characteristics, so this study does not consider the impact of temperature and precipitation on ecosystem health for the time being.

Response Factors (R)

"Response" represents human protection measures to improve adverse effects, combined with the characteristics of the study area, mainly for coal mining activities and urbanization responses, including distance to wetland park in coal mining subsidence area (R1), and distance to important ecological control zone (R2) and distance from ecological red line control zone (R3).

Quantitative Analysis of Spatial Drivers of Ecosystem Health

Research Methods

Regarding the choice of research methods, due to the spatial correlation between spatial drivers and ecosystem health (EH), the general statistical methods cannot be used for correlation analysis and regression analysis, which will ignore the spatial correlation (spatial dependence). Because adjacent units are more likely to be physically, socially, and economically connected [39]. Ecosystem health in a spatial unit is affected not only by individual elements, but also by elements in adjacent units. That is, if the ecosystem health of surrounding units deteriorates, the ecosystem health of intermediate units may deteriorate [40]. Meanwhile, drivers of ecosystem health consistently exhibit spatial autocorrelation. Neighborhood factors and spatial autocorrelation should be considered when understanding the drivers of ecosystem health. However, traditional statistical methods, including geographic detector models [41], grey relational analysis [42], logistic regression [43], multiple regression models [44], usually ignore spatial dependence effects. This restricts the coordinated governance of land-use and ecosystem protection to a certain extent [45].

Therefore, using the method of spatial econometrics to analyze is in line with the actual situation, and measure its spatial correlation and its spillover effect. This paper selects Stata and GeoDa software for spatial econometric analysis, and SPSS and Excel for auxiliary data processing. Spatial econometric analysis was carried out on the pressure factors, state factors and response factors under the PSR framework of ecosystem health in JMA.

(1) Measurement model setting

Commonly used spatial econometric models include spatial error model (SEM) and spatial autoregressive model (SAR):

$$
\begin{aligned}
Y_{it} &= \alpha + \beta_j X_{it} + \varepsilon_{it} \\
\varepsilon_{it} &= \lambda \varepsilon_{it} + \theta_{it}
\end{aligned}
\tag{2}
$$

$$
Y_{it} = \alpha + \rho W Y_{it} + \beta_j X_{it} + \varepsilon_{it} \tag{3}
$$

Table 1. Spatial drivers affecting ecosystem health.

	Index level	Data Sources
	Land-use change (P1)	Extracted from land-use data.
P	Distance to coal mining subsidence area with accumulated water (P2)	According to the data of the coal mining subsidence area with stagnant water, it is extracted with the Euclidean distance tool.
	Distance to coal mining subsidence area (P3)	Extracted with Euclidean distance tool based on coal mining subsidence area data.
	Distance to national highway (P4)	Extracted with Euclidean distance tool based on national highway data.
	Distance to provincial road (P5)	Extraction with Euclidean distance tool based on provincial road data.
	Distance to railway (P6)	Extracted with Euclidean distance tool based on railway data.
	Distance to city center (P7)	Extracted with Euclidean distance tool based on city center data.
	Distance to industrial and mining land (p8)	Extraction with Euclidean distance tool based on industrial and mining land data.
	Distance to rural settlement (P9)	Extracted with euclidean distance tool based on rural settlement data.
	Population density (P10)	/
S	NDVI (S1)	Extracted from land-use data.
	DEM (S2)	/
	Slope (S3)	Extraction from DEM data.
	Aspect (S4)	Extraction from DEM data.
	Distance to a river (S5)	Extracted with Euclidean distance tool based on river data.
	Distance to lake or wetland (S6)	Extracted with Euclidean distance tool based on lake wetland data.
R	Distance to wetland park in coal mining subsidence area (R1)	Extracted by Euclidean distance tool according to the data of wetland park in coal mining subsidence area.
	Distance to important ecological control zone (R2)	Extracted with Euclidean distance tool based on the data of important ecological control areas.
	Distance from ecological red line control zone (R3)	Extracted with Euclidean distance tool according to ecological red line data.

Among them, (2) is the spatial error model, (3) is the spatial autoregressive model; i and t refer to the grid and year respectively; Y is the EH level, W is the spatial weight matrix, and WY is the lag term of the dependent variable; X is the independent variable; α is the constant term; ρ is the lag term coefficient; β_j is the estimated coefficient of the independent variable; ε is the random interference term. For the specific model selection, this paper makes a judgment through the LM (Lagrange multiplier test).

(2) Spatial weight matrix setting

In order to ensure the stability of the conclusion, this paper sets two spatial weight matrices of geographic adjacency and geographic distance in the empirical analysis. The geographic adjacency matrix is assigned by the principle of car adjacency, and the value of two grids adjacent to each other is 1; otherwise, it is 0. Its setting principle is:

$$W_{ij} = \begin{cases} 0 & \text{If grid i is not adjacent to grid j} \\ 1 & \text{If grid i is adjacent to grid j} \end{cases} \quad (4)$$

The geographic distance matrix is constructed using the inverse of the two grid distances. The specific matrix settings are as follows:

$$W_{ij} = \begin{cases} 0 & if\ i = j \\ 1/d_{ij} & if\ i \neq j \end{cases} \quad (5)$$

Among them, w_{ij} is the spatial weight matrix, and d_{ij} is the distance from grid i to grid j.

Influencing Factors

Based on the core idea of geographic spatial difference, and considering the significant global and local spatial autocorrelation of the comprehensive

Table 2. Explanatory variable and explained variable.

	Variable name	Variable symbol
Explained variable	Ecosystem Health	EH
Explanatory	Land-use change	(P1)
Variables	Distance to coal mining subsidence area with accumulated water	(P2)
	Distance to coal mining subsidence area	(P3)
	Distance to national highway	(P4)
	Distance to provincial road	(P5)
	Distance to railway	(P6)
	Distance to city center	(P7)
	Distance to industrial and mining land	(P8)
	Distance to rural settlement	(P9)
	Population density	(P10)
	NDVI	(S1)
	DEM	(S2)
	Slope	(S3)
	Aspect	(S4)
	Distance to a river	(S5)
	Distance to lake or wetland	(S6)
	Distance to wetland park in coal mining subsidence area	(R1)
	Distance to important ecological control zone	(R2)
	Distance from ecological red line control zone	(R3)

index of ecosystem health (EH) quality in JMA, a cross-sectional spatial econometric model was used to empirically analyze its influencing factors, in the stata software, through the regression analysis of the cross-sectional data, to explore the main spatial influencing factors. According to Table 1, a cross-sectional spatial econometric model was constructed (Table 2). The explanatory variable is ecosystem health (EH), and the explanatory variables are the three spatial drivers of pressure -state-response.

Multicollinearity Test

The correlation between independent variables is ubiquitous, in order to prevent "serious multicollinearity" of independent variables, a multicollinearity test (>10) is required. After the stata software test, p3 and r1 in 2020 have serious collinearity. By deleting p3 and r1, the results in 2020 in Table 3 are obtained (the VIF of all the remaining data are below 10). It shows that the coal mining subsidence area has serious collinearity with other indicators, and the wetland park in coal mining subsidence area has serious collinearity with other indicators.

Ecological Source Patch Grade Evaluation

In this paper, the landscape connectivity index (IIC and PC) was selected as the basis for evaluating the importance of ecological source patches, and the area ratio dA value was used as a comparison to evaluate the importance of patches.

(1) Evaluation method of importance of ecological source patches

The location of each patch in the ecosystem and its impact on landscape ecological processes are important factors in determining its ecological potential. In this study, changes in ecological source patch connectivity can reflect the importance of each patch in maintaining ecosystem connectivity.

Inter Index of Connectivity (IIC)

$$dIIC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{a_i a_j}{1+nl_{ij}}}{A_L^2} \quad (6)$$

Among them, n is the total number of patches, a_i and a_j represent the patch area, nl_{ij} is the number of connections, and A_L is the total area of the study area.

Table 3. Multicollinearity test results.

Variable	VIF	1/VIF
P1	1.15	0.8713
P2	2.67	0.3745
P3	/	/
P4	2.21	0.4521
P5	1.35	0.7421
P6	4.72	0.2117
P7	5.76	0.1737
P8	1.46	0.6866
P9	1.21	0.8284
P10	1.11	0.9042
S1	1.64	0.6116
S2	2.50	0.3999
S3	1.08	0.9286
S4	1.01	0.9892
S5	1.72	0.5804
S6	1.65	0.6076
R1	/	/
R2	3.17	0.3154
R3	2.67	0.3746

When the value of dIIC is 0, it indicates that the plaques are not connected, and when the value is greater than 0, it indicates that the plaques are connected.

Probability of Connectivity Index (PC)

$$dPC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} a_i a_j P_{ij}^{*}}{A_L^2} \tag{7}$$

Its a_i and a_j represent the patch area, respectively, A_L represents the total area of the study area, and P^*_{ij} is the species diffusion probability. When the value of dPC is 0, it indicates that the patches are not connected, and when the value is greater than 0, it indicates that the patches are connected. The larger the value, the stronger the ability to maintain the connectivity of the landscape.

According to the study area, based on the Conefor software platform, referring to the results of previous studies [46], 10 km was selected as the threshold of patch connectivity.

Results

Ecological Sensitivity Assessment Spatial Econometric Analysis

Before model estimation, an LM test was first performed on the results of ordinary least squares (OLS) regression to judge which model was appropriate (Table 4). Only the spatial error model (SEM), whose LM value and robust LM value both passed the 1% significance test, showed that the geographic distance matrix and the spatial error model were more suitable.

According to Table 4, LM test to judge, the use of spatial error model (SEM) is appropriate. Therefore, this paper focuses on the interpretation and analysis of the estimation results of the spatial error model. The regression results from the 2020 spatial error model are shown. Only P1, P4, p5, S1, S6 and R3 passed the significance test for the spatial drivers of ecosystem health.

(1) The influence coefficient of land-use (P1) reached 0.0609, and was positively correlated, with a significance level of 1%. After analyzing the reasons, the scoring level is sorted according to the size of ecosystem service value coefficient, namely water > forest > grass > cultivated >unused >urban, reflecting the impact of ecosystem service value on land-use.

(2) The influence coefficients of the distance from the national highway and the provincial highway (P4, P5) are 0.0653 and 0.0956, which are positive correlations, and the significance level reaches 1%. Analyzing the reasons, away from traffic roads, the healthier the ecosystem is. This is also the conclusion verified by many scholars. Here, this general law is also verified.

Table 4. LM test of cross-section spatial measurement model.

	Geographic adjacency matrix		Geographic distance matrix	
LM test	Statistics	P value	Statistics	P value
SEM-LM	4.6852	0.03042**	16.4457	0.00005***
SEM-Robust LM	0.0562	0.81259	0.3859	0.53445
SAR-LM	4.8966	0.02691**	16.2363	0.00006***
SAR-Robust LM	0.2676	0.60494	0.1766	0.67435

Note: *, **, *** indicate that they passed the 10%, 5%, and 1% significance level tests, respectively.

Table 5. Regression results of cross-sectional spatial measurement model.

Variable	SEM (Spatial Error Model)	
	Coefficient	P value
λ	0.1715	0.0000***
P1	0.0609	0.0062***
P4	0.0653	0.0083***
P5	0.0956	0.0002***
S1	0.2225	0.0000***
S6	-0.1122	0.0009***
R3	-0.0697	0.0257**
N	1017	/
R2	0.1697	/
Log likelihood	496.15	/

Note: *, **, *** indicate that they passed the 10%, 5%, and 1% significance level tests, respectively.

(3) The influence coefficient of NDVI (S1) is 0.2225, and it is positively correlated, and the significance level reaches 1%. Analysis of the reasons, this conclusion is obvious, it is the primary productivity of the ecosystem.

(4) The influence coefficient of distance to lake or wetland (S6) is -0.1122, which is negative correlation, and the significance level reaches 1%. Analysis of the reasons, this conclusion is obvious, the smaller the distance from the lake or wetland, the more conducive to the coverage of the water system and the growth of vegetation.

(5) The influence coefficient of the distance from the ecological red line control area (R3) is -0.0697, which is a negative correlation, and the significance level reaches 5%. Analysis of the reasons, this conclusion is obvious, the closer to the ecological red line control area, the more conducive to the growth of vegetation and the health of the ecosystem.

Based on ecological sensitivity assessment to identify ecological source patches, according to Table 6 conclusion, only six spatial drivers have a significant impact on ecosystem health (EH) (Fig. 4). According to the regression results of the spatial error model (SEM) in 2020, the correlation coefficient was converted into the weight of the PSR model, and the negative value of the coefficient was evaluated in the reverse direction to determine the index and weight of the ecological sensitivity assessment (Table 6).

The ecological sensitivity assessment adopts five scores of 1, 2, 3, 4, and 5. According to the previous results, the positive and negative correlation coefficients are divided into positive and negative evaluation. Positive evaluation, the higher the grade, the higher the score. In the reverse evaluation, the lower the grade, the higher the score, and the evaluation standard is formed (Table 7). Based on this, a grid database for ecological sensitivity assessment is established (Fig. 4).

Comprehensive Stacking Results

On the basis of the single-factor ecosystem sensitivity assessment results (Table 5), according to the determined factor weights (Table 6), the grid weighted stacking operation is performed (through the grid calculator in ArcGIS), and the final ecological sensitivity assessment results (Fig. 5, Table 8). From the evaluation results, it can be seen that the areas with high sensitivity to ecosystem health are generally distributed in coal mining subsidence areas, the northern and eastern shores of the Southern Four Lakes, wetlands/ water areas, soil and water conservation areas, and water source protection areas.

Identification of Ecological Source Patches and Their Grade Evaluation

Identification of Ecological Source Patches

The identification of ecological source patches is a prerequisite for building an ecological security pattern (ESP), and it is a key step. Combined with existing research, the identification methods of ecological source patches can be classified into two types: 1. Direct identification. The ecological source patches are directly extracted through high-definition remote sensing images and spatial data of wetland parks and nature reserves. 2. Evaluate the importance of patches to identify ecological source patches. The evaluation method can take more account of the relationship

Table 6. Ecosystem health sensitivity assessment index and its weight.

Standard layer	Standard layer Weight	Indicator	Meaning	Original coefficient	Indicator weight	Sorting
		P1	Land-use change	0.0609	0.0973	6
Pressure (P)	0.35	P4	Distance to national highway	0.0653	0.1043	5
		P5	Distance to provincial road	0.0956	0.1527	3
State (S)	0.54	S1	NDVI	0.2225	0.3553	1
		S6	Distance to lake or wetland	-0.1122	0.1792	2
Response (R)	0.11	R3	Distance from ecological red line	-0.0697	0.1113	4

Table 7. The grading standard and evaluation value of each factor of ecosystem health sensitivity assessment.

Indicator layer	Classification	Score	Description
Land-use change (P1)	Water	5	Refer to the ranking of ecosystem services value (positive evaluation).
	Forest	4	
	Grass	3	
	Cultivated	2	
	Unused	1	
	Urban	0	
Distance to national highway (P4)	More than 13000 m	5	Refer to the natural breakpoint classification in ArcGIS and adjust it according to the actual situation (positive evaluation).
	8800-13000 m	4	
	5600-8800 m	3	
	2700-5600 m	2	
	0-2700 m	1	
Distance to provincial road (P5)	8100 m	5	Refer to the natural breakpoint classification in ArcGIS and adjust it according to the actual situation (positive evaluation).
	5700-8100 m	4	
	3600-5700 m	3	
	1700-3600 m	2	
	0-1700 m	1	
NDVI(S1)	0.76 < NDVI	5	Refer to the natural breakpoint classification in ArcGIS and adjust it according to the actual situation (positive evaluation).
	0.58< NDVI <0.76	4	
	0.38< NDVI <0.58	3	
	0.13< NDVI <0.38	2	
	NDVI <0.13	1	
Distance to lake or wetland (S6)	0-1500 m	5	Refer to the natural breakpoint classification in ArcGIS and adjust it according to the actual situation (reverse evaluation).
	1500-3100 m	4	
	3100-4800 m	3	
	4800-7500 m	2	
	7500 m	1	
Distance from ecological red line (R3)	0-2000 m	5	Refer to the natural breakpoint classification in ArcGIS, and adjust it according to the actual situation (reverse evaluation).
	2000-4500 m	4	
	4500-7100 m	3	
	7100-11000 m	2	
	More than 11000 m	1	

between ecological source patches and socioeconomic environmental factors, reflecting that the formation of ecological source patches is the result of natural and artificial systems. Therefore, the evaluation method is selected in this paper. Based on a combination of qualitative and quantitative methods, the important spatial driving forces affecting ecosystem health in the study area were obtained and related weights (coefficients) were obtained (Table 6). Then, an ecological sensitivity assessment was constructed to obtain the results (Fig. 5, Table 8), and the ecological source patches in the two stages were evaluated to obtain the results (Fig. 6, Table 9). Based on this, the identification of ecological source patches was carried out.

Ecological security stage: On the basis of ecosystem sensitivity assessment zoning (Fig. 5, Table 8), the ecosystem sensitivity of the coal mining subsidence area was evaluated as extremely high, high and medium areas were selected as the ecological source patches. At the same time, the patches larger than 50 hectares were selected as the ecological source patches, a total of 89. The results are shown in Fig. 6 and Table 9.

Ecosystem health stage: On the basis of ecosystem sensitivity assessment zoning (Fig. 5, Table 8), the ecosystem sensitivity of coal mining subsidence area, ecological red line, soil and water conservation area and water source protection area is evaluated as extremely high, high and medium areas were selected as the ecological source patches. At the same time, the patches larger than 50 hectares were selected as the ecological source patches, a total of 154. The results are shown in Fig. 6 and Table 9.

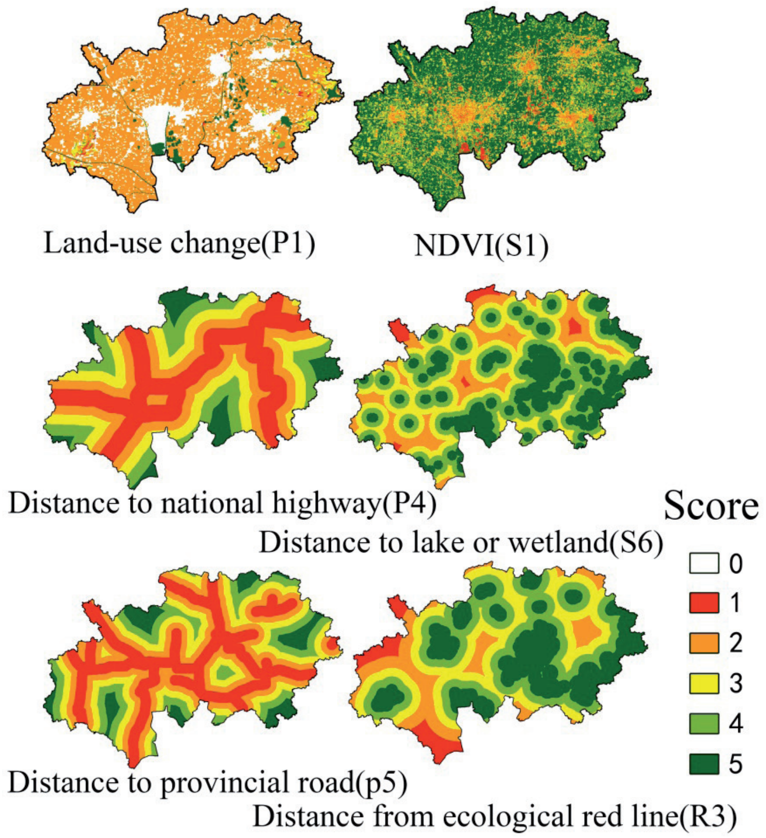

Fig 4 Main drivers of significant impact on ecosystem health

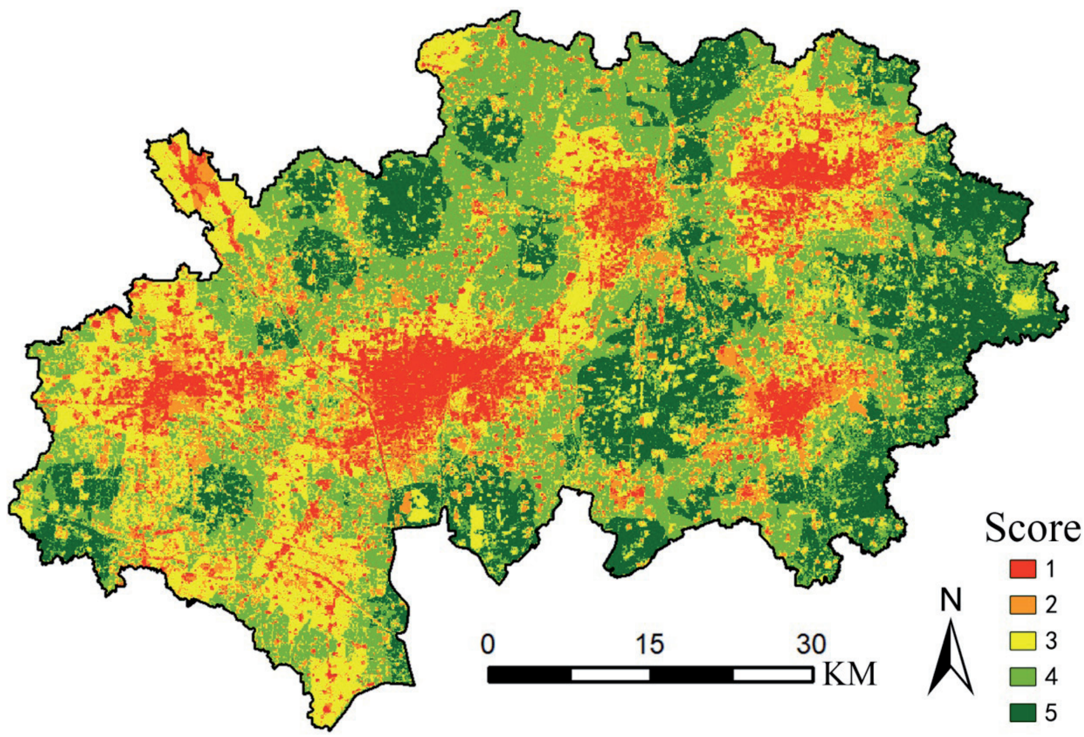

Fig. 5. Evaluation results of ecosystem sensitivity assessment.

Table 8. Ecosystem sensitivity assessment area division in JMA.

Sensitive area	Area (ha)	Proportion (%)
Extremely sensitive area (5)	67517	19.01
High Sensitivity Area (4)	109970	30.97
Medium Sensitive Area (3)	88163	24.83
Hyposensitive area (2)	55305	15.57
Non-sensitive area (1)	34171	9.62
Total	355125	100.00

Classification of the Importance of Ecological Patches

In the range of ecological security stage, the calculated dIIC values are arranged in descending order, and the importance level of the source patch is determined by the level of the value. Referring to the research on patch connectivity by related scholars, the value is divided into three levels. There are 68 source patches in the 0-1 interval (level 3 ecological patches), and 13 source patches in the 1-2.5 interval (level 2 ecological patches). There are 8 greater than 2.5 (level 1 ecological patches), a total of 89, and the important patches of the ecosystem are mainly distributed in the heavily coal mining subsidence areas of the study area (most of which have accumulated water and become wetlands), moderate coal mining subsidence areas appearing in woodlands, grasslands and wetlands (Fig. 7).

In the range of ecosystem health stage, the calculated dIIC values are sorted in descending order, and the importance level of source patches is determined by the level of the value. Referring to the research on patch connectivity by relevant scholars, the value is divided into three levels. There are 115 source patches in the 0-1 interval (level 3 ecological patches), and 23 source patches in the 1-2.5 interval (level 2 ecological patches), there are 16 greater than 2.5 (level 1 ecological patches), a total of 154. The important patches of the ecosystem

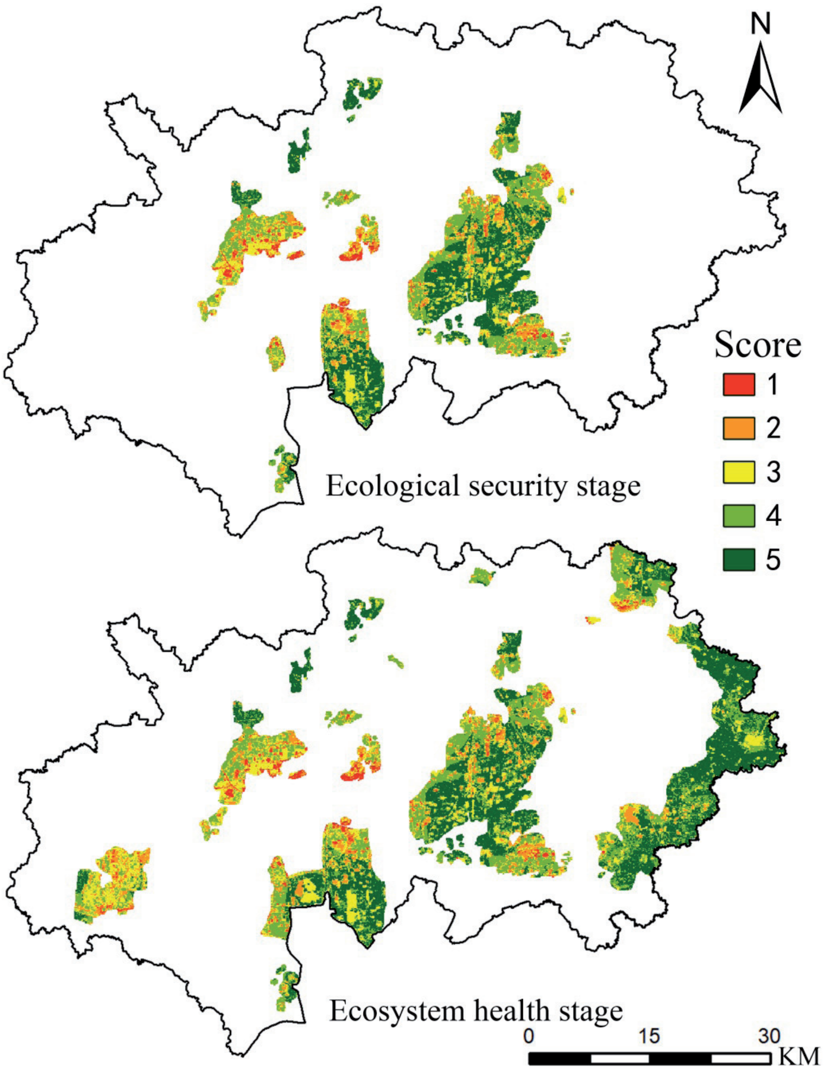

Fig. 6. Ecological sensitivity assessment results in two stages.

Table 9. Ecosystem sensitive area division.

Scope of ESP	Sensitive area division	Area (ha)	Proportion (%)	Quantity
Ecological security stage	Extremely sensitive area	15784	39.27	68
	High Sensitivity Area	14759	36.72	13
	Medium Sensitive Area	9651	24.01	8
	Total	40194	100.00	89
Ecosystem health stage	Extremely sensitive area	30656	42.19	115
	High Sensitivity Area	25670	35.33	23
	Medium Sensitive Area	16330	22.48	16
	Total	72656	100.00	154

Note: Only the extremely sensitive areas, high sensitive areas and medium sensitive areas are counted, and the area of a single patch is greater than 50 hectares.

are mainly distributed in large areas, mainly in the heavy coal mining subsidence areas of the study area (Most of them have accumulated water and become wetlands), important water source protection areas and soil and water conservation areas, moderate and mild coal mining subsidence areas appearing in woodlands, grasslands, and wetlands (Fig. 7).

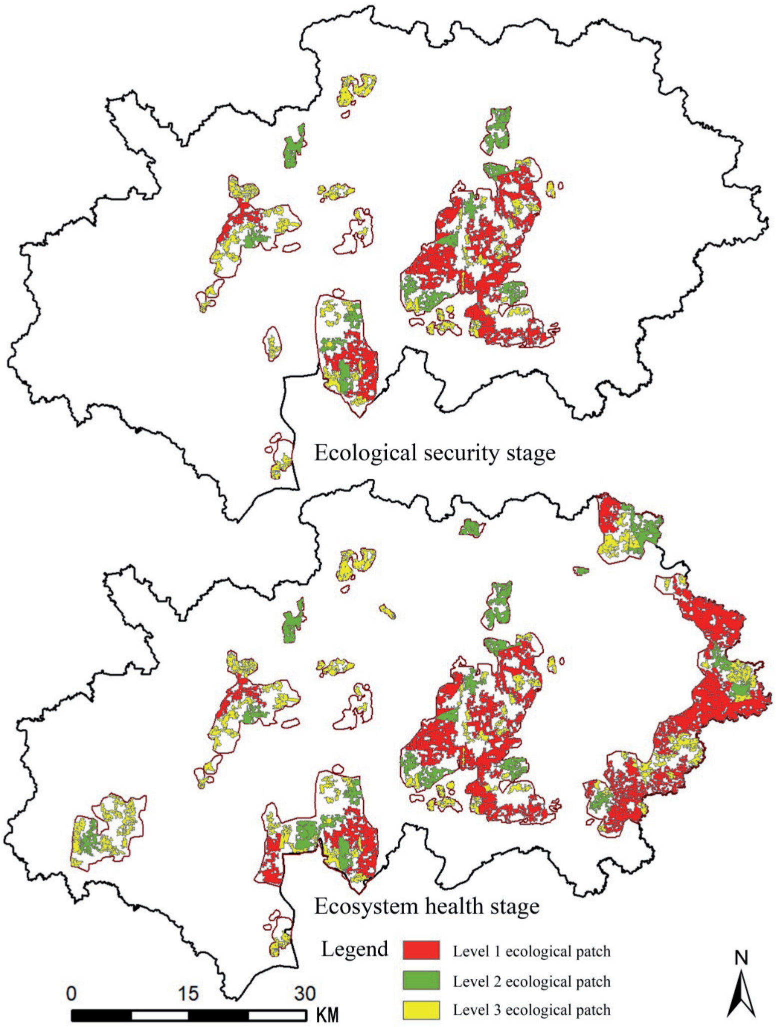

Fig. 7. ES and EH stage ecological patch grade evaluation.

Table 10. The determination of landscape resistance values.

Land-use type	Landscape resistance value
Forest	1
Grassland	4
Cultivated land	30
Waters	5
Urban land	1000
Industrial and mining land	1000
Rural settlement	800
Unused	120

Identification and Classification of Ecological Corridors

The ecological source patch has the ability of internal homogeneity and outward expansion in the ecological process, and it needs to overcome the resistance of different landscape types in the expansion process to realize its expansion. Therefore, the construction ESP needs to analyze and identify the spatial resistance relationship of different landscape types.

This paper uses ArcGIS "minimum cumulative resistance" to generate potential corridors. According to the research results of relevant scholars and the characteristics of the study area, resistance values are set up for different landscape types between ecological patches, and resistance surfaces are constructed. Use the "Cost Path" tool under the ArcGIS distance analysis module to calculate the minimum cumulative resistance between "source" and "destination" to generate ecological corridors between ecological patches.

Resistance Factor, Resistance Coefficient and Resistance Surface Determination

The maintenance and expansion of ecological patches are mainly affected by topographic and geomorphological factors, habitat quality factors and surface cover types. JMA is located in the plains and hills, with low altitude and little change. Topographic factors can be ignored. The influence of landform, habitat quality and land cover type does exist, but they can all correspond to land-use types. Land-use types were analyzed as resistance factors (Table 10).

Referring to related studies, the type of land-use is the main factor affecting the landscape resistance [43]. Due to the rich water system in the study area, the wetlands evolved from the coal mining subsidence area are also increasing, and then evolve into a complex water ecosystem. The water system/water area is an important potential corridor in the study area, so the resistance value is set to 5, and finally determined various types of landscape resistance values (Table 10). At the same time, the landscape resistance surface is constructed based on ArcGIS software.

Identification and Induction of Ecological Corridors

Use the "Cost Path" tool under the ArcGIS distance analysis module to calculate the minimum cumulative resistance between "source" and "destination" to generate ecological corridors between ecological patches. 151 potential ecological corridors were generated in the ecosystem health stage, as shown in Fig. 8.

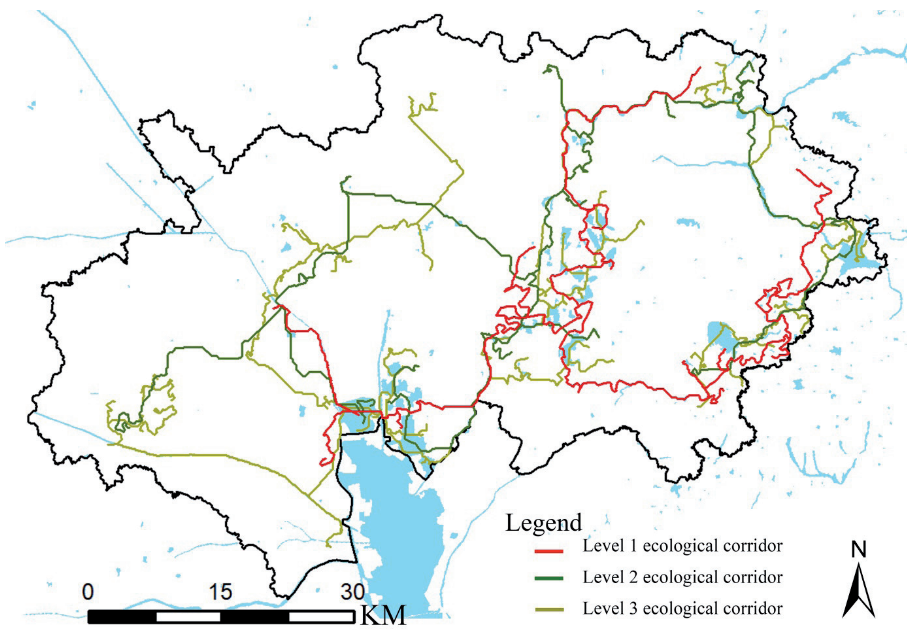

Fig. 8. Summary of ecological corridors.

Table 11. Construction ESP.

Stage	Category	Number (Total)	Main Distribution
	Level 1 ecological patch	8 (89)	It mainly includes wetlands formed by heavy coal mining subsidence areas, mainly distributed in Green Core and the east bank of Nansi Lake (refer to Fig.7).
Ecological security	Level 2 ecological patch	13 (89)	It mainly includes woodlands, grasslands and wetlands formed by coal mining subsidence areas with a smaller area (refer to Fig 7).
	Level 3 ecological patch	68 (89)	/
	Level 1 ecological patch	16 (154)	Including woodland, grassland, important wetlands, water source protection areas and soil and water conservation areas (refer to Fig. 7).
Ecosystem health	Level 2 ecological patch	23 (154)	It mainly includes small forest land, grassland, important wetland, water source protection area and soil and water conservation area (refer to Fig. 7).
	Level 3 ecological patch	115 (154)	/
	Level 1 ecological corridor	15 (151)	Refer to Fig. 8.
Ecosystem health	Level 2 ecological corridor	22 (151)	Refer to Fig. 8.
	Level 3 ecological corridor	114 (151)	/

According to the importance level of connecting ecological patches, the ecological corridors are divided into three levels. Although the number of ecological corridors is large, there are still rules to follow. They are basically arranged according to the water system. The main river is usually the first-level ecological corridor.

Construction ESP

Combined with the land distribution in the study area, the forest land, grassland, important wetlands, water source protection areas, and soil and water conservation areas with high ecological value within the study area. Based on previous research and conclusions, construct a short-term and long-term ESP consisting of ecological patches, ecological corridors and ecologically sensitive areas (Tables 11 and 12, Fig. 8).

According to the ecosystem sensitivity assessment (Fig. 4), the non-evaluated and low-evaluated areas are combined into low ecologically sensitive areas, those evaluated as medium correspond to medium ecologically sensitive areas, those evaluated as high correspond to higher ecologically sensitive areas, and those evaluated as extremely high corresponding to highly ecologically sensitive areas. The areas outside the ecological control area were divided into four levels: low, medium, high and high ecologically sensitive areas (Table 12, Fig. 9).

Discussion and Conclusion

Discussion

The coal mining activities and urbanization of China's coal resource-based cities have caused many ecological and environmental problems that cannot be ignored, seriously threatening regional ecological security and the formulation of urban development policies [47]. Building an ecological security pattern (ESP) is an effective way to balance ecological protection, coal mining activities and urbanization. Taking Jining City as an example, this study proposes a new ecological sensitivity assessment (ESA) method based on a combination of qualitative and quantitative analysis, and then proposes a new ESP construction method based on ESA.

Table 12. The division of ESP ecologically sensitive areas.

Ecologically sensitive area level	Corresponding Ecological Sensitivity Assessment
High ecologically sensitive area	Extremely sensitive
Higher ecologically sensitive area	Highly sensitive
Middle ecologically sensitive area	Moderate sensitive
Low ecologically sensitive area	No and low sensitive

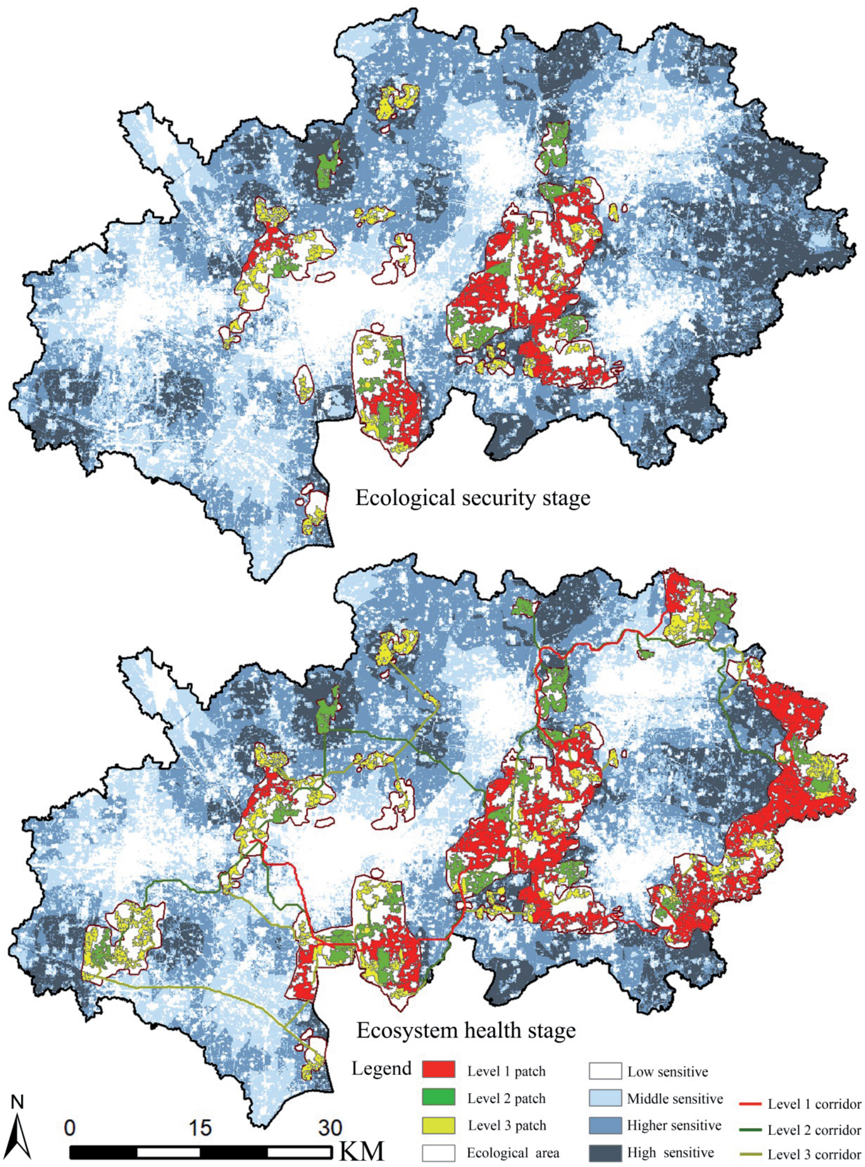

Fig. 9. ESP construction.

The regression results from the 2020 spatial error model are shown. The only spatial drivers of ecosystem health are Land-use change (P1), Distance to national highway (P4), Distance to provincial road (p5), NDVI (S10), Distance to lake or wetland (S6) and Distance from ecological red line (R3) passed the significance test. It reflects the important driving forces affecting coal resource-based urban ecosystem health under the influence of coal mining activities and urbanization.

In Jining City, coal mining activities and urbanization jointly affect urban ecosystem health, affect the urban ecological security and development, and cause uncertainty in urban development [48]. Based on this, the ecological security pattern in the short-term and long-term stages is proposed: 1. The short-term goal (ecological security stage) refers to the priority protection of ecological patches within the coal mining subsidence area, and the protection sequence adopts the importance level; 2. The long-term goal (ecosystem health stage) is to comprehensively protect the ecological patches and corridors in coal mining subsidence areas, ecological red lines and water source protection areas/water and soil conservation areas. And then gradually ease the uncertainty in urban development, and gradually achieve the ultimate goal of urban ecosystem health.

As shown in Fig. 10, the ecological network planning of JMA presents a dual-center structure, namely "two cores, three corridors and multiple points". "Two cores" refers to the green core (the largest ecological patch group) and the blue core (Nansi Lake Reserve); "Three Corridors" refers to the Sihe Corridor and the green space beside it; the The Beijing-Hangzhou Grand Canal and its adjacent green space and the Zhuzhao Xinhe Corridor and its adjacent green space. The most important corridor is the Sihe Corridor, which

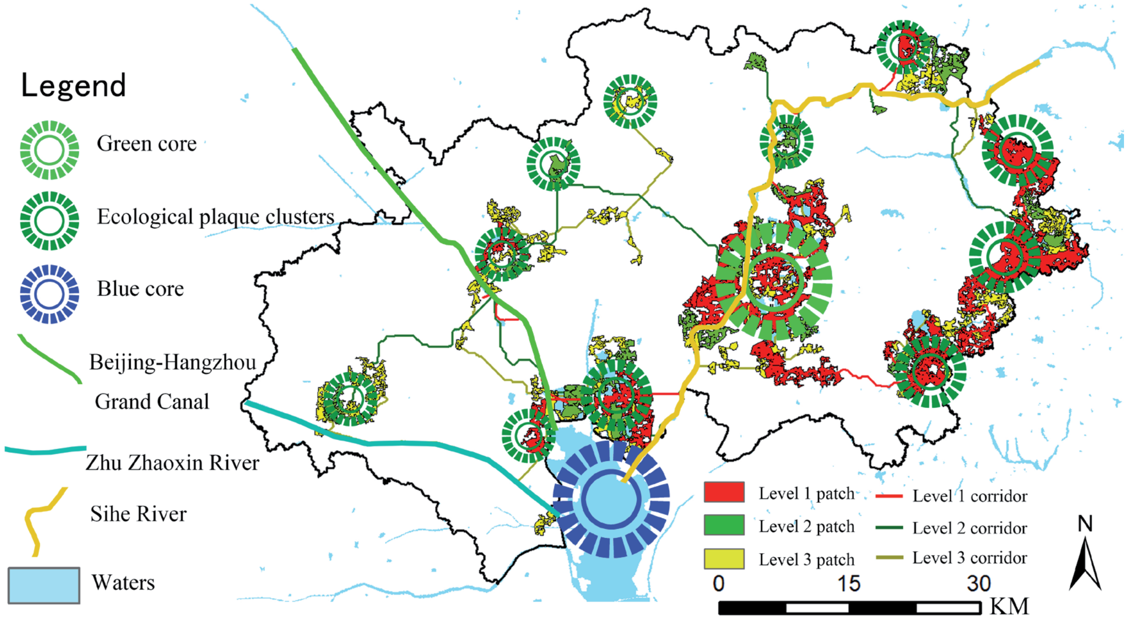

Fig. 10. Ecological network planning in JMA.

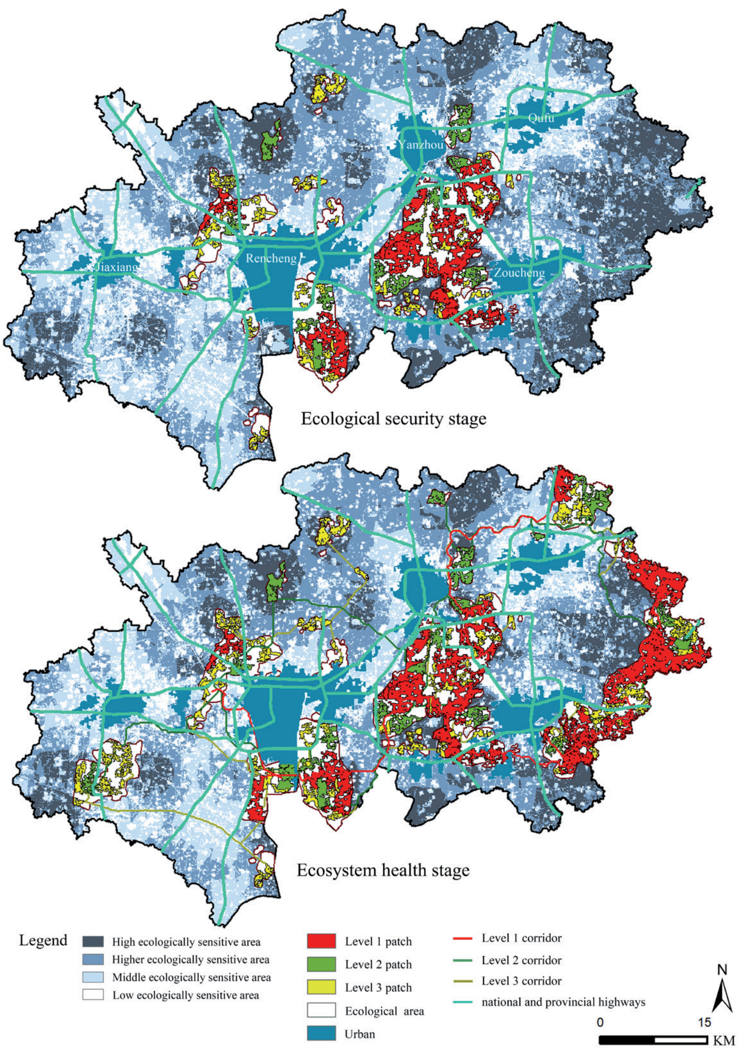

Fig. 11. The urban development direction and strategy in JMA.

Table 13. Urban development strategies at different stages.

Strategy	Jiaxiang	Rencheng	Yanzhou	Zoucheng	Qufu
Ecological security stage	Linear	Filled / Linear	Filled / Linear	Filled	Linear
Ecosystem health stage	Linear	Filled	Filled / Linear	Filled	Filled / Linear

connects the blue core, the green core and a first-level ecological patch group (Sihe water source protection area). The construction of the Grand Canal Ecological Corridor will combine historical culture and ecological value, and it is a new attempt of "ecology-historical culture priority" under the sustainable development of coal resource-based cities. "Multiple spots" refers to a plurality of ecological patch clusters.

According to the ecological security pattern and ecological network planning, the urban development direction and strategy can be analyzed (Fig. 11).

According to the previous analysis, national highways and provincial highways are important factors affecting ecosystem health, and the correlation coefficient is positive, that is, the closer to the national highway and provincial highway network, the lower the ecosystem health level (Table 6). The network conducts certain urban expansion. In addition, urban development is required to avoid urban ecological control areas and high and higher ecologically sensitive areas.

In the near future (ecological security stage), this stage is mainly faced with the urgent task, that is, the management and control of dynamic changes in coal mining subsidence areas. Combined with the transportation network, Jiaxiang can expand eastward and northward to a certain extent, because most of the areas there are in middle and low ecologically sensitive areas, and the city can develop linearly. The urban expansion of Rencheng is subject to many restrictions. The south and north are restricted by ecological control area, and the east and west are also restricted by high and middle ecologically sensitive areas, and there is little room for west and east expansion, it is recommended to develop a combination of infill and linear. The eastern and southern parts of Yanzhou are restricted by ecological control areas, and the northward is restricted by higher ecologically sensitive areas, so they can only develop to the west, and there is not much room for development. It is recommended to develop infill and linear. The east, north and west sides of Qufu are restricted by higher and highly ecologically sensitive areas. Combined with the transportation network, only a certain expansion to the south is recommended, and linear development is recommended. Zoucheng is restricted by ecological control areas in the west, and restricted by higher and highly ecologically sensitive areas to the east and south. There is not much room for expansion in the north, and infill development is recommended (Fig. 11).

In the long-term (ecosystem health stage), on the basis of the ecological security stage, this stage adds ecological control areas, water source protection/water and soil conservation area protection, puts forward the concept of ecosystem health in the entire study area, and coordinate important ecological reserves in the whole region. The southern part of Jiaxiang is limited by ecological control areas and secondary ecological corridors. Combined with the transportation network, it can expand eastward and northward to a certain extent, because most of the areas there are in middle and low ecologically sensitive areas, and the city can develop linearly. Rencheng's urban expansion is subject to many constraints, with ecological control zones and primary and secondary ecological corridors to the south and north. The east and west sides are also restricted by high and middle ecologically sensitive areas and first-level ecological corridors, and there is little room for expansion to the west and east. Infill development is recommended. The eastern and southern parts of Yanzhou are restricted by ecological control areas and first-level ecological corridors, and the northwards are restricted by higher ecologically sensitive areas, and can only develop westward. Infill and linear integrated development is recommended. The east, west, south and north of Qufu are restricted by ecological control areas, higher and middle ecologically sensitive areas and first-level ecological corridors, and there is little room for expansion. Infill and linear comprehensive development is recommended. Zoucheng is limited by ecological control areas and first-level ecological corridors in the west, east and south, and there is not much room for expansion in the north, so infill development is recommended (Fig. 11). Arranged as in Table 13.

Conclusion

Building an ecological security pattern (ESP) is an effective way to balance ecological protection, coal mining activities and urbanization. Taking Jining City as an example, this study draws the following conclusions:

1. Based on the combination of qualitative and quantitative analysis, a new ecological sensitivity assessment (ESA) method is proposed.

In the past, the selection of ecological sensitivity assessment (ESA) indicators usually adopts subjective methods, such as various frameworks such as nature-society-ecology, PSR, etc. The determination of indicator weights mostly adopts the analytic hierarchy process based on expert experience, which has certain advantages, but, the lack of objective verification links will inevitably bring errors. Based on previous research, this study attempts to obtain indicators and their weights by adding objective verification links.

First, the spatial drivers of ecosystem health (EH) are qualitatively analyzed through the PSR framework. Secondly, quantitative analysis and testing of the results of qualitative analysis through spatial econometrics method, it is found that not all indicators are spatially related to ecosystem health, and insignificant indicators are eliminated to obtain the results of quantitative analysis, and then to obtain indicators and its weight.

2. Based on ESA, combined with landscape connectivity evaluation and MCR model, a new ESP construction method is proposed.

3. Based on the ecological corridor level, ecological patch level and ecological sensitive area level, the ecological security pattern is constructed, and the ecological network planning of "two cores, three corridors and multiple points" is proposed.

4. Guide the urban development of Jining based on the ecological security pattern and its ecological network planning.

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Conflict of Interest

The author declares no conflict of interest.

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