land

MDPI

Article

Ecological Restoration and Protection of National Land Space in Coal Resource-Based Cities from the Perspective of Ecological Security Pattern: A Case Study in Huaibei City, China

Zixuan Li [1], Jiang Chang [1,2,3,*], Cheng Li [1] and Sihao Gu [4]

[1] School of Architecture and Design, China University of Mining and Technology, Xuzhou 221116, China
[2] Jiangsu Collaborative Innovation Center for Building Energy Saving and Construct Technology, Jiangsu Vocational Institute of Architectural Technology, Xuzhou 221116, China
[3] Research Center for Transition Development and Rural Revitalization of Resource-Based Cities in China, China University of Mining and Technology, Xuzhou 221116, China
[4] School of Architecture and Urban Planning, Nanjing University, Nanjing 210093, China
* Correspondence: changjiang@cumt.edu.cn

Abstract: Mining activities have contributed to the growth of the city, but also raised non-negligible eco-geological environmental issues that threaten ecological safety. Ecological security pattern (ESP), as an important grip on the ecological restoration and protection of national land space, helps to balance mining activities and ecological protection in coal resource-based cities. Taking Huaibei City as a study area, we applied the ESP research paradigm: an ecosystem "function-structure" conceptual framework was developed to identify ecological sources, the "coal mining subsidence—economic activities" framework was used to revise ecological resistance surface, and the circuit theory was used to extract ecological corridors. Then, key areas for ecological restoration and protection were identified, including ecological pinch points, barrier points, and fracture points. Finally, the pattern and strategies for ecological restoration and protection were proposed. Study results show that there were 51 ecological sources, covering an area of 152.75 km^2; 111 ecological corridors were extracted with 6000 as truncation threshold; 17 pinch points, 75 barrier points, and 117 fracture points were identified. Ecological restoration and protection patterns of "one axis, two shields, four zones, eight belts and multiple corridors", and strategies for key areas were proposed. The results of the study are important for the sustainable development of coal-resource-based cities.

Keywords: resource-based city; ecological security pattern; ecological conservation and restoration; circuit theory; Huaibei City

check for updates

Citation: Li, Z.; Chang, J.; Li, C.; Gu, S. Ecological Restoration and Protection of National Land Space in Coal Resource-Based Cities from the Perspective of Ecological Security Pattern: A Case Study in Huaibei City, China. *Land* **2023**, *12*, 442. https://doi.org/10.3390/land12020442

Academic Editor: Teodoro Semeraro

Received: 29 December 2022
Revised: 29 January 2023
Accepted: 3 February 2023
Published: 8 February 2023

1. Introduction

Coal resource-based cities are a type of city where the exploitation of coal resources is closely related to the development and decline of the city [1]. As an important part of China's urban types, coal resource-based cities have made a significant contribution to the country's development [2]. However, compared to general cities, coal resource-based cities have had direct or indirect impacts on natural ecosystems and the social life of human beings as a result of long-term and extensive coal mining activities [3,4]. There is a complex spatial relationship between mining areas and urban areas, and ecological problems are dynamic and variable [5,6]. Eco-geological environmental issues, including reduced urban ecological space, landscape instability and fragmentation, biodiversity loss, soil erosion, surface subsidence, and vegetation degradation, have affected regional land-use patterns and threatened ecological security [7–9]. Therefore, the ecological restoration and protection of coal resource-based cities can not only optimize the development of mineral resources but also contribute to green transformation and sustainable development [10].

Ecological restoration and protection have always been key and difficult issues for coal resource-based cities [11,12]. It is common to implement ecological restoration engineering measures from a targeted approach to a single ecological problem that has occurred or is occurring. Such as ecological reconstruction of abandoned coal mining areas [13,14], reclamation and monitoring of coal mining subsidence [15,16], prevention of soil erosion and water losses [3,17], and management of geological hazards such as landslides and ground fissures [18,19]. Although targeted restoration projects can reduce the risk of disasters, there may be conflicts between these separate projects [20]. Furthermore, it is difficult to relieve the overall ecological pressure on the region and restore ecosystem function [21]. Therefore, there is a need to focus on the systematic management of the whole spatial area of mountains, water, forests, fields, lakes, grasses, and sands [22,23]. With an integrated perspective of the whole area and all elements, carrying out ecological restoration and protection of the national land space, and restoring and rebuilding key areas that are vulnerable to damage and degradation is crucial to improving the overall efficiency of the ecological process and the level of ecological safety in the region.

The ecological security pattern (ESP) derived from landscape ecology is a spatially optimized allocation scheme for key ecological elements in the region, which is important for maintaining the integrity of the landscape pattern and regional ecological security [24,25]. The construction of ESPs is one of the basic ways to resolve the conflict between environmental protection and economic development to achieve regional ecological security and human survival security and to promote the implementation of ecological restoration and protection of national land space [26]. Therefore, it is more systematic and ecologically valuable to carry out ecological restoration and protection of national land space from the perspective of ESP. Theoretical and methodological research on the construction of ESPs is abundant [27]. At present, the basic paradigm of "ecological source—resistance surface—ecological corridor" has been initially developed [28].

In the process of identifying ecological sources, most previous studies have directly extracted large patches of landscape and nature reserves with good habitat conditions as ecological sources, failing to take into account the differences in the ecological functions provided by different types of ecological lands [29,30]. In recent years, studies have identified ecological sources based on the results of certain important ecosystem service functions or assessments of ecosystem sensitivity and importance [31–33]. However, the ecological space of coal resource-based cities has been squeezed and destroyed by mineral extraction, resulting in fragmented ecological structures. It is important to consider connectivity and landscape heterogeneity between ecological patches [34,35]. For the construction of the ecological resistance surface, many scholars assign resistance values to each type of land according to the landscape type and then revise them with the nightlight index or other indices such as impervious surface area (ISA) [36]. Some studies have also determined the resistance values for each land unit by referring to the results of ecological sensitivity assessments or based on the results of habitat quality [37,38]. Despite the universality of these approaches, coal mining activities have a large impact on the environment and coal resource-based cities need to consider the impact of issues such as geological hazards on ecological resistance factors. For the extraction of ecological corridors, the minimum cumulative resistance model (MCR), gravity models, and circuit theory are mostly used for identification [39–42]. The advantage that circuit theory has over other models is that it is not limited to identifying a single best path, but can identify all possible paths for animals to move between habitats [43]. On the one hand, the simulated current densities reflect the importance of the corridor and the nodes, giving the advantage of exploring the width of the corridor and accurately identifying the location of ecological pinch points [44]. On the other hand, the change in the current before and after the removal of each area allows for the identification of ecological barrier points, allowing for the accurate identification of areas that affect the connection between ecological sources [45,46]. This not only makes up for the difficulties of other models in responding to information exchange but also allows for the precise identification of key areas to be restored and protected, such as ecological pinch points and ecological barrier points [47,48]. The identification of key areas through circuit theory can guide the actual implementation of ecological restoration and protection of the national land space. Moreover, some researchers have proposed that significant impact of ecological fracture points on ecological processes [25]. Research has been conducted to provide ideas and methodologies for the development of ecological restoration and protection of national land space [49]. However, there is a lack of research on the ecological restoration of national land space for coal resource-based cities, and in-depth research is needed.

Huaibei City is a typical coal resource-based city in the Huang-Huai-Hai Plain of China. The city thrived on coal, with production spaces and living spaces concentrated in the mines for a long time. However, long-term coal mining activities squeezed and broke the ecological space. In addition, the large amount of coal mining subsidence affected the development pattern of the city. Following Huaibei City's inclusion on the list of resource-depleted cities in 2009, a series of ecological restoration projects for urban areas and mining areas were carried out, with certain ecological transformation results achieved. However, the city's overall ecological elements have not developed into a system, and there are potential threats to regional ecological security. Therefore, this paper conducted a study on the ecological restoration and protection of the national land space in coal resource-based cities using Huaibei City as the study area. Specifically, the objectives were to (1) identify ecological sources accurately by developing the ecosystem 'function-structure' conceptual framework; (2) revise the basic ecological resistance surface by using the ' coal mining subsidence—economic activities ' framework; (3) extract ecological corridors that are both economic and ecological and construct ESP on circuit theory; (4) identify ecological pinch points, barrier points, and fracture points to constitute key areas for ecological restoration and protection of the national land space; (5) lay out ecological restoration and protection pattern that take into account the ESP, ecological base and relevant planning; and (6) propose strategies for key areas under the local characteristics and the guidance of restoration and protection patterns.

2. Study Aera and Data Sources

2.1. Study Aera

Huaibei City is located in the Huang-Huai-Hai Plain in the north of Anhui Province, at the junction of the three provinces of Anhui, Jiangsu and Henan(116°24′–117°03′ E, 33°16′–34°10′ N). As shown in Figure 1, it contains three districts and one county, with a total area of 2741 km^2 and a resident population of approximately 2,254,000. The "enclave" Town—Duanyuan Town—bordering Xuzhou City in Jiangsu Province is special. Since the start of coal mining in 1957, Huaibei was founded on the basis of coal, and the city's development is closely related to the coal industry. After half a century of development, it has become an important industrial city in the Huaihai Economic Zone, and a typical coal resource-based city in eastern China. According to statistics, there are 80 mines with proven resource reserves in Huaibei City, of which 52 are coal mines. Long-term mining activities have encouraged urbanization, but have also brought many geological disasters such as subsidence, landslides, and fissures. Among them, there are 45 coal mining subsidence areas, with a total area of 40.83 km^2. Until now, the direct damage to the national land of Huaibei City due to mining is 190 km^2, and the damaged area is 817.28 km^2, which is approximately 29.8% of the municipal area.

2.2. Data Sources

Two data forms (spatial data and statistical data) were used. Spatial data included: (1) Land-use data for the year 2020 were provided by the third national land survey of Huaibei. Land-use data were reclassified as cultivated land, garden land, forest land, grassland, water, mining land, construction land, rural settlements, and bared land. (2) Digital elevation model (DEM) with a spatial resolution of 30 m supplied by the Geospatial Data Cloud (http://www.gscloud.cn/, accessed on 10 July 2022). (3) Annual average precipitation data in 2001–2020 were obtained from the National Earth System Science Data Center (http://www.geodata.cn, accessed on 12 July 2022) at a spatial resolution of

1 km. (4) Soil datasets were obtained from the National Cryosphere Desert Data Center (http://www.ngdc.ac.cn/, accessed on 20 July 2022) at a spatial resolution of 1 km. (5) The Nightlight Index for the year 2020 was obtained from National Oceanic and Atmospheric Administration (https://www.ngdc.noaa.gov/, accessed on 26 July 2022) at a spatial resolution of 500 m. (6) Evapotranspiration data for the year 2020 was obtained from MOD16A2 product for 8-day synthesis. The spatial resolution of data was 500 m. (7) Vector data, including administrative division, mining area, and mining subsidence, were supplied by the Bureau of Natural Resources and Planning of Huaibei. Statistical data included mining data from coal mines. These were derived from the report on the survey of coal mining subsidence areas and the third round of mineral resources planning in Huaibei City. All data were converted to the common spatial reference (WGS1984, UTM Zone 50 N), and the grid of raster data was resampled to be 30 m × 30 m.

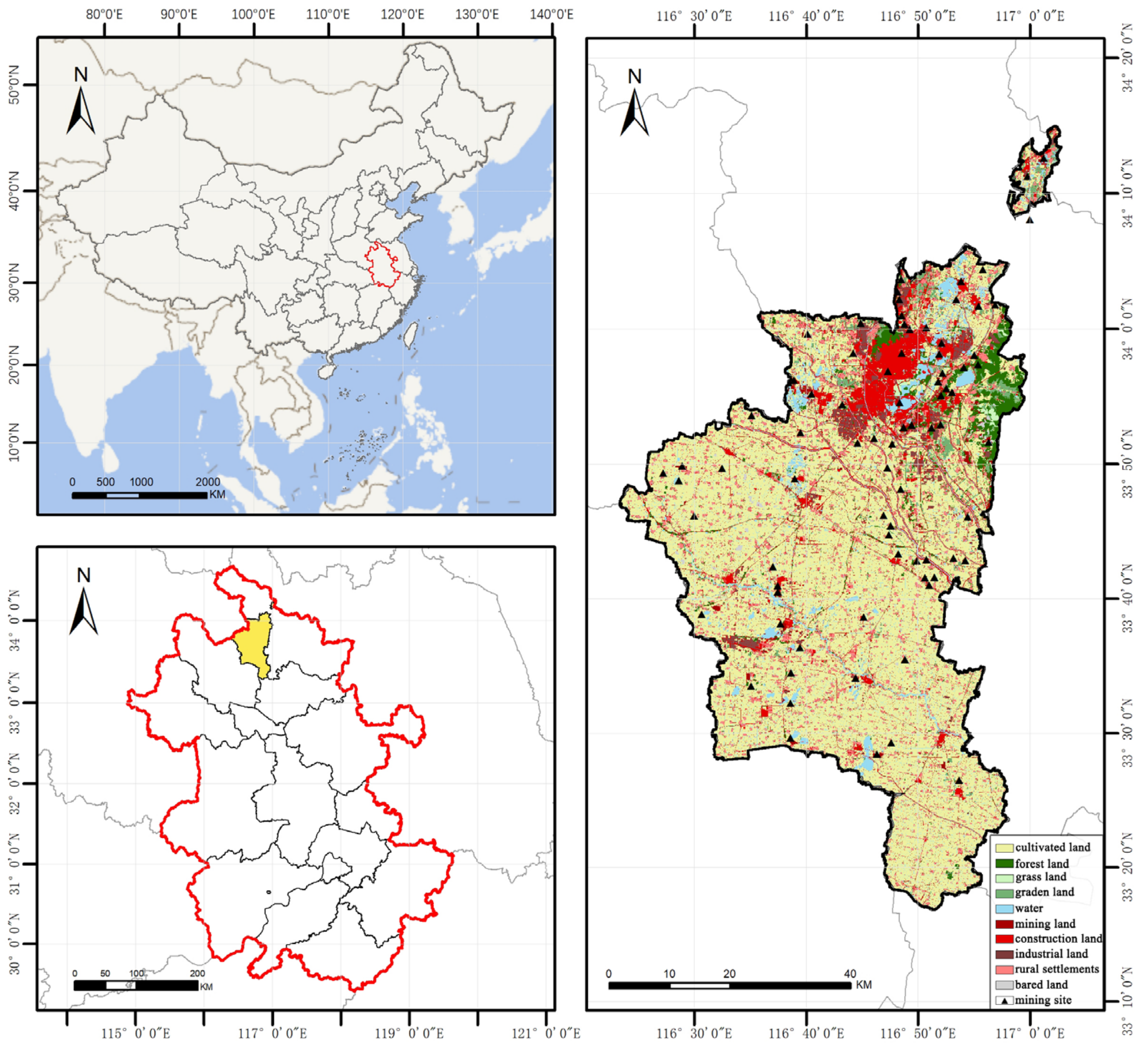

Figure 1. Location of Huaibei City.

3. Methodology

The logical line of "ESP—key areas—ecological restoration and protection pattern and strategies" is used in this study. The methodological framework is shown in Figure 2. Firstly, the ecosystem 'function-structure' conceptual framework was developed to identify ecological sources. 'Ecosystem Function' is to identify multifunctional ecological patches by assessing ecosystem service functions. "Ecosystem Structure' is a comprehensive analysis of landscape heterogeneity and landscape connectivity, identifying multifunctional ecological patches with good interrelationships and dynamic stability. Secondly, the basic ecological resistance surface is revised with' coal mining subsidence—economic activities ' framework. Thirdly, ecological corridors are extracted based on circuit theory and construct ESP with ecological sources and ecological corridors. Fourthly, based on the ESP, ecological pinch points, ecological barrier points, and ecological fracture points are identified as key areas for ecological restoration and protection. Finally, based on the ESP and characteristics of important mountains, rivers, lakes, and wetlands in the study area, ecological restoration and protection patterns and strategies for key areas are provided.

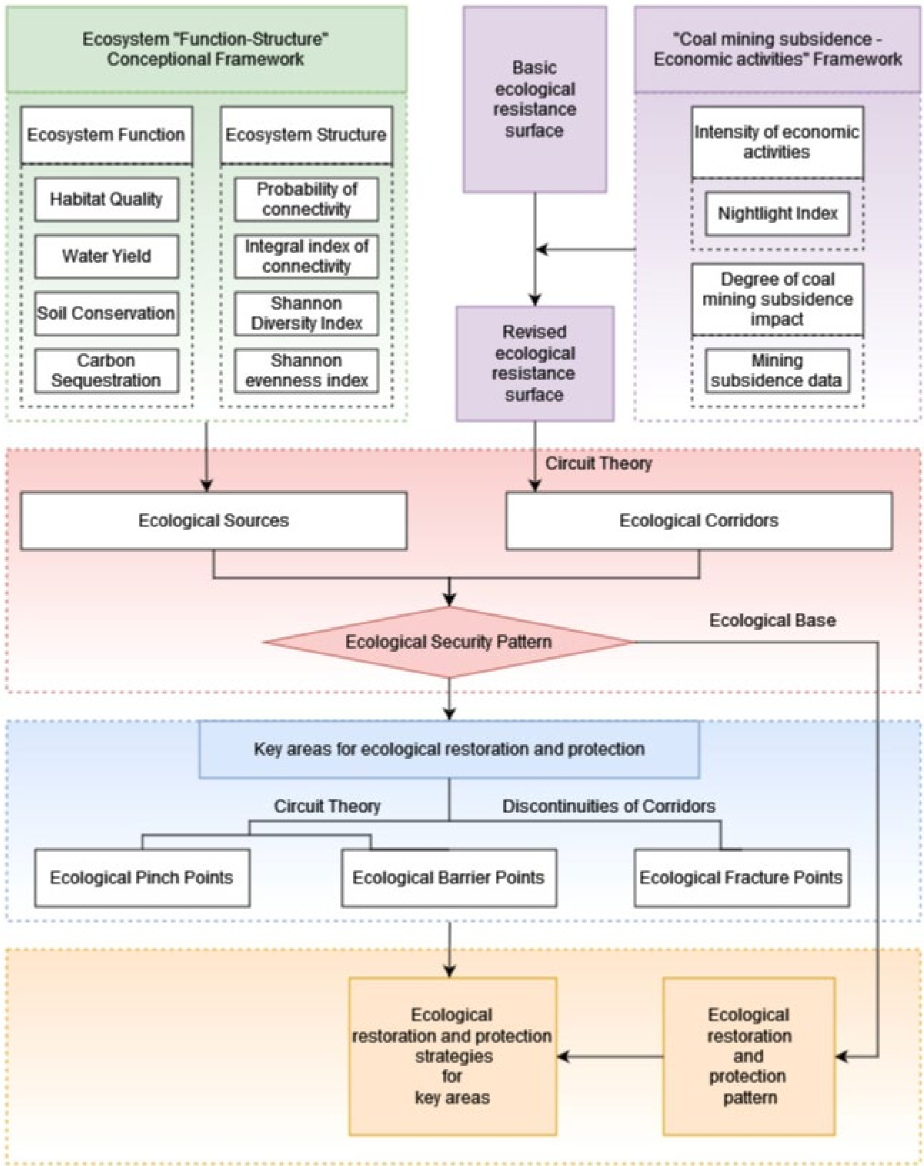

Figure 2. The research flow chart.

3.1. Identifying Ecological Sources with Ecosystem "Function-Structure" Conceptual Framework

3.1.1. Developing Ecosystem 'Function-Structure' Conceptual Framework

Ecological sources are the basis for constructing ESP and are ecological patches that are important to regional ecological security or have a radiating function. They should both have the ability to provide ecosystem services and maintain the structural stability of the ecosystem [50,51]. Structure, as the inner rule, characterizes the system; function is the expression of the role of structure and refers to the impact and utility of the functioning of the ecosystem on the surrounding environment. On the one hand, ecosystem function can significantly influence the formation and development of ecosystem structures, and, on the other hand, ecosystem structure determines ecosystem function to a certain extent [52]. Considering that coal resource-based cities are affected by mining activities, there are a large number of mining landscapes and unstable ecological environments. Therefore, in order to balance the importance of ecosystem function and structure in the identification of ecological sources, ecosystem "function-structure" conceptual framework is developed (Figure 3).

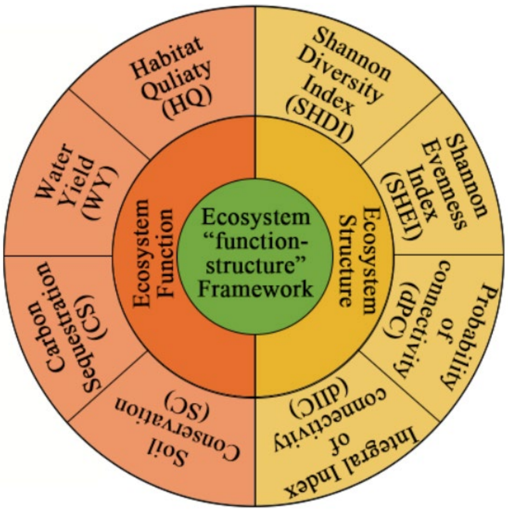

Figure 3. Ecosystem "function-structure" conceptual framework.

In terms of ecosystem function, ecosystem services can correspond to the three main ecological functions of ecological regulation, product supply, and habitat protection, which are key indicators of ecosystem health and sustainable development, and provide an important resource and environmental basis for human survival [53]. Quantitative assessments of ecosystem service functions can indicate the capacity of ecosystems to provide services to humans as a measure of ecosystem function [52,54]. Ecological processes are hampered to some extent by water scarcity, soil erosion, and loss of biodiversity due to human disturbance and coal mining activities in the study area. Therefore, four corresponding ecosystem service functions were selected for assessment, i.e., water yield, soil conservation, carbon sequestration, and habitat quality. The specific evaluation methods and calculation process are shown in Table 1.

Terms of ecosystem structures, also known as the organizing power of ecosystems, indicate the interrelationship of ecosystem components and the diversity of ecological elements [55]. The spatial continuity between landscape units directly influences the convenience of movement of energy and material between patches [52]. Ecosystem structure is one of the important indicators in the evaluation of regional ecological security and is mainly determined by landscape heterogeneity and landscape connectivity [51]. Landscape heterogeneity refers to the degree of inhomogeneity and complexity that ecosystem exhibit in terms of space and time. Despite its apparent heterogeneity, this state of affairs happens to erase to some extent the dramatic changes that occur in the landscape, tending more towards dynamic stability [56–58]. Landscape connectivity refers to the convenience of ecological flows and is an important indicator of ecological processes. Maintaining good landscape connectivity is one of the key factors in conserving biodiversity and maintaining the stability of ecosystems [59]. Therefore, in this study, landscape heterogeneity and landscape connectivity are selected to measure ecosystem structure quantitatively. The specific evaluation methods and calculation procedures are shown in Table 2.

Table 1. Methods and calculation processes for ecosystem service functions.

Ecosystem Service Functions	Method	Formula and Variable Description
Habitat Quality (HQ)	InVEST habitat quality model	$Q_{xj} = H_j\left[1 - \frac{D_{xj}^Z}{D_{xj}^Z + k^z}\right]$ Q_{xj}: habitat quality of raster x in land use type j; H_j: the habitat suitability of land use type j; D_{xj}: total threat level of raster x in land use type j; z: a scaling parameter and is 2.5 in this paper; k: a half-saturation constant, typically assigned a value of 0.5.
Water Yield (WY)	InVEST Annual Water Yield model	$Y_{xj} = \left(1 - \frac{AET_{xj}}{P_x}\right) \cdot P_x$ Y_{xj}: water yield of raster x in land use type j; P_x: annual average precipitation of raster x; AET_{xj}: evapotranspiration of raster x in land use type j.
Soil Conservation (SC)	modified universal soil loss equation (RUSLE)	$A_c = R \times K \times L \times S \times (1 - C)$ A_c: the amount of soil conservation (t/hm^2·a); R: the factor of rainfall erosivity (MJ·mm/hm^2·h·a); K:factor of soil erodibility (t·hm^2·h/hm^2·MJ·mm); L and S: are the topographic factors, this paper uses topographic relief to calculate.
Carbon Sequestration (CS)	InVEST carbon storage and sequestration model	$C_{\text{total}} = C_{above} + C_{\text{below}} + C_{\text{soil}} + C_{\text{dead}}$ C_{total} : the total amount of carbon storage; C_{above}: above-ground biomass carbon stocks; C_{below} : below-ground biomass carbon stocks; C_{soil} : soil carbon stocks; C_{dead} : dead organic matter carbon stocks. The biomass carbon density for the different land-use types was derived from the results of a relevant study [60].

Table 2. Methods and calculation processes for ecosystem structure.

Ecosystem Structure	Method	Formula and Variable Description
Probability of connectivity (dPC)	Conefor2.6	$dPC = \frac{PC - PC_{remove}}{PC} \times 100\%$ dPC: the patch importance for maintaining the overall probability of connectivity; PC_{remove}: the value of PC after removing a specific patch. The distance threshold was set to 5000 m, and the probability of connectivity was set to 0.5
Integral index of connectivity(dIIC)	Conefor2.6	$dIIC = \frac{IIC - IIC_{remove}}{IIC} \times 100\%$ $dIIC$: the patch importance for maintaining the integral index of connectivity; IIC_{remove}: the value of IIC after removing a specific patch. The distance threshold was set to 5000 m, and the probability of connectivity was set to 0.5
Shannon Diversity Index (SHDI)	Fragstats4.2	$SHDI = -\sum_{i=1}^{m}(p_i \times \text{In}(p_i))$ $SHDI$: Shannon Diversity Index; m: the total land-use type; p_i: the proportion of type i in the total type. The moving window search radius was set to 100 m
Shannon evenness index (SHEI)	Fragstats4.2	$SHEI = SHDI/\text{In}(m)$ $SHEI$: Shannon evenness index; m: the total land-use type. The moving window search radius was set to 100 m

3.1.2. Identifying Ecological Sources

Based on the ecosystem "function-structure" conceptual framework, we identify multifunctional ecological patches with a certain scale and stable ecosystem structure as ecological sources. Specifically, firstly, equally weighted superimposed ecosystem service function, and the natural breakpoint method was applied to classify the evaluation results into five levels, resulting in a comprehensive evaluation of multiple ecosystem service functions. The high-value area patches were extracted, which are multifunctional ecological patches. Secondly, equally weighted superimposed SHDI and SHEI, resulting in an assessment of landscape heterogeneity. The assessment of landscape heterogeneity is overlaid with multifunctional ecological patches, and the low-value patches are removed. Finally, small and fragmented patches with weaker radiation capacity were eliminated. Equally weighted superimposed dPC and dIIC of the extracted ecological patches, obtaining the integrated connectivity index (Ltx). The low-value patches are removed.

3.2. Revising Ecological Resistance Surface Using "Coal Mining Subsidence—Economic Activities" Framework

The ecological resistance surface expresses the extent to which the migration of species and the flow of energy in ecological processes are spatially disturbed by natural or anthropogenic activities [61]. Assigning various resistance values based on land use types to create ecological resistance is most commonly used [62,63]. However, this strategy not only ignores differences in ecological resistance under the same land type but also ignores the interference of anthropogenic activities. Coal resource-based cities have a more complex impact on ecological resistance from large-scale mining activities [64]. Additional assessment of anthropogenic activities disturbance is required, depending on the actual situation in the study area. In Huaibei city, long-term and extensive coal mining has resulted in varying degrees of coal mining subsidence, affecting the flow of material and energy in the ecosystem. At the same time, the coal industry promoted economic and social development and urbanization, making urban areas and mining areas closely related [5]. Therefore, the 'coal mining subsidence—economic activities' framework is used to revise the basic ecological resistance surface. The basic ecological resistance coefficient was assigned by land-use type. With reference to relevant studies [36,65], the basic ecological resistance coefficients for cultivated land, garden land, forest land, grassland, water, mining land, construction land, rural settlements, and bared land were assigned values of 120, 20, 50, 50, 20,300, 240,200 and 80, respectively. The specific revision of the basic ecological resistance surface by the "coal mining subsidence-economic activities" framework and the calculation process are shown in Table 3, and the final revised ecological resistance surface is calculated as follows:

$$R_m = 1/2R_x + 1/2R_I \tag{1}$$

where R_m is the final ecological resistance surface revised using the "coal mining subsidence—socio-economic" framework; R_x is the ecological resistance surface revised by the impact of coal mining subsidence; R_I is the ecological resistance surface c revised by data on nightlight index.

Table 3. Revising framework of "coal mining subsidence-economic activities".

Correct Indexes	Formula	Variable Description
The degree of coal mining subsidence impact	$R_x = \frac{CX_i}{CX_a} \times R$	R_x: ecological resistance values revised by the impact of coal mining subsidence; CX_i: the value of impact of mining subsidence of raster i; CX_a: the average value of mining subsidence impact for raster i corresponding to land use type a
Intensity of economic activities	$R_I = \frac{NL_i}{NL_a} \times R$	R_I: ecological resistance revised by nightlight index; NL_i: the value of nightlight index of raster i; NL_a: the average value of mining nightlight index for raster i corresponding to land use type a

3.3. Extracting Ecological Corridors and Constructing Esp Based on Circuit Theory

As a connecting vehicle for the transfer of material and energy flows and ecological processes between ecological sources, ecological corridors are important components of ESP [66]. Accurate identification and protection of ecological corridors is of great importance in safeguarding the integrity of regional ecosystems and maintaining the bottom line of ecological security [67]. In this study, Linkage Mapper 3.0 Toolkit software and circuit theory were used to extract ecological corridors. Circuit theory is a combination of landscape ecology and circuit random travel theory that draws on the physics of electrons traveling randomly in a circuit, treating the landscape as a conductive surface and the species in a complex landscape as a random wanderer and modeling the migratory movement of biological flows in a heterogeneous landscape [68–71]. Based on the determination of source and resistance, Linkage pathway tool in the Linkage Mapper 3.0 calculates cost-weighted distance (CWD) in multiple pairs of sources, creates a CWD surface to discern least-cost paths (LCP), and determines the location and shape of the corridors.

The spatial characteristics of the corridor width are closely related to the ecological functions it performs. While the widening of the corridor can make species more spatial path choices when migrating, it may also encroach on more construction land, as well as affecting the urban economy and requiring higher construction and maintenance costs. Therefore, the width of the ecological corridor should achieve balance relationship between ecological protection and economic development as far as possible. Referring to previous research methods [22], firstly, the truncation threshold of the ecological corridor was increased from 1000 to 10,000 (minimum truncation increment was 1000). Secondly, we spatially superimposed ecological corridors and the current land-use data. Finally, we calculated the growth slope k of overlapping area of corridor and construction land to determine the width of the ecological corridor. Ecological sources and ecological corridors together form the ESP of Huaibei.

3.4. Identifying Key Areas for Ecological Restoration and Protection

3.4.1. Identifying Ecological Pinch Points

Ecological pinch points, also known as 'bottlenecks', are areas with a high probability of migration of species, high density of biological flows, which are important for connectivity of the sources [70]. In circuit theory, pinch points are identified by grounding one node and feeding the same current to each of the other nodes. The cumulative current density value of each image element is obtained by iterative operations, and the area with the high current density value is the pinch point [72]. Ecological degradation or loss of pinch points is likely to compromise connectivity between ecological sources [73]. This study uses the Pinchpoint Mapper tool in the Linkage Mapper 3.0 Toolkit and selects the "all-to-one" mode iterative operation with the same threshold as the ecological corridor. Current density value was divided into three levels by the natural breakpoint method. The high-value areas were extracted, which are pinch points.

3.4.2. Identifying Ecological Barrier Points

Ecological barrier points are areas where the movement of species between ecological sources is impeded, and their removal will greatly improve connectivity between sources. In circuit theory, barrier points are identified by calculating the magnitude of the cumulative current recovery value. The higher values represent the greater contribution to improving overall landscape connectivity when the area is removed, and its restoration can significantly reduce resistance to the migration process of species [46]. This study uses the Barrier Mapper tool in the Linkage Mapper 3.0 Toolkit and selects the Maximum mode. With reference to existing studies and the average width of the patches in the study area, we use a radius of 200 m for the iterative operations. Current recovery value was divided into three levels by the natural breakpoint method. The high-value areas were extracted, which are barrier points.

3.4.3. Identifying Ecological Fracture Points

Ecological fracture points are interstitial points at discontinuities in ecological corridors. Ecological fracture points affect the fluidity of material and energy flows in ecological corridors [31,74]. In this study, the intersection of the main transport routes, railways, and ecological corridors are identified as ecological fracture points. Additionally, considering the special characteristics of coal resource-based cities, mining sites located within the corridor are included. In contrast to ecological barrier points, ecological fracture points are irreplaceable major transport infrastructures or mining enterprises that are major contributors to regional development and cannot be easily demolished. Therefore, targeted ecological restoration tools are needed for ecological fracture points.

4. Result

4.1. Ecological Sources

4.1.1. Results of Ecosystem Function

The results of the assessment of ecosystem service functions with grades 1–5 representing the lowest to the highest grade of importance. As shown in Figure 4, the areas with habitat quality above Grade 4 are mainly located in the forested areas of the northeastern and in wetland parks of the central portion, which have a lot of vegetation and have undergone ecological restoration projects. The high-value areas for soil conservation are mainly concentrated in the forested areas and mountainous areas in the north, while all other areas are low. Huaibei City has been subjected to long periods of mineral resource development, with problems of soil erosion exacerbated by poor forest land conditions. The high-value areas for carbon sequestration are also located in mountainous and forested areas. In terms of water yield, the value of construction land is high due to the low infiltration of precipitation and high flood flows on impermeable surfaces; the infiltration of forest land soils is high and has a deterrent effect on surface runoff, and thus the value of the water yield is low. Overall, the important areas of multiple ecological functions above Grade 4 are mainly located in the northern forested area, the scattered waters in the southern, and the 'enclave' town. Superposition of single and multiple ecosystem functions at five grades to obtain multifunctional ecological patches, which have an area of 160.45 km^2 (5.85% of the study area) and are concentrated in the north and scattered in the south. These areas are important components of regional ecological sources.

4.1.2. Results of Ecosystem Structure

As shown in Figure 5, SHDI and SHEI are consistent with the spatial distribution. As a whole, the landscape heterogeneity shows a spatial characteristic of high in the north and low in the south. The high-value areas are mainly located in the main urban areas, Duanyuan Town and the Linhuan Mining Area. As the main distribution area of towns and mining areas, the land-use types are variable and composed of many categories due to the impact of human and mining activities. In contrast, the land-use types in central and southern are dominated by cultivated land, which is less affected by human activities, thus leading to lower values of landscape heterogeneity in these areas. We overlaid the multifunctional ecological patches with the evaluation of the landscape heterogeneity, eliminated patches with poor landscape heterogeneity (at Grade 1), and further selected ecological patches with an area greater than 0.5 km^2 to calculate landscape connectivity. They have the ability to characterize the ecological status of the entire study area [34]. The spatial distribution of dPC and dIIC for extracted patches is very similar. High values are concentrated in the north, while low values are mainly distributed in Duanyuan Town and the southern cities. The result of Ltx is a composite reflection of landscape connectivity. The patches with Ltx below Grade 2 are mainly located in the south and west.

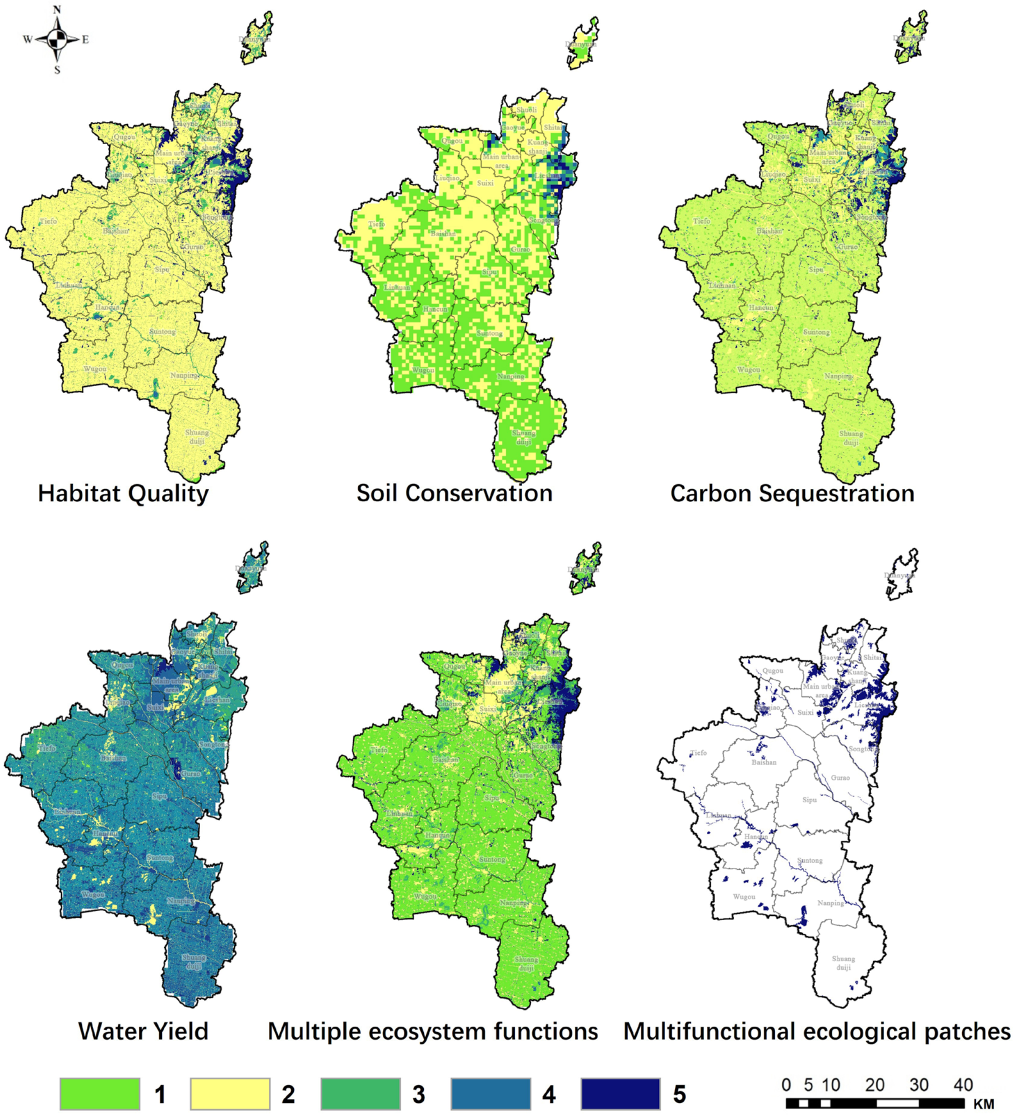

Figure 4. Spatial distribution of ecosystem service functions grades and multifunctional ecological patches in Huaibei City (Grade 1 = lowest; Grade 5 = highest).

4.1.3. Identifying Ecological Sources

Ecological sources are defined as multifunctional ecological patches with stable ecosystem structures, as well as patches larger than 0.5 km^2. There are 51 ecological sources, covering an area of 152.75 km^2, accounting for 5.57% of the total area of the study area. Huaibei City has few ecological sources and their spatial distribution is uneven, with a pattern of "concentrated in the north and sparse in the south", divided into four areas of distribution. Specifically, the first is the eastern and northern mountain woodland zone, including the Longji Mountain, Xiang Mountain, and Huajia Lake reservoirs, etc.; the second is the central lake wetland zone, including the South Lake, Middle Lake, and Lvjin Lake wetland parks; the third is the central river zone, including the upstream and downstream sections of the Xiaosuixin River and the Nantuo River; the fourth is the southern river wetland zone, including the natural river wetland of the Kuai River and the coal mining subsidence wetland of the Linhuan Mining Area. Essentially, there are no ecological sources in the south side of the Kuai River, which is related to the presence of a large number of active coal mines in southern city. Additionally. Duangyuan Town, which is a special enclave town in the study areas, lacks ecological sources.

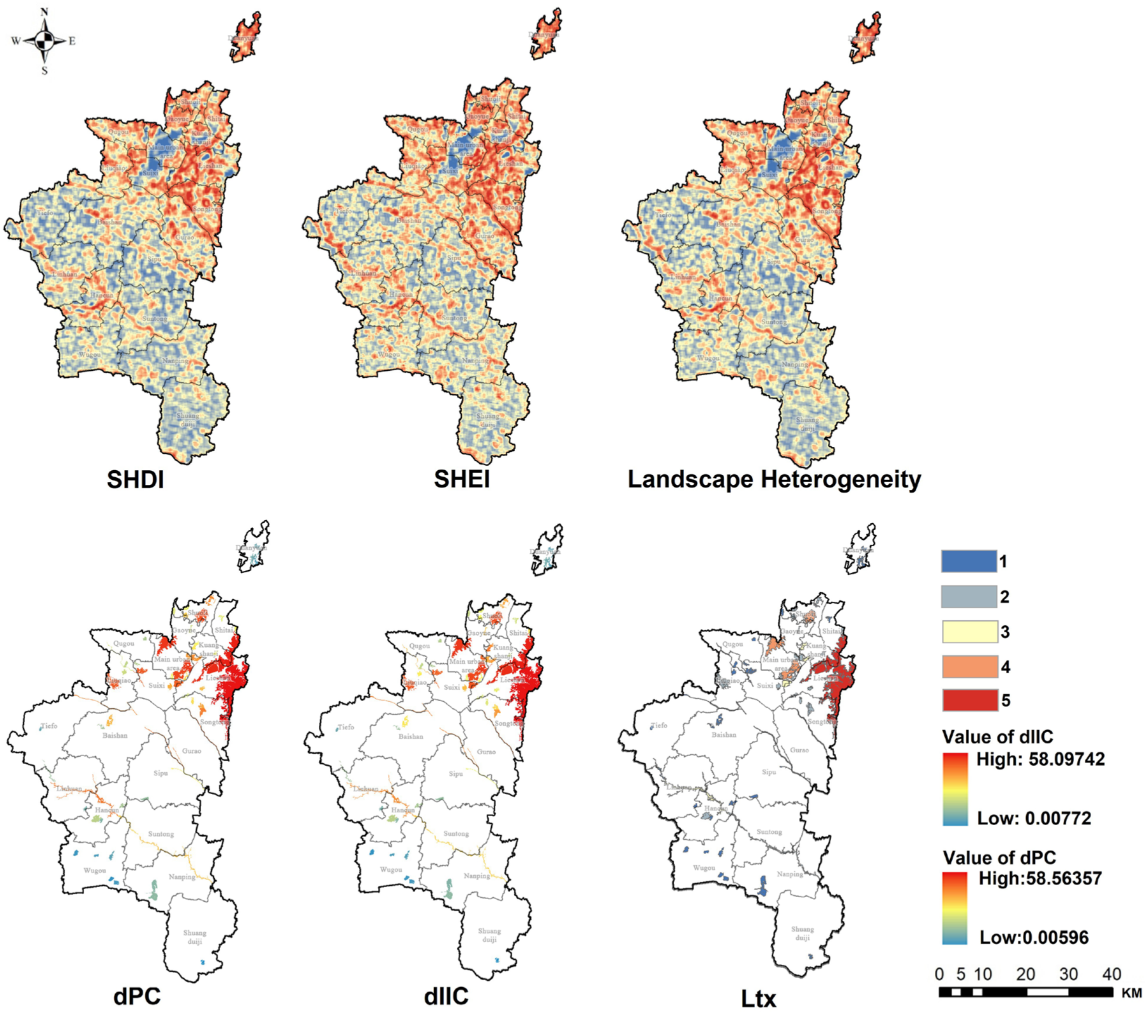

Figure 5. Spatial distribution of ecosystem structure grades in Huaibei City (Grade 1 = lowest; Grade 5 = highest).

4.2. Ecological Resistance Surface

As shown in Figure 6, the basic ecological resistance values assigned by land-use type range from 20 to 300. This study uses the "coal mining subsidence—economic activities" framework to revise the basic ecological resistance surface, demonstrating the special characteristics of coal resource-based cities. The value of coal mining subsidence impact degree is between 0 and 5, with an average value of 2.51. The high-value areas are mainly located in the coal mining subsidence area of northern Shuoli Town, western Baishan Town, and Linhuan Mining, and the dynamic subsidence area of Renlou Mining Area. The value of the nightlight index represents the intensity of economic activities, which ranges from 34 to 174, with an average value of 69.1. The high-value areas are mainly located in the main urban areas and the southern Linhuan and Qingdong mining areas due to the dense population. The spatial heterogeneity of the ecological resistance surfaces, as revised by the 'coal mining subsidence-economic activities' framework, is significant, reflecting the fact that Huaibei is affected by the disturbance of mining activities and anthropogenic activities. The values of the revised ecological resistance surface range from 11.11 to 505.01, with a mean value of 128. The overall spatial characteristics show high resistance values in the north and south and low values in the central portion. The high-value areas are mainly the concentration of mining and construction land, which has a certain resistance effect on energy and material exchange.

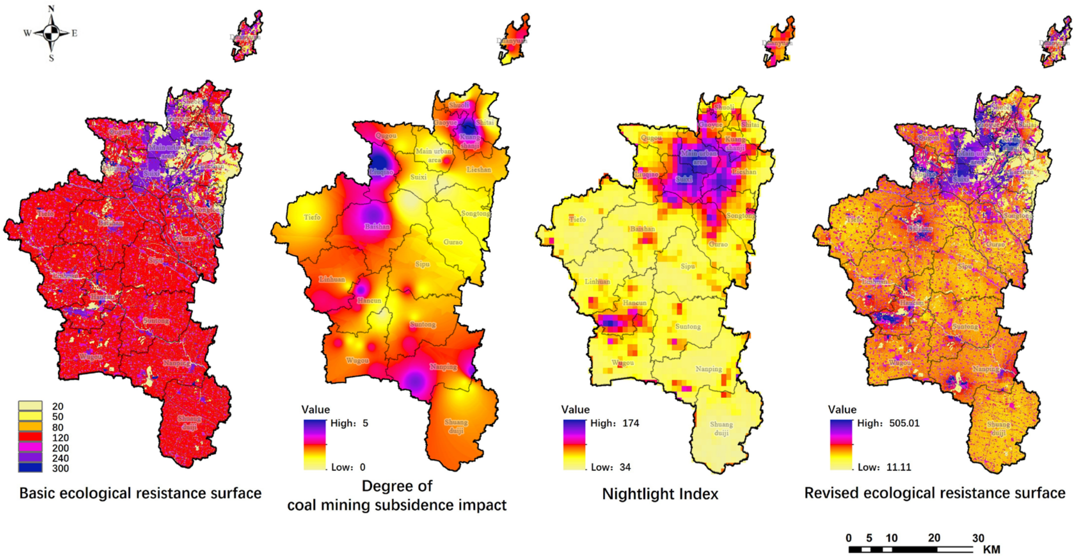

Figure 6. Spatial distribution of ecological resistance surface.

4.3. Ecological Corridors

Based on circuit theory, the width of the ecological corridor is determined by the cumulative truncation threshold for the CWD. By comparing the overlapping area of construction land and ecological corridor, the optimal corridor width is determined to achieve the goal of i dual stability of ecological protection and socio-economic development. The results show that the corridor width increases as the threshold increases, but the overall spatial layout does not change significantly (Figure 7). The area of the corridor at different thresholds is shown in Figure 8. The area of the ecological corridor increases from 16.24 km^2 to 61.29 km^2. While the widening of the corridor area can make species face more spatial path choices when migrating and enhances regional stability, it may also encroach on a certain amount of construction land of the city. The statistical comparison of the overlapped areas shows the following (Figure 9): In the 1000–6000 threshold range, the growth slope k of the overlapping area of corridor and construction land is relatively flat. When the threshold is greater than 6000, in the range of 7000–10,000, the growth slope k increases abruptly, representing a significant increase in the amount of construction land that would be occupied if the corridor were to be extended beyond this threshold. Under the trade-off between ecological conservation and economic development, we concluded that 6000 would be more conducive to achieving the balance. Therefore, we have chosen 6000 as the cumulative truncation threshold to determine the width of the corridor and thus constructed ESP.

There are 111 ecological corridors, ranging from 0.04 to 22.25 km in length, with a total length of 472.24 km and a total area of 33.07 km^2, accounting for 1.2% of the study area, the land-use types are mostly water, forest, and grassland. Of these, ecological corridors in the north are more numerous, densely distributed, and shorter. Although ecological sources are concentrated in the northern city, close to each other, and have a potential tendency to be connected, they do not form connected corridors. The southern ecological corridors are distinctly linear, sparsely distributed, and span a large area. This is because ecological sources in the south mainly consist of the Nantuo River, the Kuai River, and the coal mining subsidence wetlands, which are separated from each other by a large spatial distance, and the ecological resistance surface is mainly cultivated land with low resistance values. Overall, the spatial pattern of corridors is “dense in the north, sparse and long in the south”.

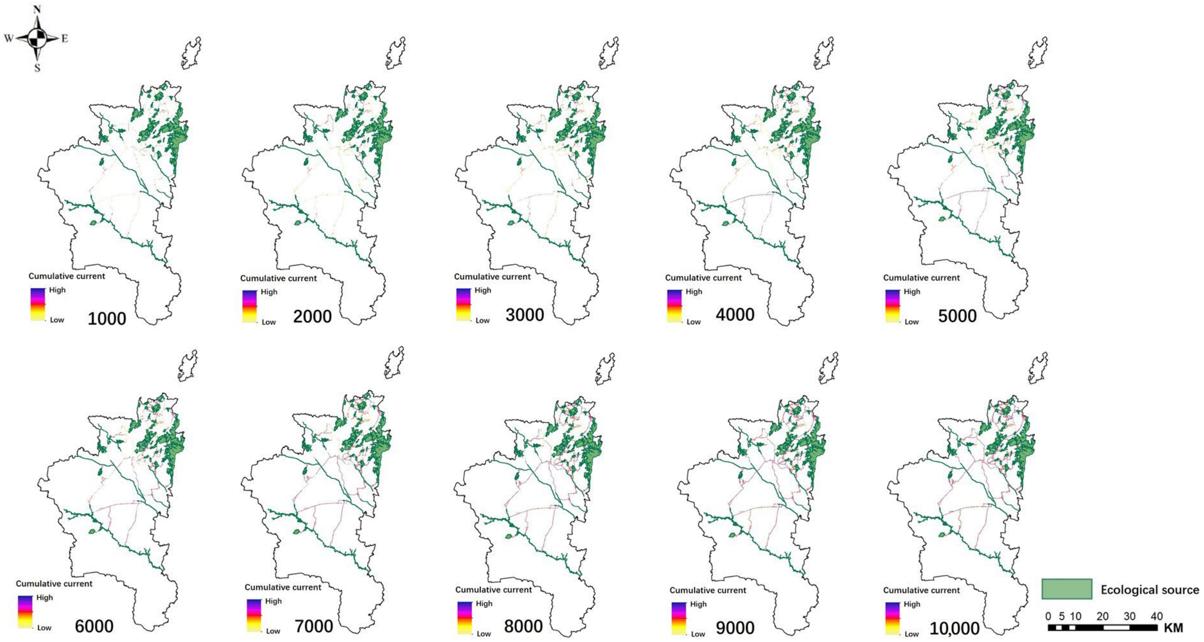

Figure 7. Spatial distribution of ecological corridors for thresholds from 1000 to 10,000.

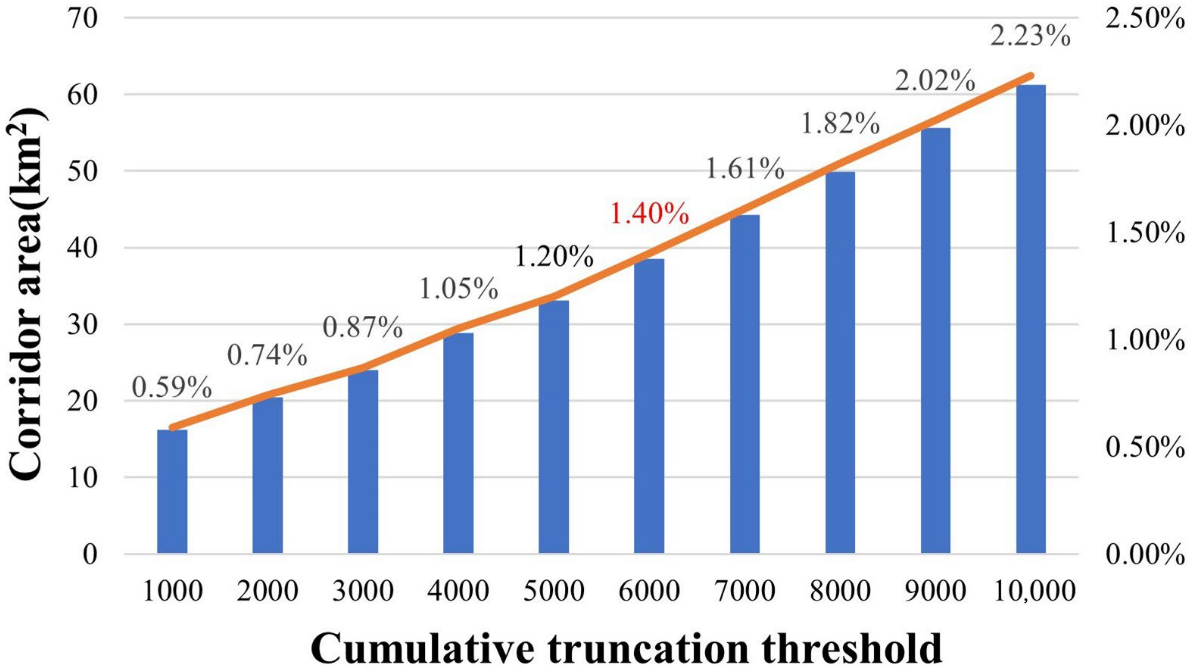

Figure 8. Corridor area under different thresholds.

4.4. Ecological Security Pattern

The ecological elements of sources and corridors together construct the ecological security pattern in Huaibei (Figure 10). These include 51 ecological sources, which are all multifunctional patches with stable ecosystem structures, consisting of water and forest land and providing important habitats for organisms; 111 ecological corridors, which show the network pattern, linking sources in an organic way, providing an accessible path for species migration.

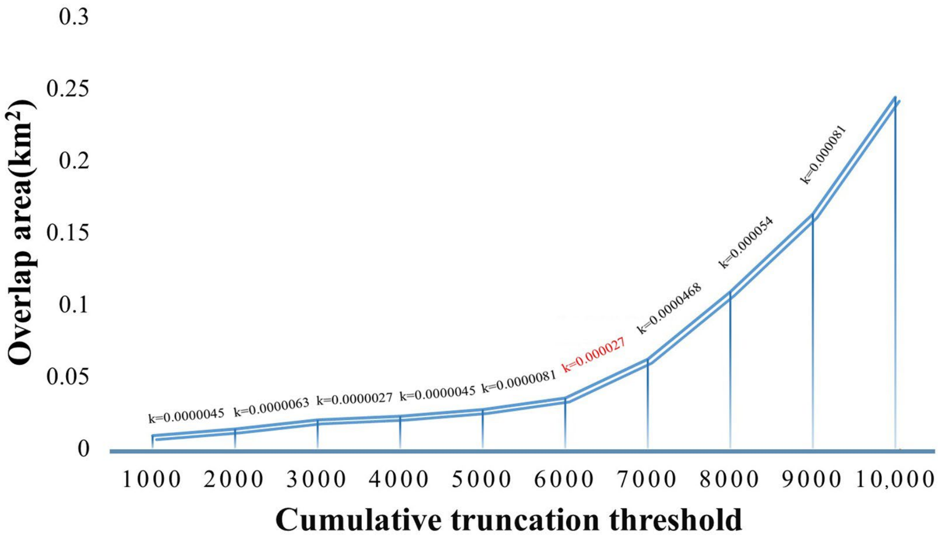

Figure 9. Area of overlap between different corridor areas and construction land.

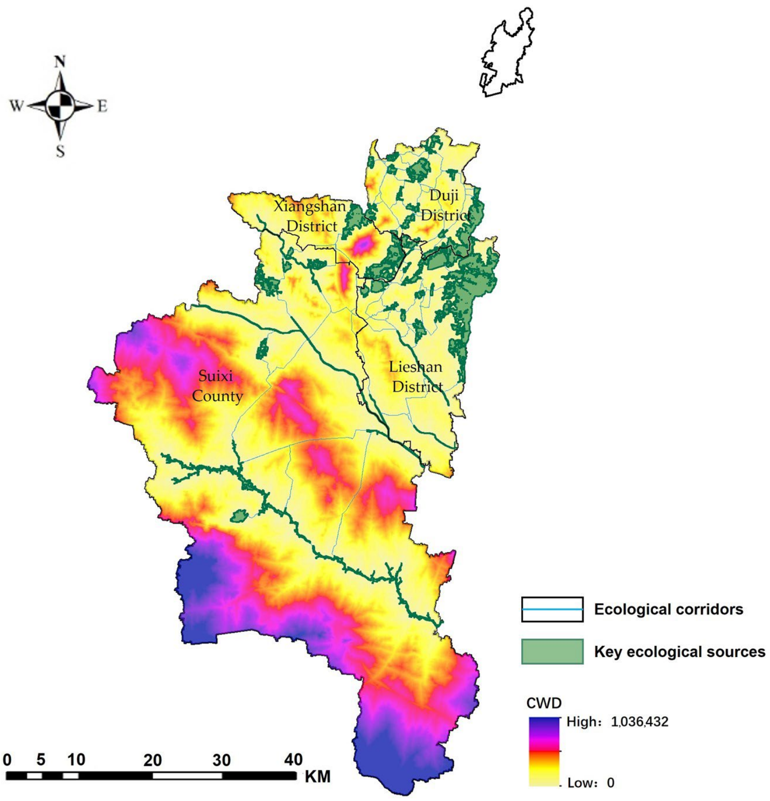

Figure 10. Spatial distribution of ESP.

4.5. Key Areas for Ecological Restoration and Protection

4.5.1. Identifying Ecological Pinch Points

As shown in Figure 11, a total of 17 ecological pinch points were identified, with a total area of 3.71 km^2. These pinch points show a "dense north-south comb" pattern, with the majority of them located in the north of the Nantuo River, with a total of 15. On the administrative scale, there are seven pinch points in Lieshan District, three in Duji District, four in Suixi County, and one in Xiangshan District (Table 4). This represents that inter-source species movement is more intensive in the northern city and less connected in the southern region with large spatial separation and high cumulative ecological resistance between sources. From the perspective of spatial characteristics, pinch points are distributed in narrow strips and overlap spatially with ecological corridors in Huaibei. The superposition of pinch points with the current land-use data shows that the current land use of the pinch points is mainly composed of water and forest land, with water accounting for the largest proportion (70.12%). The superposition with remote sensing images shows that the ecological pinch points in Duji District and Lishan District are mainly composed of natural rivers; pinch points in Xiangshan District are mainly composed of trees and grassland at the connection between forestland and rivers; pinch points in Suixi County are mainly composed of artificial ditches connecting the main natural rivers. In general, the ecological connectivity function undertaken by rivers and ditches and their surrounding areas is prominent. However, most of the pinch points are located in the main urban area and are at high risk of ecological degradation due to the impact of surface runoff and pollutant discharge. These areas, which are irreplaceable and important for enhancing interconnectivity between sources, need to be protected and restored.

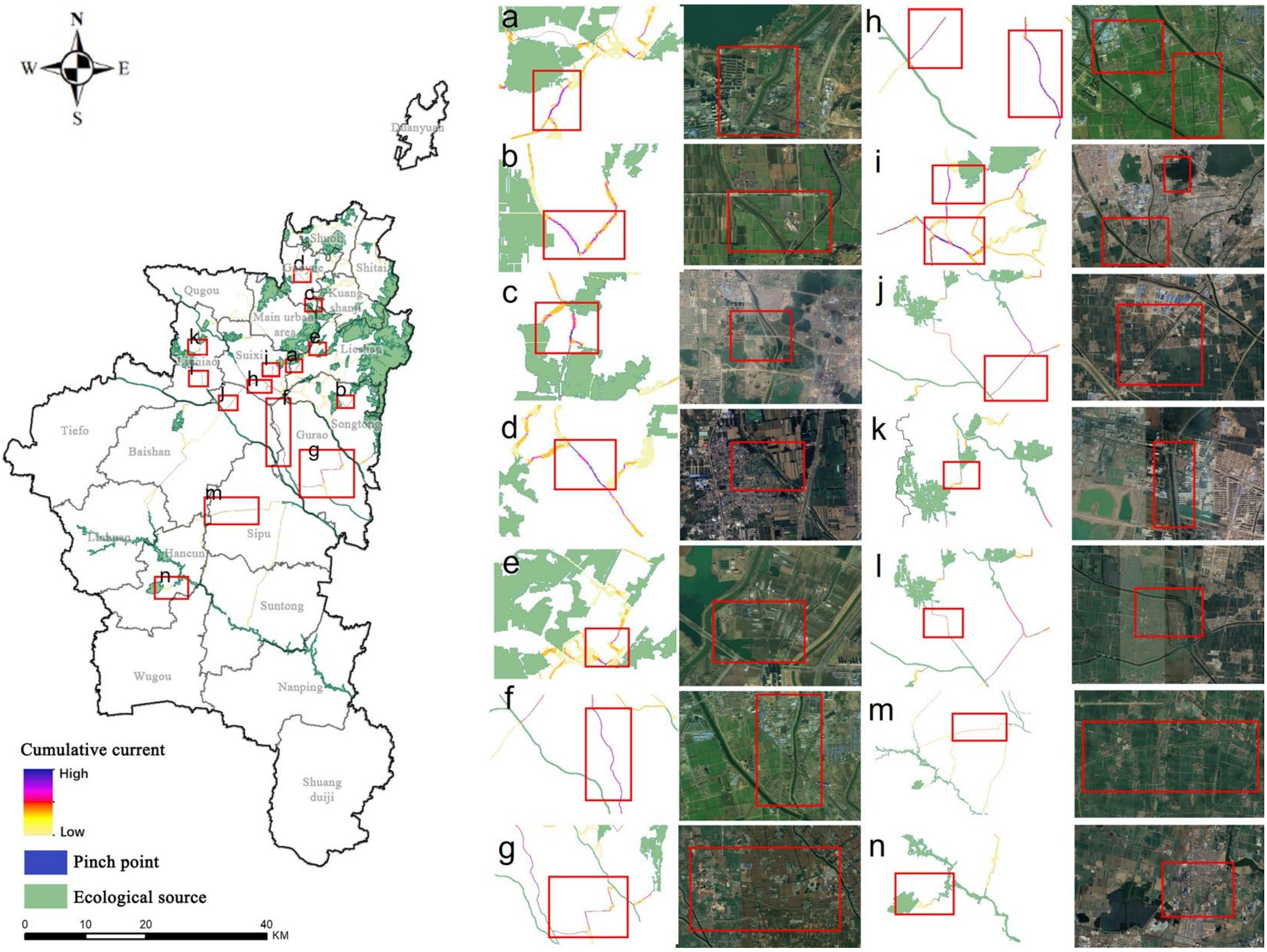

Figure 11. Ecological pinch points in Huaibei City. Red frame shows the exact location of pinch points. Subfigures(**a**–**n**) are subfigures showing a real view of pinch points.

Table 4. Distribution of ecological pinch points in Huaibei City.

Districts	Number	Area (km^2)	Location	Land-Use Type
Xiangshan District	1	0.20	1. The connection of Xiangshan Forest Park with the Xiaosuixin River	Forest land Grassland
Lieshan District	7	1.28	1. The Longdai River (east of South Lake, south of Shuoyong Road)	Water
			2. Confluence of Ji Ditch and the Zha River	
			3. The Wangyin River (the section from Xiaohuai Road to S101)	
			4. Pa River—Qiujia Ditch—Changfu Canal (confluence of the Xiao Xiaosuixin River and the Zhahe River)	
			5. The Ditch connecting the Hongjian River to the Wangyin River	
			6. Confluence of the Laosui River and Xiaosuixin River	
			7. The Old Sui River (the middle section between Qianlong Lake and Nan Lake)	
Duji District	3	0.53	1. The Dai River (the section from Huaihaidong Road to Lianxin Avenue)	Water Cultivated land
			2. The Dai River (the section of Pangshan Village)	
			3. The connection between the Longdai River and the Zha River	
Suixi County	6	1.70	1. The Ditch connecting the Hongjian River to the Wangyin River	Water Cultivated land
			2. Suilin Ditch (confluence of the Nantuo River and Xiaosuixin River)	
			3. The Zhi River (the section from Baiyang Road to Suiyong Road)	
			4. Wangyin Ditch (the middle section of Cao Ditch and Pa River)	
			5. The Jiehongxin River (the middle section of the Suiti Ditch and Yanming Ditch)	
			6. The connection between Linhuan Lake with the Kuai River	

4.5.2. Identifying Ecological Barrier Points

A total of 75 ecological barrier points were identified, covering a total area of 16.37 km^2. These barrier points are densely distributed in the main urban area, showing a pattern of scattered and trivial distribution (Figure 12). Of these, there are 27 barrier points in the Lishan District, 34 in Duji District, 12 in Suixi County, and 2 in the Xiangshan District (Table 5). For the area scale, the number of obstacle patches with an area of less than 0.1 km^2 is 37, accounting for 49.33%; there are only 8 patches with an area of more than 0.5 km^2, which are mainly located within mining areas in Shuoli Town and Songtong Town. Overall, barrier points are mainly located near the ecological corridor and the edge of the ecological source. The superposition of barrier points with the land-use data shows that the largest proportion of the land-use type is construction land, accounting for 36.33%, followed is cultivated land, accounting for 29.53%, and the smallest is patches of land, such as forest land and water, a total of 2.3%. The superposition with remote sensing images shows that the barrier points in Duji District are mainly composed of township settlements and industrial factories around ecological sources; barrier points in Xiangshan District are mainly composed of industrial and mining enterprises and farmland in the mining areas; barrier points in Lieshan District are mainly composed of residential communities next to the ecological sources; and the barrier points in Suixi County are mainly composed of rural settlements and farmland near the ecological corridor. In general, construction land, dominated by industrial factories and residential communities, has the greatest impact on the fluency of species migration. These areas have high ecological resistance values and directly affect the connectivity between sources. Additionally, mining activities and population density also contribute directly or indirectly to the formation of barrier points.

By developing ecological protection and restoration strategies to remove ecological barrier points, the capacity for material flows in ecological processes can be enhanced.

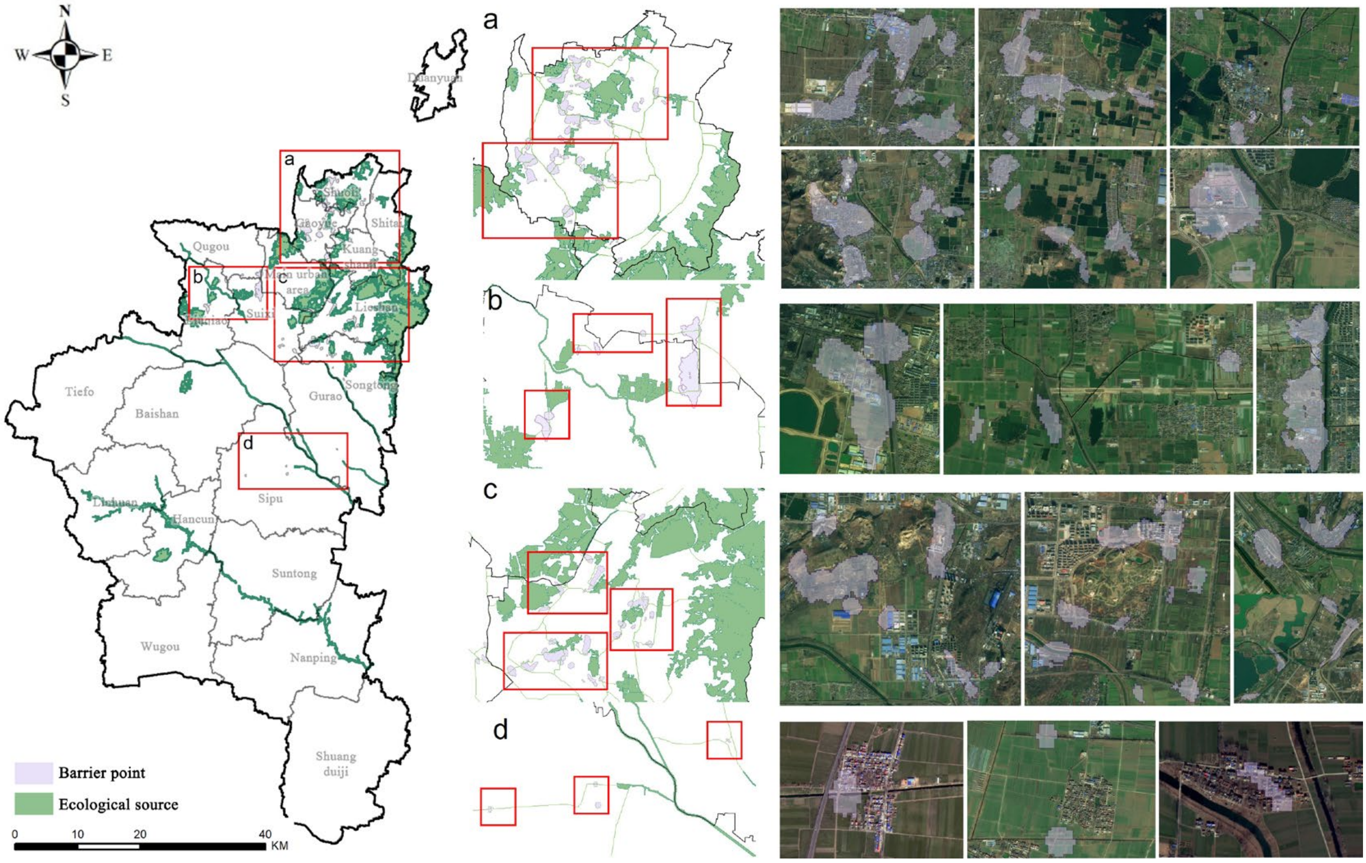

Figure 12. Ecological barrier points in Huaibei City. Red frame shows the exact location of barrier points. Subfigures(**a**–**d**) are subfigures showing a real view of barrier points.

Table 5. Distribution of ecological barrier points in Huaibei City.

Districts	Number	Area (km^2)	Location	Land-Use Type
Xiangshan District	2	0.70	Southern Qugou Town; Adjacent to Qugou Town and Suixi Town	Construction land Cultivated land Rural settlements Mining land Grassland
Lieshan District	27	4.36	Southern Gurao Town; Southwestern Lieshan Town	Construction land Cultivated land Mining land Water
Duji District	34	8.47	Mid-Southern Shuoli Town; The central portion of Gaoyue Street; Southern Shitai Town; Western Kuangshanji Town	Construction land Rural settlements Cultivated land Mining land
Suixi County	12	2.84	Mid-Northern Liuqiao Town; Northern and Eastern Suixi Town; The central portion of Sipu Town	Rural settlements Cultivated land Water

4.5.3. Identifying Ecological Fracture Points

Ecological fracture points hinder landscape connectivity and pose a threat to the fluidity of biological flows. From the identification results of the fracture points, there are 117 fracture points in Huaibei (Figure 13). Of these, ecological corridors have 84 intersections with main transport routes, 21 with railways, and 12 mines (including 2 coal mines, 1 clay mine, 5 quarries, and 4 metal mines) that are still in production or under infrastructure (Table 6). In terms of spatial distribution, fracture points are concentrated within the main urban area. Huaibei was formed by mines, and the mining areas and city are integrated and closely related. As a result, the dense traffic network in the main urban area and the non-stopped mines impede connectivity between sources. Although fracture points exacerbate ecological resistance, railways, routes, and mining sites all affect local economic development and people's livelihoods and cannot be removed directly. Additional targeted facilities are needed at the fracture points, which can alleviate the conflict between species migration and human activities to a certain extent.

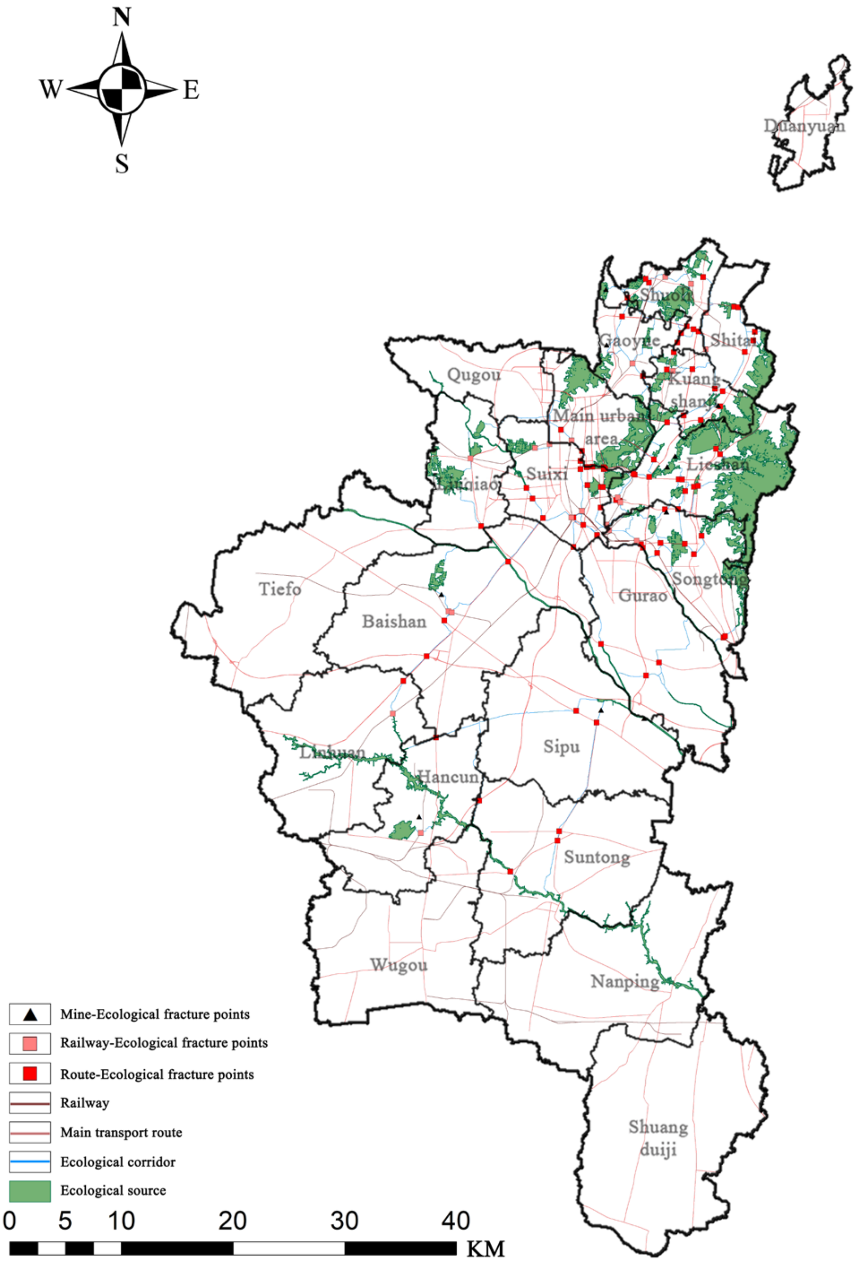

Figure 13. Ecological fracture points in Huaibei City.

Table 6. Distribution of ecological fracture points in Huaibei City.

Types	Number	Location
Route-Ecological fracture points	84	Northwestern and southern Shuoli Town; Eastern Shitai Town; the central portion of Kuangshanji Town; Western Lieshan Town; Eastern Suixi Town; the central portion of Songtong Town; the central portion of Baishan Town; Southern Gurao Town; the central portion of Sipu town; the central portion of Suntong Town
Railway-Ecological fracture points	21	The central portion of Shuoli Town; the central portion of Gaoyue Street; Western Kuangshanji Town; Northern and southern Suixi Town; Western Lieshan Town; Western Gurao Town; the central portion of Liuqiao Town; the central portion of Baishan Town; Northeastern Linhuan Town; the central portion of Hancun Town
Mine Ecological fracture points	12	The western part of Shuoli Town; the western part of Gaoyue Street; the western part of Lishan Town; the southeastern part of Kuangshanji Town; the northern part of Songtong Town; the northeastern part of Sipu Town; the central portion of Hancun Town.

5. Discussion

5.1. Pattern of Ecological Restoration and Protection

The core of ecological restoration and protection in national land space is systematic protection and holistic governance. Constructing ESP to identify ecological sources and ecological corridors is conducive to basic requirements for regional spatial regulation [22]. Linking the ESP with upper ecological planning and local ecological base can better provide a reference pattern for the integrated management and targeted strategies. Therefore, we have laid out a general pattern of ecological restoration and protection, namely, "one axis, two shields, four zones, eight belts, and multiple corridors" (Figure 14), to achieve the goal of the coordinated development of environmental protection and restoration.

The "one axis" refers to the central lake axis formed by coal mining subsidence areas that have undergone land reclamation and landscape reconstruction in the central city. This axis is integrated with the main urban area, where the lakes and wetland parks are mostly important ecological sources, providing diverse ecosystem services and having a strong interactive relationship with the residents, and is the focus of transformation of the resource-based city into a livable city.

The "two shields" refer to the two concentrated and contiguous mountain areas of Xiang Mountain and Longji Mountain, which play the role of ecological bottom-building and shield to ensure the ecological security of the region.

The "four zones" are ecological restoration and protection type zones, divided into two parts: ecological protection zones and ecological restoration zones, which provide guidance on conservation principles and restoration directions for specific implementation strategies and projects. Among them, the ecological protection zone is the natural mountain-forest ecological protection zone; the ecological restoration zone consists of an urban ecological quality improvement zone, an agricultural field ecological improvement zone, and a mine ecological restoration zone (Table 7).

The "eight belts" refers to the eight natural rivers, namely, Wangyin River, Nantuo River, Long River, Dai River, Xiaosuixin River, Kuai River, Xie River, and Zha River. Eight belts of blue-green ecological space run from northwest to southeast across the city, linking the natural landscape along the riverbanks.

The "multiple corridor" is composed of ecological corridors extracted based on circuit theories, which weave scattered, distributed ecological sources in series into an ecological network and are important spaces for guaranteeing species migration and energy flow.

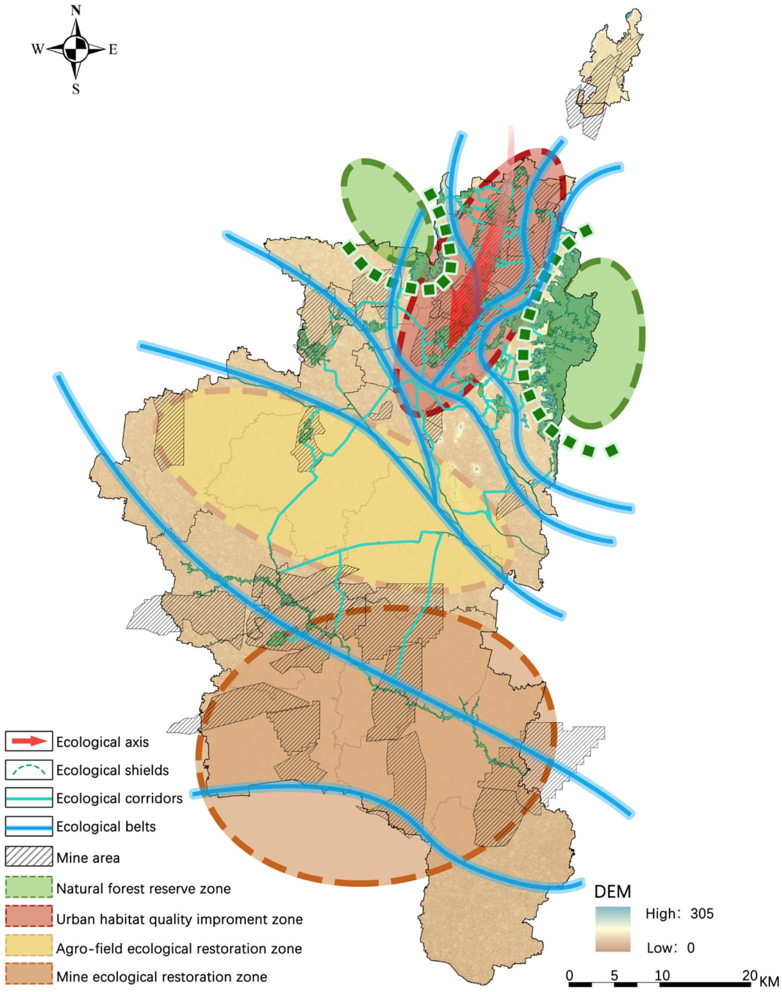

Figure 14. Ecological restoration and protection pattern in Huaibei City.

Table 7. Ecological restoration and protection type zones.

Types	Location Ranges	Characteristics
Natural mountain-forest ecological protection zone	Area east of the East Outer Ring Road; Xiang Shan Forest Park	1. Forested ecological source lands are the main component; 2. As an important ecological green space in the region, providing ecosystem services such as water conservation and carbon sequestration.
Urban ecological quality improvement zone	Shuoli Town; Shitai Town, Qugou Town, Central urban area, Suixi County; Liuqiao Town	1. Major concentration of production and life with high population density; 2. Insufficient connectivity of ecological sources of lakes and low quality of landscape infrastructure.
Agricultural field ecological improvement zone	Qugou Town, Songtong Town, Gurao Town, Tiefo Town, Baisan Town, Sipu Town, Nanping Town, Shuangdui Town	1. Concentrated areas of arable land, less affected by coal mining; 2. Problems of pollution from agricultural production and soil erosion; 3. Low grade of ecosystem services function and lack of important ecological patches.
Mine ecological restoration zone	Liuqiao Town, Linhuan Town, Hancun Town, Wugou Town, Suntong Town, Nanping Town	1. Some coal mines are still in production; 2. Coal mining subsidences have not been stabilized; 3. Complex ecological problems and lack of ecological sources.

5.2. Ecological Restoration and Protection Strategies for Key Areas

Ecological restoration and protection pattern in Huaibei City realizes the ecological control and management of the whole area. At the same time, the pattern has delineated zones to provide guidance on conservation principles and restoration directions. Under the guidance of the pattern, targeted and systematic strategies can be proposed for key areas that are important for regional ecological security.

In the natural mountain-forest ecological protection zone, pinch points are fragmented and small, and the current states are mostly rivers, forestland, and reservoirs; the number of barrier points is small, and the current situations are mostly rural settlements and fragmented industrial land; fracture points are mainly transport routes and mines under infrastructure. For these key areas, we propose the following strategies: (1) carry out forestland conservation measures to reduce landscape fragmentation and enhance the ecosystem service functions; (2) strengthen the planting and cultivation of vegetation on both sides of rivers and around reservoirs. Establish river ecological conservation areas and promote the succession of communities themselves; (3) wildlife migration routes such as 'culverts' and 'green bridges' should be set up, and protection measures should be strengthened around the mines under construction to alleviate the conflict between ecological space and living space.

In urban ecological quality improvement zones, the number of pinch points is large, concentrated, and still influenced by the historical relationship between urban areas and mining areas. Although there are no active mines in the zone, and land reclamation and coal mining subsidence landscape reconstruction have been implemented, there are still barrier points, which hinder landscape connectivity. In addition, the dense route network has caused the dense distribution of fracture points. For these key areas, we propose the following strategies: (1) appropriately increase the natural shoreline retention rate of urban rivers and establish ecological buffers on both sides of the river banks; (2) hold fast to the red line of the wetland ecological conservation area in the central lake axis, enhance the landscape quality of the wetland park, reasonably control the flow of visitors, and reduce disturbance from human activities; (3) strengthen the construction of sponge city projects in pinch point areas and promote the construction of pocket parks and small wetlands within the city; (4) regenerate and transform barrier points such as industrial and mining wastelands into urban green infrastructure, providing good ecological space for species migration and habitat; (5) restore and conserve vegetation on both sides of urban traffic roads to reduce the disturbance of ecological processes at fracture points.

In the agricultural field ecological improvement zone, pinch points are located in ditches connected to natural rivers and are more susceptible to disturbance due to their greater span and lower density of biological flows; barrier points are mainly rural settlements, rural roads, and cultivated land; fracture points are scattered road fracture points and mining enterprises around the corridor. Due to the inferior ecological condition of the zone and the lack of ecological elements, the ecological restoration strategy is mainly anthropogenic engineering measures: (1) regularly inspect and repair the banks on both sides of the ditches and strengthen the planting of protective forests to reduce soil erosion; (2) monitor water quality at outfalls in real-time, control the proper use of pesticides and fertilizers in farming, and prevent water pollution problems caused by heavy metal migration, etc.

In the mine ecological restoration zone, several mines are still in production, with dynamic and complex ecological and geological problems. There is a lack of key areas for ecological restoration from the perspective of ecological security patterns, and only one pinch point is located at the connection between Linhuan Lake and the Kuai River. Therefore, strategies should be carried out from the work of green construction and green production of mines: (1) strengthen the monitoring of geological and environmental problems, reduce environmental problems such as dust and soil, and timely repair of geological hazard sites; (2) promote mineral enterprises to synchronize production and remediation, and timely disposal and transfer of gangue and other sources of pollution from mine production.

5.3. Limitations and Future Work

Although this study has made some contributions to the ecological protection and restoration of national space in coal resource cities, there are still some limitations. Firstly, the ecosystem "function-structure" conceptual framework was developed to identify regional ecological sources and then further construct ESP. However, some scholars have argued that the supply and demand of regional ecosystem services are critical for improving human well-being [75–77]. This study identified ecological sources from the perspective of ecosystem service supply. Therefore, such supply and demand considerations should be included in the process of ecological sources identification and construction of ESP in future studies. Secondly, the construction of ESP did not include the time scale [36]. There are dynamic effects of coal mining activities on ecological resistance surfaces in time and space, and the functions and structures of regional ecosystems change over time [78]. In addition, by using long-term time series data, the driving mechanism of ecosystem evolution can be accurately understood, which can further effectively guide the development of ecological restoration and protection [51]. Thirdly, this study took the whole area of Huaibei as the study area but lacked multi-scale nested analysis. Some scholars have pointed out that the construction of ESP from a single scale is prone to the misalignment of ecological structures between the upper and lower scale [79]. Consequently, future research needs to optimize the hierarchically nested structure of the ESP according to the characteristics of ecological problems between different characteristic scales and to realize the organic coupling of landscape ecological structure-process functions. The organic coupling of ecological structure-function of the landscape. Furthermore, this study identified ecological pinch points, barrier points, and fracture points as key areas for ecological restoration and protection based on ESP, but the ecological problems only remain at the level of qualitative diagnosis and proposed planning strategies. Some scholars have constructed quantitative diagnosis index systems for ecological problems for different restoration objects, diagnose ecological problems, and delineate ecological restoration zones [80]. Therefore, the quantitative diagnosis of ecological problems in different ecological restoration objects is the focus of future research. Finally, we need to make sustainable development the development goal of coal resource-based cities [81,82], linking ESP to urban ecological resilience and enhancing the resilience of cities and their ability to respond proactively to natural disasters [83].

6. Conclusions

This study conducted holistic and systematic research on the ecological restoration and protection of national land space in coal resource-based cities. Taking Huaibei City as the study area, we constructed the ESP in accordance with local conditions and precisely identified key areas for ecological restoration and protection of national land space. Finally, the ecological restoration and protection pattern and strategies for key areas were proposed. The research results show the following: (1) 51 ecological sources were identified, with a total area of 152.75 km^2, accounting for 5.57% of the study area, showing a pattern of "concentrated in the north and sparse in the south" and were divided into four zones; (2) 111 ecological corridors with a total area of 33.07 km^2 and a total length of 472.24 km, connecting ecological sources, distributed in the northern densely; (3) ecological pinch points, barrier points, and fracture points constituted key areas for ecological restoration and protection. Among them, there were 17 pinch points, covering an area of 3.71 km^2, and mainly distributed in the northern areas of the Nantuo River; 75 barrier points were identified, with a total area of 16.37 km^2, and concentrated in the main urban area; there were 117 ecological fracture points, including 84 route-fracture points, 21 railway-fracture points, and 12 mine-fracture points; (4) we suggested a "one axis, two shields, four zones, eight belts, and multiple corridors" ecological protection and restoration pattern and proposed implementation strategies for key areas. The results of the study can provide valuable references to ensure the ecological security and green ecological transformation of coal resource-based cities.

Author Contributions: Conceptualization, Z.L. and J.C.; methodology, Z.L.; software, Z.L.; investigation, Z.L. and S.G.; data curation, Z.L.; writing—original draft preparation, Z.L.; writing—review and editing, Z.L.; supervision, C.L. and J.C.; project administration, J.C. and C.L.; funding acquisition, J.C. and C.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number 42001241; Jiangsu Collaborative Innovation Center for Building Energy Saving and Construct Technology, grant number SJXTZD2104; Graduate Innovation Program of China University of Mining and Technology, grant number 2022WLJCRCZL327.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank the reviewers for providing constructive comments on this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wen, B.; Pan, Y.H.; Zhang, Y.Y.; Liu, J.J.; Xia, M. Does the Exhaustion of Resources Drive Land Use Changes? Evidence from the Influence of Coal Resources-Exhaustion on Coal Resources-Based Industry Land Use Changes. *Sustainability* **2018**, *10*, 2698. [CrossRef]
2. Ruan, F.L.; Yan, L.; Wang, D. The complexity for the resource-based cities in China on creating sustainable development. *Cities* **2020**, *97*, 102571. [CrossRef]
3. Harnischmacher, S.; Zepp, H. Mining and its impact on the earth surface in the Ruhr District (Germany). *Z. Für Geomorphol.* **2014**, *58*, 3–22. [CrossRef]
4. Guan, J.; Yu, P. Does Coal Mining Have Effects on Land Use Changes in a Coal Resource-Based City? Evidence from Huaibei City on the North China Plain. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11616. [CrossRef] [PubMed]
5. Guan, J.; Jiao, H.F. The evolution process and influencing factors of urban-rural spatial structure in coal resource-based city: A case study of Huaibei city in Anhui province. *J. Nat. Resour.* **2021**, *36*, 2836–2852. [CrossRef]
6. Farrington, J.D. The Impact of mining activities on mongolia's protected areas: A status report with policy recommendations. *Integr. Environ. Assess. Manag.* **2005**, *1*, 283–289. [CrossRef] [PubMed]
7. Almenar, J.B.; Bolowich, A.; Elliot, T.; Geneletti, D.; Sonnemann, G.; Rugani, B. Assessing habitat loss, fragmentation and ecological connectivity in Luxembourg to support spatial planning. *Landsc. Urban Plan.* **2019**, *189*, 335–351. [CrossRef]
8. Li, S.C.; Xiao, W.; Zhao, Y.L.; Lv, X.J. Incorporating ecological risk index in the multi-process MCRE model to optimize the ecological security pattern in a semi-arid area with intensive coal mining: A case study in northern China. *J. Clean. Prod.* **2020**, *247*, 119143. [CrossRef]
9. Walz, R. Development of Environmental Indicator Systems: Experiences from Germany. *Environ. Manag.* **2000**, *25*, 613–623. [CrossRef]
10. Cumming, G.S.; Allen, C.R. Protected areas as social-ecological systems: Perspectives from resilience and social-ecological systems theory. *Ecol. Appl.* **2017**, *27*, 1709–1717. [CrossRef]
11. Martin, D.M. Ecological restoration should be redefined for the twenty-first century. *Restor Ecol* **2017**, *25*, 668–673. [CrossRef] [PubMed]
12. Larondelle, N.; Haase, D. Valuing post-mining landscapes using an ecosystem services approach—An example from Germany. *Ecol. Indic.* **2012**, *18*, 567–574. [CrossRef]
13. Lee, D.-K.; Mojtabai, N.; Lee, H.-B.; Song, W.-K. Assessment of the influencing factors on subsidence at abandoned coal mines in South Korea. *Environ. Earth Sci.* **2013**, *68*, 647–654. [CrossRef]
14. Wirth, P.; Chang, J.; Syrbe, R.U.; Wende, W.; Hu, T.H. Green infrastructure: A planning concept for the urban transformation of former coal-mining cities. *Int. J. Coal Sci. Technol.* **2018**, *5*, 78–91. [CrossRef]
15. Galanina, T.; Koroleva, T.; Zakamskaya, L.; Tretyakova, I. The land reclamation concept as a key factor in solving the environmental problems of coal mining regions. In Proceedings of the E3S Web of Conferences, Kemerovo, Russian, 1 October 2020; p. 02017.
16. Akcin, H.; Kutoglu, H.S.; Kemaldere, H.; Deguchi, T.; Koksal, E. Monitoring subsidence effects in the urban area of Zonguldak Hardcoal Basin of Turkey by InSAR-GIS integration. *Nat. Hazards Earth Syst. Sci.* **2010**, *10*, 1807–1814. [CrossRef]
17. Lei, K.; Pan, H.; Lin, C. A landscape approach towards ecological restoration and sustainable development of mining areas. *Ecol. Eng.* **2016**, *90*, 320–325. [CrossRef]
18. Zhao, H.; Ma, F.; Zhang, Y.; Guo, J. Monitoring and mechanisms of ground deformation and ground fissures induced by cut-and-fill mining in the Jinchuan Mine 2, China. *Environ. Earth Sci.* **2013**, *68*, 1903–1911. [CrossRef]
19. Palamakumbure, D.; Stirling, D.; Flentje, P.; Chowdhury, R. ArcGIS V. 10 Landslide Susceptibility Data Mining Add-in Tool Integrating Data Mining and GIS Techniques to Model Landslide Susceptibility. In Proceedings of the Engineering Geology for Society and Territory—Volume 2, Cham, switzerland, 2 September 2015; pp. 1191–1194.
20. Mace, G. Global change: Ecology must evolve. *Nature* **2013**, *503*, 191–192. [CrossRef] [PubMed]

21. Sasaki, T.; Furukawa, T.; Iwasaki, Y.; Seto, M.; Mori, A.S. Perspectives for ecosystem management based on ecosystem resilience and ecological thresholds against multiple and stochastic disturbances. *Ecol. Indic.* **2015**, *57*, 395–408. [CrossRef]
22. Gao, M.; Hu, Y.; Bai, Y. Construction of ecological security pattern in national land space from the perspective of the community of life in mountain, water, forest, field, lake and grass: A case study in Guangxi Hechi, China. *Ecol. Indic.* **2022**, *139*, 108867. [CrossRef]
23. Silva, A.M.d.; Bortoleto, L.A.; Castelli, K.R.; Silva, R.A.E.; Mendes, P.B. Prospecting the potential of ecosystem restoration: A proposed framework and a case study. *Ecol. Eng.* **2017**, *108*, 505–513. [CrossRef]
24. Yu, K. Security patterns and surface model in landscape ecological planning. *Landsc. Urban Plan.* **1996**, *36*, 1–17. [CrossRef]
25. Fang, Y.; Wang, J.; Huang, L.Y.; Zhai, T.L. Determining and identifying key areas of ecosystempreservation and restoration for territorial spatial planning based on ecological security patterns: A case study of Yantai city. *J. Nat. Resour.* **2020**, *35*, 190.
26. Peng, J.; Yang, Y.; Liu, Y.-x.; Hu, Y.n.; Du, Y.; Meersmans, J.; Qiu, S. Linking ecosystem services and circuit theory to identify ecological security patterns. *Sci. Total Environ.* **2018**, *644*, 781–790. [CrossRef] [PubMed]
27. Peng, J.; Zhao, H.J.; Liu, Y.X.; Wu, J.S. Research progress and prospect on regional ecological security pattern construction. *Geogr. Res.* **2017**, *36*, 407–419.
28. Fu, Y.; Shi, X.; He, J.; Yuan, Y.; Qu, L. Identification and optimization strategy of county ecological security pattern: A case study in the Loess Plateau, China. *Ecol. Indic.* **2020**, *112*, 106030. [CrossRef]
29. Aminzadeh, B.; Khansefid, M. A case study of urban ecological networks and a sustainable city: Tehran's metropolitan area. *Urban Ecosyst.* **2010**, *13*, 23–36. [CrossRef]
30. Kong, F.; Yin, H.; Nakagoshi, N.; Zong, Y. Urban green space network development for biodiversity conservation: Identification based on graph theory and gravity modeling. *Landsc. Urban Plan.* **2010**, *95*, 16–27. [CrossRef]
31. Yuan, Y.; Bai, Z.K.; Shi, X.Y.; Zhao, X.J.; Zhang, J.N.; Yang, B.Y. Determining priority areas for ecosystem preservation and restoration of territory based on ecological security pattern:A case study in Zunhua City, Hebei Province. *Chin. J. Ecol.* **2022**, *41*, 750–759.
32. Jiao, S.; Liu, Y.C.; Han, Z.W.; Zhou, K.J.; Hu, L.; Liu, T.X. Determining priority areas for land ecological restoration based on ecological network-human disturbance: A case study of Changsha-Zhuzhou-Xiangtan Urban Agglomeration. *J. Nat. Resour.* **2021**, *36*, 2294–2307. [CrossRef]
33. Peng, J.; Pan, Y.J.; Liu, Y.X.; Zhao, H.J.; Wang, Y.L. Linking ecological degradation risk to identify ecological security patterns in a rapidly urbanizing landscape. *Habitat Int.* **2018**, *71*, 110–124. [CrossRef]
34. Li, S.; Zhao, Y.; Xiao, W.; Yue, W.; Wu, T. Optimizing ecological security pattern in the coal resource-based city: A case study in Shuozhou City, China. *Ecol. Indic.* **2021**, *130*, 108026. [CrossRef]
35. Zhang, X.P.; Hu, Z.H.; Wei, X.J.; Huang, Y.W. Study on Identification of Key Areas for Ecological Protection and Restoration in Resource-exhausted Region: Take Dayu County, Jiangxi as an Example. *J. Ecol. Rural Environ.* **2021**, *37*, 1031–1040.
36. Yang, R.R.; Bai, Z.; Shi, Z. Linking Morphological Spatial Pattern Analysis and Circuit Theory to Identify Ecological Security Pattern in the Loess Plateau: Taking Shuozhou City as an Example. *Land* **2021**, *10*, 907. [CrossRef]
37. Fan, X.; Cheng, Y.; Tan, F.; Zhao, T. Construction and Optimization of the Ecological Security Pattern in Liyang, China. *Land* **2022**, *11*, 1641. [CrossRef]
38. Li, J.; Xu, J.; Chu, J.L. The Construction of a Regional Ecological Security Pattern Based on Circuit Theory. *Sustainability* **2019**, *11*, 6343. [CrossRef]
39. Liu, Y.; Cui, N.; Han, R.; Guo, L. Establishing Ecological Security Patterns Based on Reconstructed Ecosystem Services Value in Rapidly Urbanizing Areas: A Case Study in Zhuhai City, China. *Sustainability* **2020**, *12*, 6629. [CrossRef]
40. Wang, Y.; Pan, J. Building ecological security patterns based on ecosystem services value reconstruction in an arid inland basin: A case study in Ganzhou District, NW China. *J. Clean. Prod.* **2019**, *241*, 118337. [CrossRef]
41. Zhang, L.Q.; Peng, J.; Liu, Y.X.; Wu, J.S. Coupling ecosystem services supply and human ecological demand to identify landscape ecological security pattern: A case study in Beijing–Tianjin–Hebei region, China. *Urban Ecosyst.* **2017**, *20*, 701–714. [CrossRef]
42. Ran, Y.; Lei, D.; Li, J.; Gao, L.; Mo, J.; Liu, X. Identification of crucial areas of territorial ecological restoration based on ecological security pattern: A case study of the central Yunnan urban agglomeration, China. *Ecol. Indic.* **2022**, *143*, 109318. [CrossRef]
43. Mcrae, B.H.; Beier, P. Circuit theory predicts gene flow in plant and animal populations. *Proc. Natl. Acad. Sci.* **2007**, *104*, 19885–19890. [CrossRef] [PubMed]
44. Fang, Y.; Huang, L.Y.; Liu, S.H.; Zou, L. Construction of Wuhan's ecological security pattern under the "quality-risk-requirement" framework. *Chin. J. Appl. Ecol.* **2019**, *30*, 615–626.
45. Ge, J.S.; Han, R.Y.; Han, Y.; Luo, Z.L.; Quan, Z.J.; Shi, N.N.; Wang, Q.; Xiao, N.W. Construction and optimization of ecological network for protected areas in Qinghai Province. *Chin. J. Ecol.* **2018**, *37*, 1910–1916.
46. Mcrae, B.H.; Hall, S.A.; Beier, P.; Theobald, D.M. Where to Restore Ecological Connectivity? Detecting Barriers and Quantifying Restoration Benefits. *PLoS ONE* **2012**, *7*, e52604. [CrossRef]
47. Huang, J.; Hu, Y.; Zheng, F. Research on recognition and protection of ecological security patterns based on circuit theory: A case study of Jinan City. *Environ. Sci. Pollut. Res.* **2020**, *27*, 12414–12427. [CrossRef]
48. Zhai, T.; Huang, L. Linking MSPA and Circuit Theory to Identify the Spatial Range of Ecological Networks and Its Priority Areas for Conservation and Restoration in Urban Agglomeration. *Front. Ecol. Evol.* **2022**, *10*, 33. [CrossRef]

49. Fu, F.J.; Liu, Z.H.; Liu, H. Identifying key areas of ecosystem restoration for territorial space based on ecological security pattern: A case study in Hezhou City. *Acta Ecol. Sin.* **2021**, *41*, 3406–3414.
50. Peng, J.; Zhao, S.; Dong, J.; Liu, Y.-x.; Meersmans, J.; Li, H.; Wu, J. Applying ant colony algorithm to identify ecological security patterns in megacities. *Environ. Model. Softw.* **2019**, *117*, 214–222. [CrossRef]
51. Ni, Q.L.; Hou, H.P.; Ding, Z.Y.; Li, Y.B.; Li, J.R. Ecological remediation zoning of territory based on the ecological security pattern recognition: Taking Jiawang district of Xuzhou city as an example. *J. Nat. Resour.* **2020**, *35*, 204–216.
52. Peng, J.; Ma, J.; Du, Y.; Zhang, L.; Hu, X. Ecological suitability evaluation for mountainous area development based on conceptual model of landscape structure, function, and dynamics. *Ecol. Indic.* **2016**, *61*, 500–511. [CrossRef]
53. Peng, J.; Hu, Y.N.; Lü, H.L.; Li, T.Y.; Chen, X. Ecological function zoning based on element structure function: A case study in Dali Bai Autonomous Prefecture. *Chin. J. Ecol.* **2016**, *35*, 2251–2259.
54. Li, S.C.; Liu, J.L.; Zhang, C.Y.; Zhao, Z.Q. The Research Trends of Ecosystem Services and the Paradigm in Geography. *Acta Geogr. Sin.* **2011**, *66*, 1618–1630.
55. Zhao, C.; Wang, C.; Yan, Y.; Shan, P.; Li, J.; Chen, J. Ecological Security Patterns Assessment of Liao River Basin. *Sustainability* **2018**, *10*, 2401. [CrossRef]
56. Li, T.S. Heterogeneity and Its Maintenance of Urban Landscape. *Chin. J. Ecol.* **1998**, *70–72*, 69.
57. Wenbin, G.; Xinxiao, Y.; Yutao, Z. Review on landscape heterogeneity. *Chin. J. Appl. Ecol.* **2002**, *13*, 495–500.
58. Turner, M.G. *Landscape Heterogeneity and Disturbance*; Springer: New York, NY, USA, 1987.
59. Wu, J.; Zhang, L.; Peng, J.; Feng, Z.; Liu, H.; He, S. The integrated recognition of the source area of the urban ecological security pattern in Shenzhen. *Acta Ecol. Sin.* **2013**, *33*, 4125–4133.
60. Zhao, J.; Li, C. Investigating Ecosystem Service Trade-Offs/Synergies and Their Influencing Factors in the Yangtze River Delta Region, China. *Land* **2022**, *11*, 106. [CrossRef]
61. Guo, X.N.; Hu, Y.N.; Liu, Y.X.; Peng, J. Constructing ecological security patterns in mountain areas based on geological disaster sensitivity: A case study in Yuxi City, Yunnan Province, China. *Chin. J. Appl. Ecol.* **2017**, *28*, 627–635.
62. Xiao, L.; Jing-hu, P. Assessment of landscape ecological security and optimization of landscape pattern based on spatial principal component analysis and resistance model in arid inland area: A case study of Ganzhou District, Zhangye City, Northwest China. *Chin. J. Appl. Ecol.* **2015**, *26*, 3126–3136.
63. Keeley, A.T.H.; Beier, P.; Gagnon, J.W. Estimating landscape resistance from habitat suitability: Effects of data source and nonlinearities. *Landsc. Ecol.* **2016**, *31*, 2151–2162. [CrossRef]
64. Zhu, F.; Yang, B.D.; Yang, Y.J.Z.; Shao, L.; Li, G.; Chen, F. Research on the Ecological Network Reconstruction of Traditional Mining City in East China. *J. Ecol. Rural Environ.* **2020**, *36*, 26–33.
65. Pickett, S.T.A.; Cadenasso, M.L.; Rosi-Marshall, E.J.; Belt, K.T.; Groffman, P.M.; Grove, J.M.; Irwin, E.G.; Kaushal, S.S.; LaDeau, S.L.; Nilon, C.H.; et al. Dynamic heterogeneity: A framework to promote ecological integration and hypothesis generation in urban systems. *Urban Ecosyst.* **2017**, *20*, 1–14. [CrossRef]
66. Guan, D.; Jiang, Y.; Cheng, L. How can the landscape ecological security pattern be quantitatively optimized and effectively evaluated? An integrated analysis with the granularity inverse method and landscape indicators. *Environ. Sci. Pollut. Res.* **2021**, *29*, 41590–41616. [CrossRef] [PubMed]
67. Wang, H.H.; Li, H.T.; Xie, M.M.; Xu, M.; Li, S.L.; Bai, Z.K. Construction of ecological security pattern for systematic restoration of industrial and mining land in resource-based cities. *J. Nat. Resour.* **2020**, *35*, 162–173.
68. Li, H.; Li, L.; Wu, G.S.; Zhou, Y.; Li, W.W.; Mei, Z.W. Analysis of the landscape-level connectivity of the Yunnan snub-nosed monkey habitat based on circuit theory. *Acta Ecol. Sin.* **2018**, *38*, 2221–2228.
69. Liu, J.; Yin, H.W.; Kong, F.H.; Li, M.H. Structure optimization of circuit theory-based green infrastructure in Nanjing, China. *Acta Ecol. Sin.* **2018**, *38*, 4363–4372.
70. Song, L.L.; Qin, M.Z. Identification of ecological corridors and its importance by integrating circuit theory. *Chin. J. Appl. Ecol.* **2016**, *27*, 3344–3352.
71. Shah, V.B.; Mcrae, B.H. *Circuitscape: A Tool for Landscape Ecology*; SciPy: Pasadena, CA, USA, 2008.
72. Mcrae, B.H.; Dickson, B.G.; Keitt, T.H.; Shah, V.B. Using circuit theory to model connectivity in ecology, evolution, and conservation. *Ecology* **2008**, *89*, 2712–2724. [CrossRef]
73. Zhu, Q.; Yuan, Q.; Yu, D.P.; Zhou, W.M.; Zhou, L.; Han, Y.G.; Qi, L. Construction of ecological security network of Northeast China forest belt based on the circuit theory. *Chin. J. Ecol.* **2021**, *40*, 3463–3473.
74. Tang, F.; Wang, L.; Zhang, P.T.; Fu, M.C. Construction of county-level ecological security pattern based on ecological protection red line and network in China. *Trans. Chin. Soc. Agric. Eng.* **2020**, *36*, 263–272.
75. Ming, L.; Chang, J.; Li, C.; Chen, Y.; Li, C. Spatial-Temporal Patterns of Ecosystem Services Supply-Demand and Influencing Factors: A Case Study of Resource-Based Cities in the Yellow River Basin, China. *Int. J. Environ. Res. Public Health* **2022**, *19*, 16100. [CrossRef]
76. Luo, Y.H.; Wang, N.; Wang, Z.Y.; Wu, J.S.; YI, T.Y.; Zhao, Y.H. Constructing an ecological security pattern in Shenzhen, China, by matching the supply and demand of ecosystem services. *Chin. J. Appl. Ecol.* **2022**, *33*, 2475–2484.
77. Zhuang, Z.; Li, C.; Hsu, W.-L.; Gu, S.; Hou, X.; Zhang, C. Spatiotemporal Changes in the Supply and Demand of Ecosystem Services in China’s Huai River Basin and Their Influencing Factors. *Water* **2022**, *14*, 2559.

78. Gao, J.; Du, F.; Zuo, L.; Jiang, Y. Integrating ecosystem services and rocky desertification into identification of karst ecological security pattern. *Landsc. Ecol.* **2021**, *36*, 2113–2133. [CrossRef]
79. Zhu, J.; Su, J.; Yin, H.W.; Kong, F.H. Construction of Xuzhou ecological network based on comprehensive sources identification and multi-scale nesting. *J. Nat. Resour.* **2020**, *35*, 1986–2001.
80. Xin, S.J.; Lian, A.H.; Liang, H.D.; Xiao, K.W.; Li, R.Y. Ecological problem identification and restoration strategy based on the mountain-water-forest-field-lake-grass-sand life community concept in Taohe River Watershed, Gannan, China. *Pratacultural Sci.* **2022**, *39*, 1256–1268.
81. Balaei, B.; Wilkinson, S.; Potangaroa, R.; McFarlane, P. Investigating the technical dimension of water supply resilience to disasters. *Sustain. Cities Soc.* **2020**, *56*, 102077. [CrossRef]
82. Alberti, M.; Susskind, L.E. Managing urban sustainability: An introduction to the special issue. *Environ. Impact Assess. Rev.* **1996**, *16*, 213–221. [CrossRef]
83. Yuan, Y.; Bai, Z.; Zhang, J.; Xu, C. Increasing urban ecological resilience based on ecological security pattern: A case study in a resource-based city. *Ecol. Eng.* **2022**, *175*, 106486. [CrossRef]