

Construction of green infrastructure in coal-resource based city: a case study in Xuzhou urban area

Jiang Chang¹ · Tinghao Hu² · Xiangxu Liu¹ · Xiaogeng Ren³

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Abstract As an important coal-resource based city in eastern China, coal mining activities have greatly promoted economic development to Xuzhou while resulted in kinds of blocks for sustainable development. Subsidence areas caused by coal mining activities and rapid urbanization process led to the losing of ecological function and decreasing of landscape connectivity in the city. As the important life-support system, urban green infrastructure (GI as short) has great significance in improving human well-beings. Taking Xuzhou urban area as the study object, this paper proposed a green infrastructure construction method based on the principle of ecological priority. Firstly, key ecological patches were identified by GIS and RS methods. Secondly, we established corridors by minimum cost path model. Then, we built GI network and evaluated the ecological importance of different patches. Finally, by comparing the status of patches and coal mining subsidence areas, we proposed a framework for constructing GI network in Xuzhou urban area.

Keywords Coal-resource based city · Green infrastructure · Green space · Xuzhou urban area

1 Introduction

Green infrastructure (GI) is an important life-support system, vital to improving the urban ecology and maintaining sustainable development (Benedict and McMahon 2006; Weber et al. 2006). However, green infrastructure in coal-mining cities is threatened not only by mining activities but also by the ongoing processes of urbanization. In China, 95% of coal is exploited from underground deposits. The extraction causes subsidence, as well as the destruction of cultivated land, residential areas and transportation infrastructure. As a result, There exist a large number of post-mining landscapes in China (Chang et al. 2011; Chang

2013). Clearly, coal-mining cities urgently require a theory for the reconstruction of mining areas in order to ensure their sustainable development (Feng et al. 2016).

Hundred years of coal mining activities have brought considerable economic benefits to Xuzhou while resulted in kinds of tumbling blocks for sustainable development. Subsidence areas caused by coal mining activities not only directly affected various production activities, but also had adverse effects on the urban ecological environment. Nevertheless, whether the damaged post-mining lands have ecological potentiality? The answer is definitely yes. Owing to the long term abandon and less human disturbance, the ecosystem in subsidence areas is in a state of self-recovery, which has formed new important areas with high ecological potential and provides vivo sphere for threatened species (Chang et al. 2011).

✉ Jiang Chang
changjiang102@163.com

¹ School of Architecture and Design, China University of Mining and Technology, Xuzhou, China

² School of Mechanics and Civil Engineering, China University of Mining and Technology, Xuzhou, China

³ School of Architecture, Southeast University, Nanjing, China

2 Theoretical fundamental of green infrastructure

2.1 GI definition

Green infrastructure is an open, systematic ecological function network which makes great significance in improving urban ecology and maintaining sustainable development (Weber et al. 2006). GI was firstly proposed by the United States in 1990s and was implemented into the state, regional and local policies. GI theory encompasses all spatial levels. It focuses on connecting urban green, aiming at multi-functionality, forging a link to the spatial provision of ecosystem services and highlighting the need for close collaboration between scientific, political and administrative actors (Pauleit et al. 2011; Benedict and McMahon 2006; Haase et al. 2014). Green infrastructure and ‘grey’ technical infrastructure are considered as essential functional systems in cities.

2.2 Functions and components of GI

Green infrastructure is a natural and man-made green network. It consists of core areas, corridors and stepping stones (Li 2009) (see in Fig. 1).

Core area is the core region of green infrastructure network. It plays the role of a variety of natural processes. It appears with various forms and scales, and different scales covers different contents, including nature reserves, forest, parks, woodlands, green space in communities, etc.

Corridor plays a role in connecting elements in green infrastructure network. It maintains key biological processes and provides recreation and leisure spaces for people as well. Corridors link up the whole green infrastructure network and keep the entire system circulating. Ecological linear spaces, rivers, and greenbelts of railways and roads are normal corridors.

The definition of stepping stone is unified and relatively blurry. In some certain scales, it can be regarded as patches that smaller than core areas, or corridors for species

migration. Stepping stones can provide ecological nodes for species migration and recreation activities for human beings. It covers small habitats, small green spaces in communities and gardens. An example is shallow water areas in Xuzhou coal mining areas. In Xuzhou, the phreatic water level is 1–1.5 m below the surface, and a large area of water bodies thus appears because of coal mining activities. In coal mining subsidence areas, many of these water bodies still remained in un-reclamation status. After years of self-recovery process, those places have been able to act as habitats of fishes and birds as well as provide some ecological functions. Although these “stepping stones” are mostly in small area and discrete distributed, they can acts as important complements of core areas and corridors in the entire GI network (see in Fig. 2).

3 Study materials

3.1 Study area

Xuzhou (117°20'E, 34°26'N) is located in the northwest of Jiangsu province, China, southeast of the north China plain. The city is rich in mineral resources and is one of the important coal production bases in the eastern plain of China. At present, there are 29 coal mines in total within study area (see in Fig. 3). In this paper, the research focused on the Xuzhou urban area which covers 3126 km².

According to the data in 2016, more than 160 km² coal mining subsidence areas were found in Xuzhou urban area. They formed a pattern of semi-surrounding the main urban area. According to distribution and pattern, coal mining subsidence areas in Xuzhou urban area could be divided into east and west parts, and nine districts in total. In the west, Pangzhuang and Jiahe District as the core, scattered around Chacheng District, Zhangji District, Yi'an District and Xinhe-Woniu District. Jiawang District, Dahuangshan District and Dongzhuang District formed east part of subsidence areas in Xuzhou urban area (see in Fig. 3).

3.2 Data sources

Using Landsat—TM images (the spatial resolution is 30 m × 30 m) of Xuzhou in July 2016 and reference of land use classification system (Li et al. 2013), we divided land use and land cover into 6 categories: woodland, grassland, cultivated land, water body, roads, urban construction land (see in Table 1 and Fig. 4). We identified Green Infrastructure (GI as short) as ecological sources, nature reserves, scenic spots, forest parks etc., which covers an area of 3.18×10^4 ha and 65.25% of the research area.

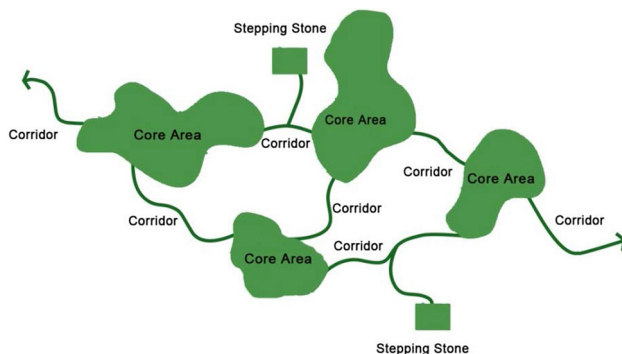


Fig. 1 Structure and components of green infrastructure



Fig. 2 Stepping stones in coal mining subsidence area in Xuzhou urban area

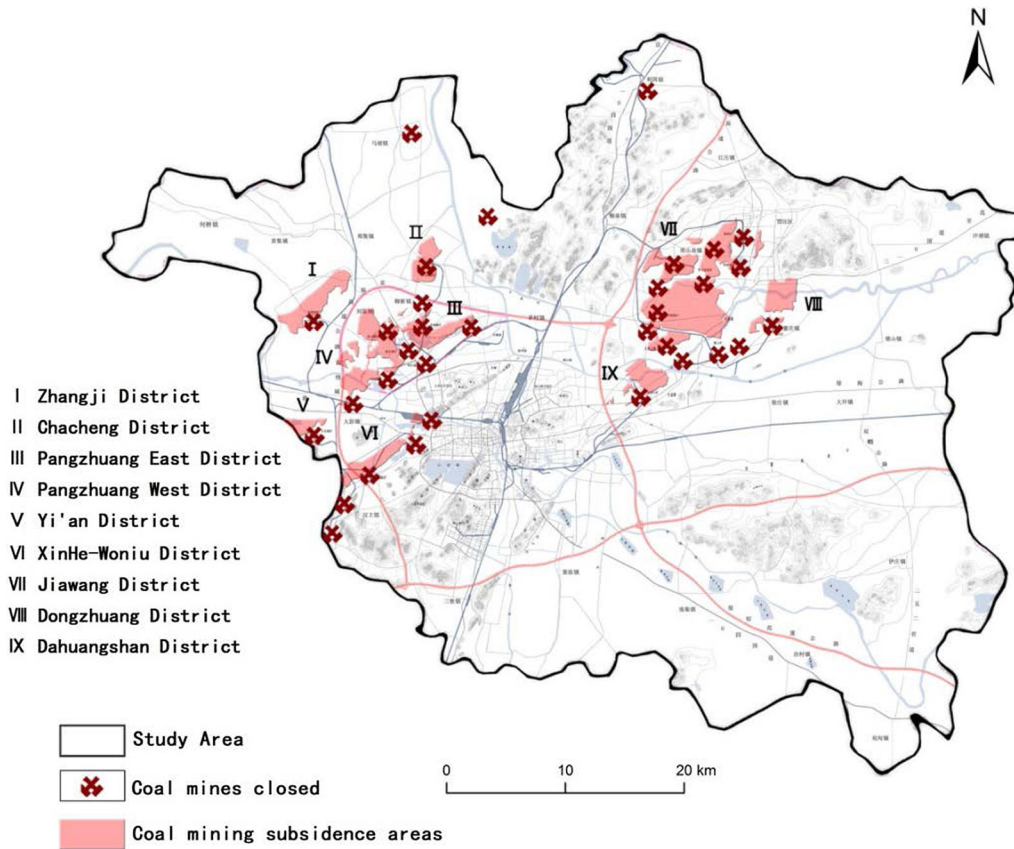


Fig. 3 Distributions of coal mines and subsidence areas in Xuzhou urban area

Table 1 Land use types in Xuzhou urban area

Land use and land cover	Area (km ²)	Proportion (%)
Woodland	374.29	11.94
Grassland	187.07	5.97
Cultivated land	1282.5	40.92
Water body	201.27	6.42
Roads	15.46	0.49
Urban construction land	1073.71	34.26

4 Process

4.1 Ecological sensitivity evaluation

Using classification method of ecological factors in McHager vertical ecological adaptability analysis, the evaluation was carried out from three aspects: human factor, ecological background and natural factor. Based on the features of the present situation of Xuzhou urban area, 10 of most fundamental factors were selected. They were: Land use type, Cultural heritage, Transportation, Pollution source, Key infrastructure, NDVI, Natural reserve area,

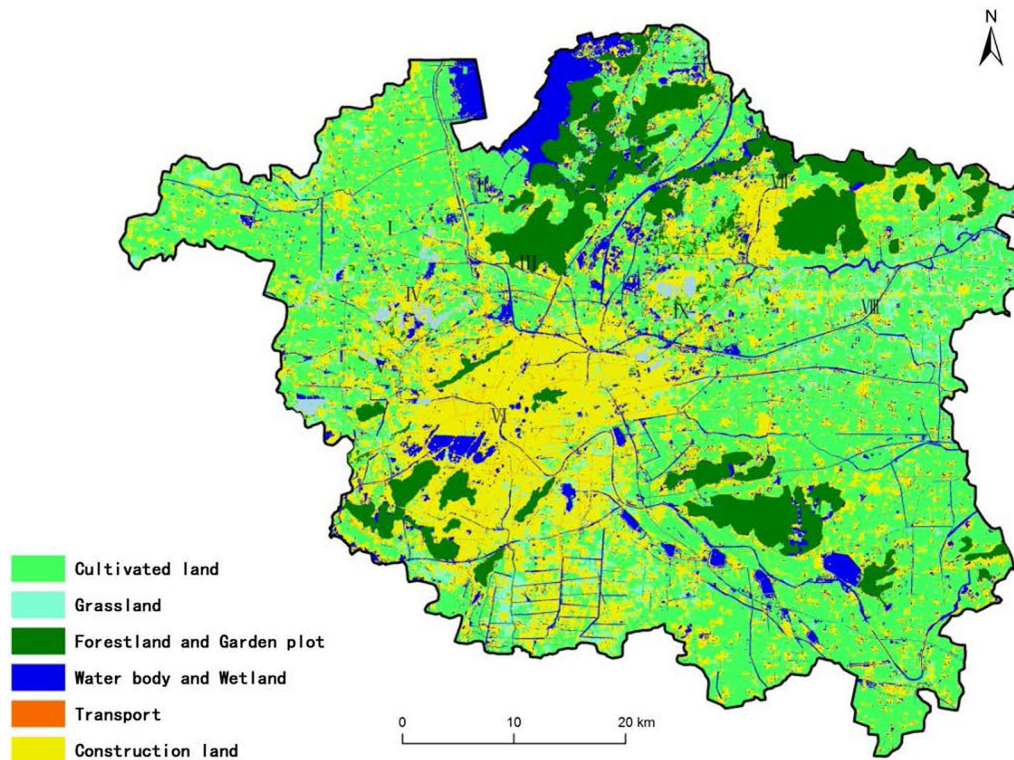


Fig. 4 Land cover and land use types in Xuzhou urban area

Water body, Gradient, and Altitude. These factors had significant impacts on ecological sensitivity in Xuzhou urban area (Shen et al. 2009; He et al. 2011; Polasky et al. 2011; Theobalda et al. 2011). Meanwhile, according to the characteristics of each index layer, the grading standard was established, and the study area was assigned by 30 m × 30 m grid.

In our study, Analytic Hierarchy Process was used to determine the weight of each index. In order to measure the evaluation variables and weights of factors, we consulted 10 specialists who had knowledge about the study area and about different research fields (Urban planning, Landscape planning, Physical geography, and Phytology, etc.) to address the necessary information. The experts discussed and rated the factors and compared the indicators in same layer to obtain the comparison matrix. Then we used MATLAB software to calculate the weight (see in Tables 2, 3).

After determining the factors and weight, the superposition of multiple factors should be considered in ecological sensitivity evaluation process. Therefore, we overlapped the data from every-single factor's partition and put the weighted superposition into the ecological suitability evaluation model (Formula 1) using grid computing function in ArcGIS10.2.

$$S = \sum_{i=1}^n w_i x_i \quad (1)$$

where S is the ecological suitability score; x_i is the score of each influencing factor; w_i is the weight of factor.

Then, we used natural break classification method to evaluate the ecological environment sensitivities. They can be divided in 5 groups: high sensitive areas, relatively high sensitive areas, middle sensitive areas, low ecological sensitive areas, and very low sensitive areas. The calculated results were shown in Fig. 5.

4.2 GI element identification

4.2.1 Patches selection process

After the sensitivity evaluation process, High sensitive areas, relatively high sensitive areas, and middle sensitive areas were chosen as patches in GI network. Meanwhile, each patch was determined by using the land use type data. Based on the geological interpretation of remote sensing, we removed the patches that deeply developed or changed by human activities. At the same time, the area less than 100 ha was removed by using the area threshold and 49 ecological patches were selected. The specific result is shown in Fig. 6.

Table 2 Weights of evaluation variables

Factor	Factor weight	Variable	Variable weight
Human factor	0.2599	Land use type	0.0821
		Cultural heritage	0.0410
		Transportation	0.0273
		Pollution source	0.0821
Ecological background	0.4126	Key infrastructure	0.0274
		NDVI	0.2063
		Natural reserve area	0.2063
Natural factor	0.3275	Water body	0.1310
		Gradient	0.0665
		Altitude	0.1310

In order to further identify the core patches that play a key role in the GI network, we introduce the concept of “source”. According to the definition of Chen et al. (2006), “Source” landscape is a landscape type which contributes positively to the development of the ecological process. As the center of GI network system, the “source” is generally referred to the large core patches that can provide integrated ecosystem services and maintain ecosystem stability. Thus we further selected 4 source patches according to “Xuzhou metropolitan area planning (2010–2030)”. They were: Weishan wetland patch, Dadong mountain scenic patch, Lvliang mountain scenic patch, Yunlong mountain scenic patch. These 4 patches were all selected from natural reserve areas and core area of scenic area (see in Fig. 4).

4.2.2 Corridors selection process

“Mining path method” was used in this study to simulate the potential corridors of animal migration. Using the identified source patches, the calculation and simulation of corridors was carried out by the assignment of landscape resistance. The minimum cost model is mainly taken into account of the three aspects: ecological sources, distance and resistance factor. The equation is:

$$C_i = \sum (D_i \times F_j), \quad (i = 1, 2, \dots, m; j = 1, 2, \dots, n) \quad (2)$$

where, the D_i refers to the actual interval of a landscape unit i to the source; F_j refers to the impedance value of a certain landscape element j in landscape space; C_i refers to the calculation result, that is, the cumulative consumption distance value of the landscape unit i to the source; m and n are the sum of the basic landscape units.

Based on TM remote sensing image data and topographic map data, we determined the different landscape resistance values by investigating the vegetation of

different land use types and human disturbance degree. We also referred others previous research results by Pascual-Hortal and Saura. (2011) and Liu, et al. (2010). The resistance values of different land use types were given in Table 4.

4.3 Patch importance evaluation

Using Conefor Sensinode 2.6 and ArcGIS 10.2, we calculated patches importance values by IIC (Integral Index of Connectivity). IIC was regard as basis for evaluating patches importance. Wherein the greater the value of IIC was, the more important the patch will be. The IIC can be indicated as:

$$I_{IIC} = \frac{\sum_{i=1} \sum_{j=1} \frac{a_i \cdot a_j}{1 + nl_{ij}}}{A_L^2} \quad (3)$$

where, n represents the total number of patches in the landscape; a_i and a_j respectively represent the area of patch i and patch j ; nl_{ij} represents the number of connections between patch i and patch j ; A_L is the area of the study area. When $0 \leq I_{IIC} \leq 1$, the value of IIC is 0, which means there is no connection between the different patches. When I_{IIC} is equal to 1, it means the whole landscape is a habitat patch.

According to the research results of Pascual-Hortal and Saura. (2007) and Fei (2011), the ecological patch connected distance threshold is set to 10,000 m and the probability of directly connected is set to 0.01 (i.e. when the distance between the two patches is less than 10000 m or the connectivity probability is greater than 0.01, there is connectivity between two patches and the connecting value is 1. Otherwise it is 0).

By analyzing the IIC, the importance of each patch was classified. Using natural break classification, IIC value interval was set as 0–0.75, 0.75–2.50, 2.50–49.00 according to differentiate importance rating. There were 17

Table 3 Indices of ecological sensitivity factors

Factor	Variable	First-class object	Second-class object	Value	
Human factor	Land use type	Land use type	Forest	5	
			River	5	
			Grassland	4	
			Farmland	3	
			Construction land	2	
	Cultural heritage	Cultural heritage	Roads	1	
			30 m buffer	5	
			30–50 m buffer	3	
			50–100 m buffer	2	
			Out of buffer range	1	
	Transportation	Railway	40 m buffer	5	
			40–100 m buffer	3	
			100–200 m buffer	2	
			Highway	30 m buffer	5
				30–80 m buffer	3
	80–150 m buffer	2			
	Pollution source	Pollution source	Other transportation factors	1	
			300 m buffer	4	
			300–500 m buffer	3	
			500–800 m buffer	2	
Out of buffer range			1		
Key infrastructure	Water supply and drainage facilities; Power supply facilities	High pressure corridor, substation	0–80 m buffer	3	
		Other key infrastructure factors		1	
		NDVI	NDVI	NDVI > 0.3	5
Ecological background	NDVI	NDVI	0.2 < NDVI < 0.3	4	
			0.1 < NDVI < 0.2	3	
			0 < NDVI < 0.1	2	
			NDVI < 0	1	
			Natural reserve area	Natural reserve area	Within reserve area
	500 m buffer	4			
	500–800 m buffer	3			
	800–1000 m buffer	2			
	Out of buffer range	1			
	Natural factor	Water body	First and second class river; reservoir; lake	50 m buffer	5
50–120 m buffer				3	
Brooklet; creek; pond				20 m buffer	5
				20–60 m buffer	3
Other water body factors					1
		Gradient	Gradient	> 20°	5
				15°–20°	4
10°–15°				3	
5°–10°				2	
0°–5°				1	
Altitude		Altitude	> 100 m	5	
			50–100 m	3	
	0–50 m		1		

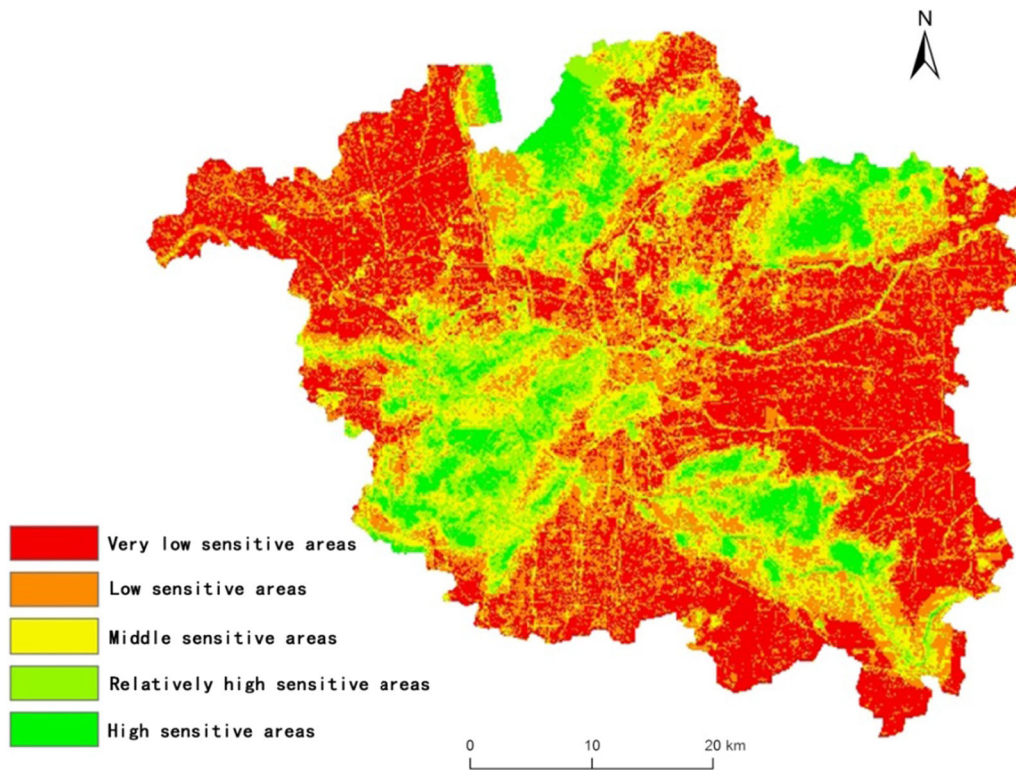


Fig. 5 Comprehensive evaluation of ecological sensitivity in study area

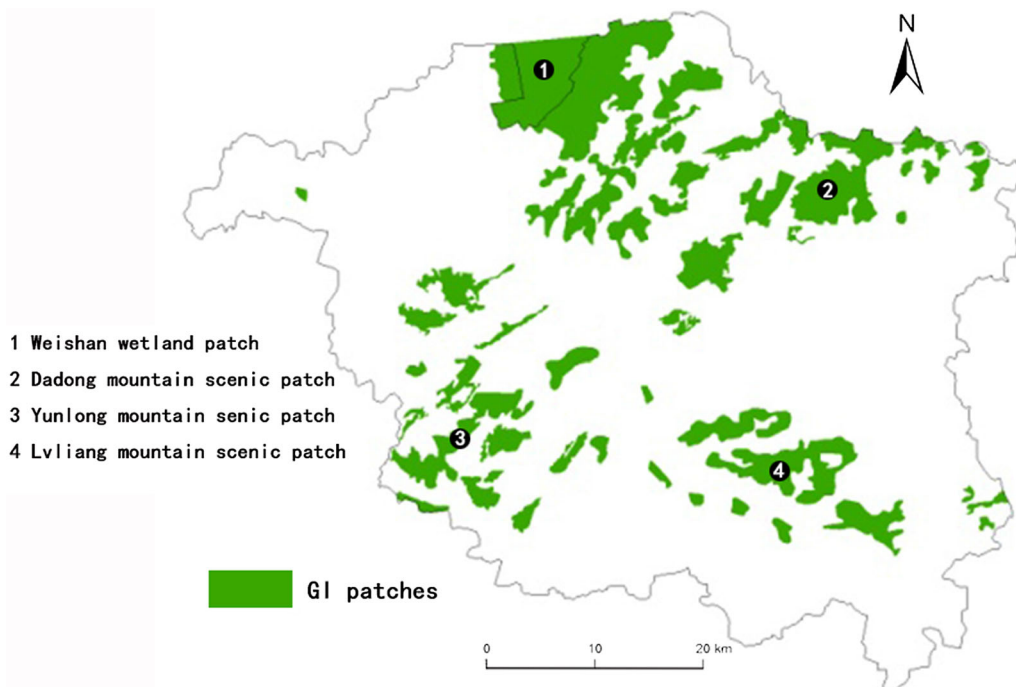


Fig. 6 GI patches in Xuzhou urban area

patches of IIC value were between 0.75 and 2.50. Values between 0.75 and 2.50 occupied 16. The left 16 patches' IIC value were remaining between 2.50 and 49.00 (see in Fig. 7).

4.4 Construction of GI network

The construction of GI network in Xuzhou urban area followed principles of urban functional arrangements, and

strictly protected the ecological resources such as mountains, wetlands waters bodies and forests. In our study, the evaluating importance and status quo of patches were both taken into consideration. By carding and linking greenbelt corridors, river corridors, traffic corridors and potential corridors through key patches, we finally drew GI network pattern in Xuzhou urban area.

5 Results

In Xuzhou urban area, we identified 49 patches (Less than 100 ha) and 32 corridors by spatial methods. To obtain the key patches in GI network, we conceptualized patches and

Table 4 Cost value of different land use types

Land use type	Cost value
Forest	1
Grassland	3
Farmland	30
Construction land	1000
Transportation	300
Water body	500

merged them within the same ecological radiation scope. 17 patches and 9 corridors were selected as the key components of GI network in Xuzhou urban area.

5.1 Patches grading results

According to the importance and area of each patch, we classified patches in 3 levels and finally attained 17 patches in total (see in Table 5). There were 4 patches in level 1. These patches were mainly scenic areas and natural reserve areas and played key role in maintaining ecosystem services and ecological stability. There were 7 patches in level 2. These patches were mostly forest parks, mountains and coal mining subsidence areas. The last 6 patches were comparatively small mountains, urban parks and other coal mining subsidence areas (see in Fig. 8).

5.2 Corridors grading results

Based on the layouts, locations and ecological status of different corridors, we classified 9 corridors in three levels (see in Table 6): regional corridor, sub-regional corridor, and local corridor. There were 4 corridors in regional level. They were responsible for connecting key patches and

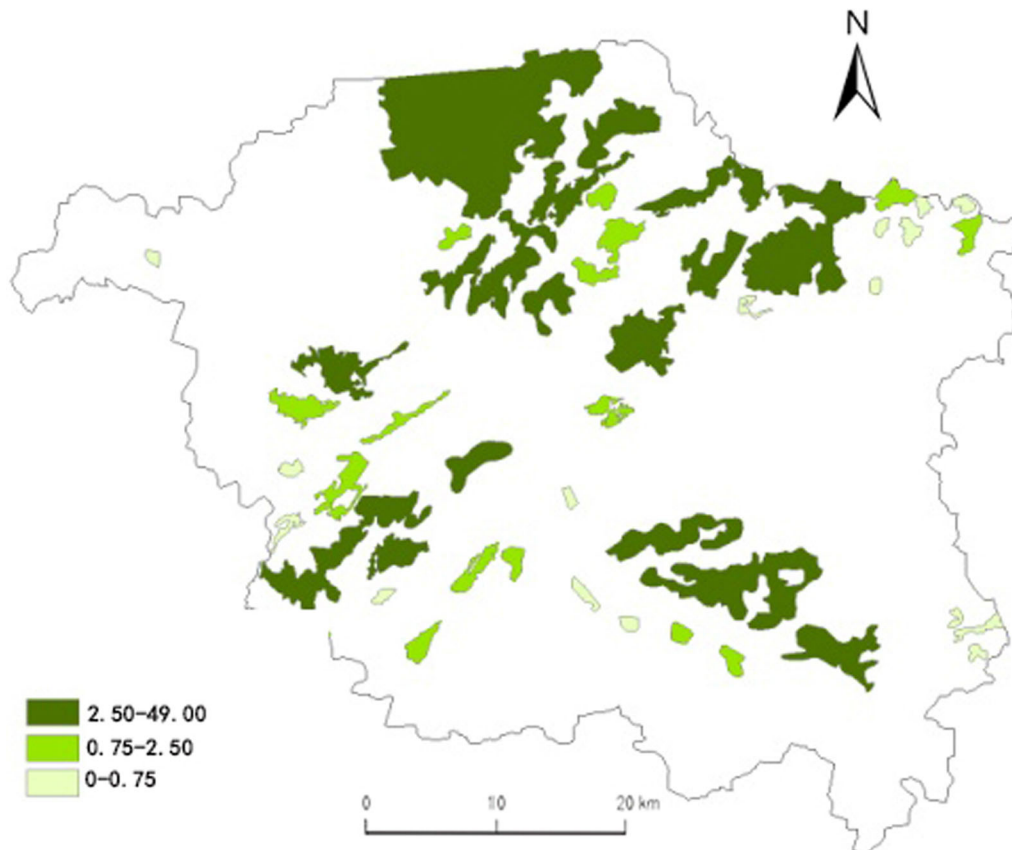


Fig. 7 GI patches importance ranking in Xuzhou urban area

Table 5 Classification of GI patches in Xuzhou urban area

Level	Quantity	Content
Patch level 1	4	Weishan wetland patch, Lvliang mountain scenic patch, Dadong mountain scenic patch, Yunlong mountain scenic patch
Patch level 2	7	Northern mountains forest patch, Pan'an wetland patch, Jiuli subsidence patch, Cuihe reservoir patch, Jiawang subsidence patch, Tuan mountain patch, Pangzhuang subsidence patch
Patch level 3	6	Tuolong mountain forest patch, Jiuli mountain patch, Northern Woniu subsidence patch, Southern Woniu subsidence patch, Dahuang mountain country park patch, Dongzhuang subsidence patch

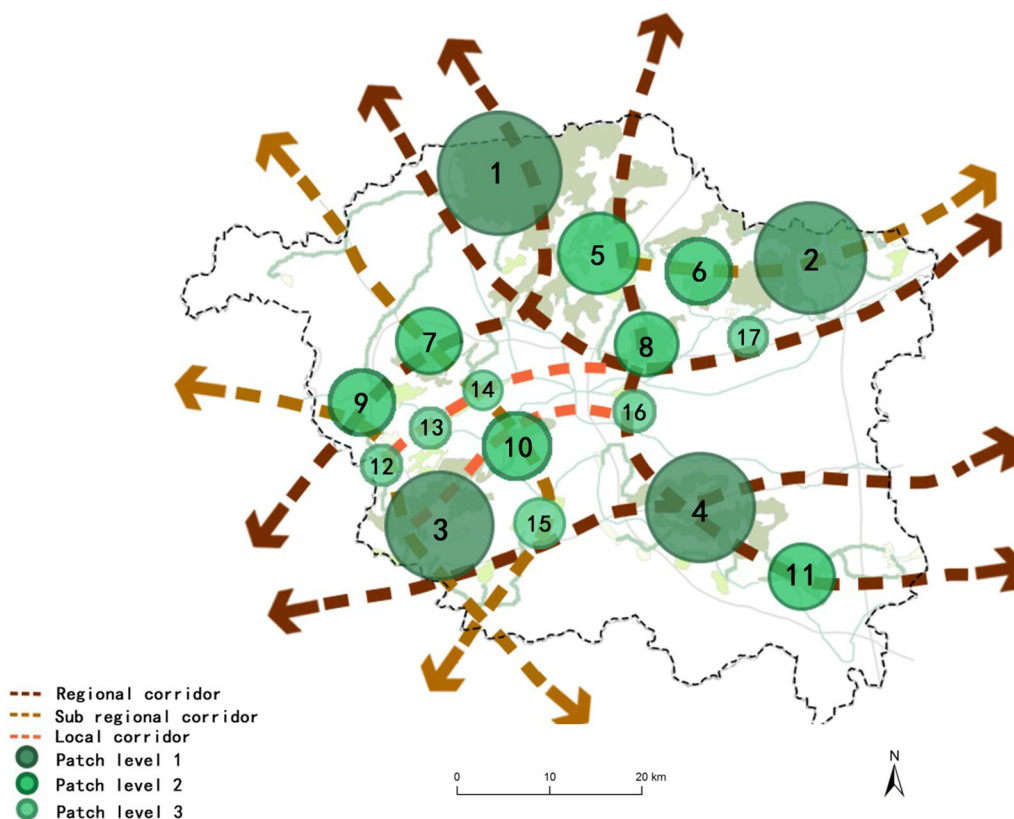


Fig. 8 GI pattern and patches in Xuzhou urban area. Patches in level 1: 1. Weishan wetland patch, 2. Dadong mountain scenic patch, 3. Yunlong mountain scenic patch 4. Lvliang mountain scenic patch. Patches in level 2: 5. Northern mountains forest patch, 6. Jiawang subsidence patch, 7. Jiuli subsidence patch, 8. Pan'an wetland patch, 9. Pangzhuang subsidence patch, 10. Tuan mountain patch, 11. Cuihe reservoir patch. Patches in level 3: 12. Southern Woniu subsidence patch, 13. Northern Woniu subsidence patch, 14. Jiuli mountain patch, 15. Tuolong mountain forest patch, 16. Dahuang mountain country park patch, 17. Dongzhuang subsidence patch

forming the main skeleton of GI network. 3 corridors were in sub-regional level. Their functions were connecting patches and corridors and extending outward. The left 2 were local corridors. They acted to connect patches and corridors within the GI network (see in Fig. 9).

5.3 Coal mining subsidence patches in GI network

In our study, 10 of 17 patches have been already preserved. While, other 7 patches were not. It has to be emphasized

that 5 of unrestored patches were coal mining subsidence areas. They were Jiawang subsidence patch, Pangzhuang subsidence patch, Northern woniu subsidence patch, Southern Woniu subsidence patch and Dahuang mountain forest park patch (see in Fig. 10). In Xuzhou urban area, the current planning system mainly focused on the original ecological places that mostly remained in good natural status, however, ignored the ecological values of coal mining subsidence areas to a great extent.

Table 6 Classification of GI corridors in Xuzhou urban area

Level	Quantity	Content
Regional corridor	4	Beijing-hangzhou canal corridor, Northern mountains—Pan'an wetland—Cuihe reservoir corridor, Yunlong mountain—Tuolong mountain—Lvliang mountain corridor, Weishan lake—Jiuli lake—Pangzhuang subsidence area corridor
Sub regional corridor	3	Jiuli lake—Tuan mountain—Tuolong mountain corridor, Pangzhuang subsidence area—Woniu subsidence area—Yunlong mountain corridor, Weishan lake—Jianwang subsidence area—Dadong mountain corridor
Local corridor	2	Dahuang mountain—Tuan mountain—Yunlong mountain corridor, Pan'an lake, Jiuli lake, Woniu Subsidence area corridor

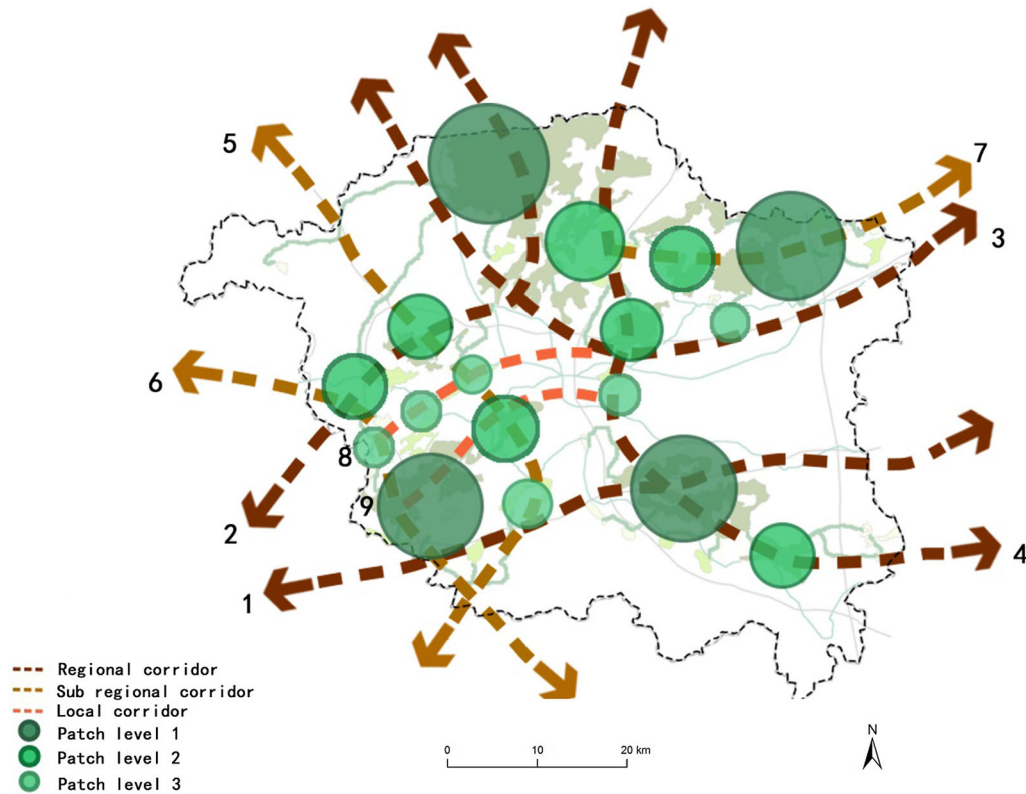


Fig. 9 GI pattern and corridors in Xuzhou urban area. Regional corridor: 1. Yunlong mountain—Tuolong mountain—Lvliang mountain corridor, 2. Weishan lake—Jiuli lake—Pangzhuang subsidence area corridor, 3. Northern mountains—Pan'an wetland—Cuihe reservoir corridor, 4. Beijing-hangzhou canal corridor. Sub regional corridor: 5. Jiuli lake—Tuan mountain—Tuolong mountain corridor, 6. Pangzhuang subsidence area—Woniu subsidence area—Yunlong mountain corridor, 7. Weishan lake—Jianwang subsidence area—Dadong mountain corridor. Local corridor: 8. Dahuang mountain—Tuan mountain—Yunlong mountain corridor, 9. Pan'an lake, Jiuli lake, Woniu Subsidence area corridor

6 Conclusion

6.1 Patches regulation

In order to realize the regulation and management of GI in Xuzhou urban area, we tried to put forward regulation suggestions for the elements in GI network. The patches regulations were proposed due to patches' level and existing ecological background of each one.

6.1.1 Level 1 patches

Level 1 patches contained Weishan wetland patch, Lvliang mountain scenic patch, Dadong mountain scenic patch, Yunlong mountain scenic patch. These patches covered natural reserve areas, scenic areas, forest parks, water conservation areas and other ecological sensitive areas. The ecological spaces in these areas were the core of the whole ecosystem and should be strictly regulated and protected. The specific regulation suggestions were as follows:

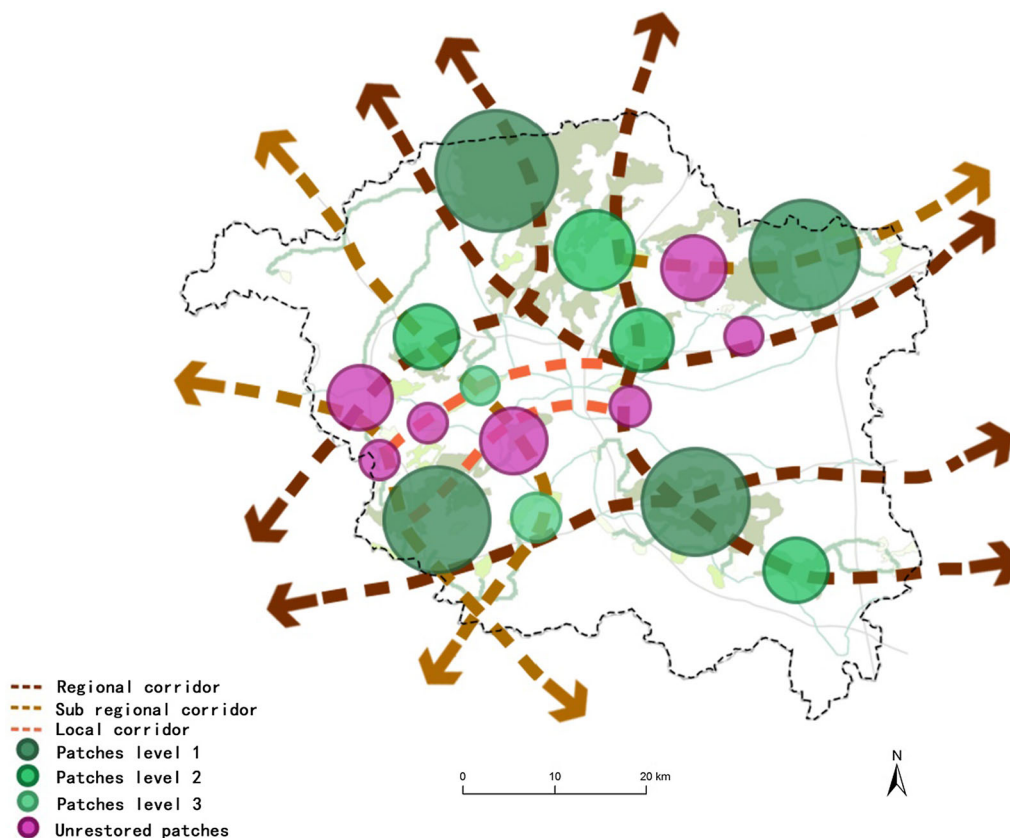


Fig. 10 Unrestored subsidence patches in GI network

- High-strength development and construction work are forbidden in these patches.
- Forest reservation and patches ecological integrity should be guaranteed.
- Ecological tourism can be appropriately carried out in areas where ecological sensitivity is not high.
- Cultural relics and historical sites should be protected and the buffer should be defined.

6.1.2 Level 2 patches

Level 2 patches contained Northern mountains forest patch, Pan'an wetland patch, Jiuli subsidence patch, Cuihe reservoir patch, Jiawang subsidence patch, Tuan mountain patch, Pangzhuang subsidence patch. These patches covered mountains, forest parks, reservoirs and wetlands. The specific regulation suggestions were as follows:

- Projects or constructions that may cause damage to wetlands, water sources and regional ecology should be forbidden.
- Enhance water source protection and recovery water quality and functions.

- Tourism development should be carried out in accordance with the latest master planning and special planning.
- Cultural relics and historical sites should be protected and Buffer should be defined.

6.1.3 Level 3 patches

Level 3 patches contained Tuolong mountain forest patch, Jiuli mountain patch, Northern Woniu subsidence patch, Southern Woniu subsidence patch, Dahuang mountain country park patch, Dongzhuang subsidence patch. These patches covered mountains, forest parks, and wetlands. The specific regulation suggestions were as follows:

- Limit the high-strength construction and construction activities in patches, and regulate the existing construction projects in the patches.
- Construction and tourism development can be carried out in accordance with the latest master planning and local standards.
- Cultural relics and historical sites should be protected and the buffer should be defined.

6.2 Coal mining subsidence patches regulation

In regard to coal mining subsidence areas, these places largely distributed in Xuzhou urban area and most of them remained unrestored. According to the patches importance evaluation, we divided coal mining subsidence areas into 3 levels to better integrate them into GI network. Priority Class 1 (high restoration priority), including: Jiuli subsidence patch, Jiawang subsidence patch, Pan'an wetland patch; Priority Class 2 (medium restoration priority), including: Dahuang mountain patch, Pangzhuang subsidence patch and northern Woniu subsidence patch; Priority Class 3 (low restoration priority), including: southern Woniu subsidence patch and Dongzhuang subsidence patch.

“Priority Class 1”. These patches were crucial in improving urban ecosystem services and habitat quality and strongly recommended to be integrated into urban GI network. These areas were suggested to be well preserved and restored into natural conservation. Large-scale human construction activities should be forbidden in these areas.

“Priority Class 2”. These areas had positive effects in improving urban ecosystem services and habitat quality and recommended to be integrated into urban GI network. These areas were suggested to avoid significant artificial trace and commercial activities, and be developed into parks and open spaces with appropriate human disturbance.

“Priority Class 3”. These areas had no obvious positive effects in improving urban ecosystem services and habitat quality and can be integrated into urban GI network when allowed by the objective conditions. These areas can be developed into either urban open spaces or used as construction lands.

6.3 Corridors regulation

6.3.1 Regional corridor

Regional corridor contained Beijing-hangzhou canal corridor, Northern mountains—Pan'an wetland—Cuihe reservoir corridor, Yunlong mountain—Tuolong mountain—Lvliang mountain corridor, Weishan lake—Jiuli lake—Pangzhuang subsidence area corridor. These corridors covered rivers, transportation, greenbelts, etc. These corridors connected key patches and made great significance for ecological resources circulation and urban ecological environment improvement. We suggested that restoration priority should be given to corridors of vital habitat and damaged areas. The human construction work should be strictly controlled on both sides of the corridors.

The width of the corridor was suggested as 300–500 m in this level.

6.3.2 Sub regional corridor

Sub regional corridor contained Jiuli lake—Tuan mountain—Tuolong mountain corridor, Pangzhuang subsidence area—Woniu subsidence area—Yunlong mountain corridor, Weishan lake—Jianwang subsidence area—Dadong mountain corridor, which covered rivers, transportation, greenbelts. These corridors mainly connected the regional corridor and promote the internal energy flow. The width of the corridor was suggested as 100–300 m in this level. The development and construction work on both sides of the corridor were restricted.

6.3.3 Local corridor

Local corridor contained Dahuang mountain—Tuan mountain—Yunlong mountain corridor, Pan'an lake, Jiuli lake, Woniu Subsidence area corridor. Types of local corridors were rivers mainly and connected regional corridors and sub regional corridors. The width of the corridor was suggested as 100 m in this level. The development and construction work on both sides of the corridor were restricted. Attention should be paid to purifying water quality and strengthening the ecological restoration on both sides of the corridor.

7 Discussion

In this study, we used a comprehensive approach to determine the patches, corridors and built up the entire GI network in Xuzhou urban area. The study was embodied the principle of “ecological priority”, demonstrating how a holistic perspective can be applied to local operation. It emphasizes that the target of ecological restoration should be started from a traditional “available” status to the overall urban ecology recovery and reconstruction. Therefore, this is an expansion in the research that focused on coal-resources based city, compared with the qualitative description and the overall evaluation of conventional methods. The approach and case study can be used as a reference for other coal-resource based cities, especially for those mining industrial cities that have ecological potentials.

However, some indicators can only reflect quantitative variances rather than quality aspects because of the mathematical characteristics of landscape patterns. Also, remote sensing interpretation is the basic of our study. When concerning about the ecology, we have not further discussed the mechanism of ecosystem services and

biodiversity in patches and between each other because of the data and methods. Additionally, expert scoring method requires researchers should validate the models to ensure their efficacy. All methods used and proposed in the study will depend on data availability for the region of interest. The formation of GI network is a long-term process with dynamic change. The research framework of this study was not sufficient to consider the dynamic connotation. Therefore, long-phase and multiscale studies are needed directions for future research. Time-scale ecological restoration scenario simulation can be conducted with the support of subsidence prediction and ecological monitoring.

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Compliance with ethical standards

Conflict of interest None of the authors have any competing interests in the manuscript.

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