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Spatio-Temporal Evolution of Key Areas of Territorial Ecological Restoration in Resource-Exhausted Cities: A Case Study of Jiawang District, China

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Abstract: Resource-exhausted cities usually face problems of environmental degradation, landscape fragmentation, and impeded ecological mobility. By clarifying the spatial heterogeneity of ecological restoration needs, efficient and coordinated ecological protection and restoration can be carried out. This study selected Jiawang District, a typical resource-exhausted city, and constructed an ecological security evaluation framework to determine the ecological source area from the three aspects of ecosystem service importance, ecological sensitivity, and landscape stability. The resistance surface was corrected with ecological sensitivity evaluation data, and ecological corridors and ecological nodes were identified using circuit theory. Finally, it explored the spatial and temporal evolution of the key areas of territorial ecological restoration in Jiawang District. This study indicates that: (1) In 2000, 2010, and 2020, the ecological source areas were 123.59 km^2, 116.18 km^2, and 125.25 km^2, and the corresponding numbers of ecological corridors were 53, 51, and 49. The total lengths of the ecological corridors were 129.25 km, 118.57 km, and 112.25 km, mainly distributed in the northern and central areas of the study area. (2) The study area contained 17, 13, and 19 ecological pinch points in 2000, 2010, and 2020, respectively, 16, 20, and 15 ecological obstacle points, and 8, 24, and 33 ecological fracture points, respectively. Targeted rehabilitation of these key areas can significantly improve ecological connectivity. (3) The key area of territorial ecological restoration in 2020 was composed of 125.25 km^2 ecological source area, 8.77 km^2 of ecological pinch point, 12.70 km^2 of ecological obstacle point, and 33 ecological fracture points. According to the present situation of land use, protection strategies are put forward.

Keywords: resource-exhausted city; ecological security pattern; circuit theory; territorial ecological restoration; Jiawang district

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1. Introduction

Resource-exhausted cities refer to those cities whose remaining exploitable resources have entered a period of depletion or decline due to long-term development [1,2]. Compared with other general cities, while resource development activities bring wealth and vitality to urban development, they inevitably lead to the problems of ecological space reduction, landscape stability reduction, and ecological function degradation derived from this type of city [3]. Territorial ecological restoration in resource-exhausted cities has received widespread attention as a core issue. In response to these problems, China's "14th Five-Year Plan" clearly states that resource-exhausted cities should adhere to green transition, accelerate the realization of low-carbon development, and further increase support for environmental protection and rehabilitation [4]. Identifying key areas of national land space that are prone to ecological damage and degradation will help to enhance ecosystem integrity and connectivity, which is of great significance in guaranteeing the ecological transition and sustainable development of resource-exhausted cities [4,5].

The purpose the of ecological transition of resource-exhausted cities is to solve the ecological environmental problems encountered in the current development, so that the indicators of urban ecosystems can be close to or even surpass those of other cities that do not rely on resources for development [6,7]. Ecological transition is a hot research topic in most resource-exhausted foreign cities, and there are two main ways to realize it. One is to use political intervention and economic restructuring to optimize the traditional economy [8]. For example, in Germany's Ruhr area and Japan's Kitakyushu region [9,10], local administrators have diversified industries by formulating appropriate urban planning and policies at different stages, and urban ecological environments have been improved due to the success of economic transition. The other is to evaluate the ecological safety of resource-exhausted cities in the context of social and economic issues on the basis of which types of ecological rehabilitation of resource extraction zones are carried out [7,11,12]. Petr Sklenicka and Eva Charvatova propose the prioritization of the conservation of the most valuable parts of the ecological network in post-mining landscapes [13]. In recent years, the ecological transition of resource-exhausted cities in China has taken full advantage of foreign experience. The level of urban economic cycle development has improved [14,15], but there are still some limitations in the attention paid to environmental improvement. At present, the research on ecological environment improvement in resource-exhausted cities is mainly based on a single time period or regional heterogeneity perspective [16]. However, there is a complex and dynamic spatial relationship between the ecological problems left behind by resource extraction and cities [17,18]. Therefore, this study hopes to comprehensively explore the spatio-temporal evolution mechanism of ecological damage and restoration in resource-exhausted cities from the time frame and spatial perspective, with a view to providing scientific guidance for the protection of ecological security and management of ecosystems in resource-exhausted regions.

Currently, ecological restoration research mainly focuses on small-scale and single-element restoration, such as soil heavy metal pollution remediation [19], coal mining collapse land remediation and monitoring [20,21], as well as soil erosion control and river ecological rehabilitation [22,23], but these studies ignore the impacts of ecological problems in certain regions. For this reason, territorial ecological restoration originating from the theory of landscape ecology has gradually become a research hotspot by establishing an ecological security pattern (ESP) and diagnosing and determining the priority areas for ecological restoration on this basis [24,25]. Territorial ecological restoration can guarantee the safety of damaged territorial spatial ecosystems, and ESPs are the spatial manifestation of landscape pattern optimization, both of which are important for maintaining the wholeness of the landscape pattern and the integrity of ecosystem functions [26–28]. Compared with large-scale ecological spatial protection, the targeted rehabilitation of obstacle areas affecting biological migration can achieve optimal ecological effects. As a result, many scholars have also begun to incorporate the concepts of ecological pinch points, ecological obstacle points, and ecological fracture points into the study of key areas of territorial space, which provides an innovative approach to the planning and management of territorial ecological restoration [27,29,30].

The construction of ESPs has formed the research paradigm of "ecological source, ecological resistance surface, and ecological corridor" [31,32]. The ecological source is the basis for constructing ESPs and consists of patches with important ecological functions. In the current research, nature reserves, parks, waters, and other elements with high ecological service value are directly selected as ecological source areas, but this only focuses on considering the attributes of the ecological patches themselves [33,34]. Another method is to select high-value ecological areas as ecological source areas by evaluating ecological indicators based on the evaluation of ecological service value and ecological sensitivity [35–39], but this method does not fully consider the integrality and connectivity of patches in the landscape space. Therefore, this study combined the importance of ecosystem services, ecological sensitivity, and landscape stability to conduct a comprehensive evaluation of ecological security [40–42]. This method pays more attention to the functional attributes of ecosystems, which is conducive to accurately extracting areas with potential environmental problems and provides an effective scientific basis for constructing ESPs [43–45].

For the construction of ecological resistance surfaces, most studies directly assigned ecological resistance values to different types of land use, a method that ignores the internal spatial heterogeneity of the same land use type [46,47]. Some scholars have used nighttime light data, ecological sensitivity assessment results, and impervious surface area to further correct the basic resistance surface on the basis of land use types [48–50]. The exploitation of coal resources destroys the ecological environment and exacerbates the sensitivity of regional ecosystems. The study used ecological sensitivity data to correct the resistance surface, which could reveal the spatial heterogeneity exhibited during species migration in a more accurate and detailed way, and provide a basis for the subsequent extraction of ecological corridors [51,52]. Ecological corridors are important corridors that safeguard the flow of energy and materials between ecological sources [53,54]. Minimal cumulative resistance (MCR) and hydrologic analysis are commonly used to simulate ecological corridors [55–58]. In contrast, circuit theory can effectively identify ecological corridors and key ecological nodes by simulating the flow-diffusion process of species in the landscape through the use of the characteristic of random electron wandering. It can also address, to some extent, the limitation that the MCR model cannot specify the specific extent of corridors and key areas [35,59]. In general, existing studies have provided reference ideas and common methods for the identification of key areas for the ecological protection and restoration of national land space. However, there are relatively few studies on territorial ecological restoration in resource-exhausted cities. This study combines regional socio-economic and ecological backgrounds to construct a framework for evaluating the ESP suitable for resource-exhausted cities. Exploring the evolution of the relationship between regional ecological damage and restoration in terms of spatial and temporal patterns and spatial matching can provide guidance for optimizing the ecosystems of resource-exhausted cities [60,61].

As a typical resource-exhausted city, Jiawang District once relied on the exploitation and utilization of coal and other natural resources for its urban development. The ecological problems triggered by long-term coal resource exploitation have, to a certain extent, severed the ecological spatial integrity and functional stability of ecosystems. With the depletion of resources, the spatial imbalance of territorial ecological restoration in the national space has become a core problem in Jiawang District. Therefore, how to coordinate sustainable urban development and territorial ecological restoration has become the main contradiction [18,62]. This study identifies the key areas of territorial ecological restoration in Jiawang District based on the ESP and circuit theory. This paper mainly consists of the following: (1) constructing an ecological security assessment framework of ecosystem service importance, ecological sensitivity, and landscape stability to identify ecological source areas so as to clarify the extent to which ecosystems have been affected by human activities; (2) identification of ecological corridors and ecological nodes based on circuit theory using ecological sensitivity data to correct resistance surfaces; (3) determination of the priority areas of territorial ecological restoration, including ecological sources, ecological pinch points, ecological obstacle points, and ecological fracture points; (4) proposition of corresponding protection measures for key areas of territorial ecological restoration.

2. Overview and Data Sources of the Study Area

2.1. Overview of the Study Area

Jiawang District is located in the northeast of Xuzhou City, Jiangsu Province (Figure 1). Its geographical coordinates are 34°17′–34°32′ north latitude and 117°17′–117°42′ east longitude, with a total area of 620 km^2. Jiawang District is located in the transition zone between hills and the Huang-Huai alluvial plain. The main landform features are low mountains, hills, and plains. The total terrain is high in the west and low in the east, and high in the north and low in the south. Jiawang District is rich in coal mining resources, with a history of more than 130 years of coal mining. There are 23 mines, including Xiaqiao, Qingshanquan, Yaozhuang, Hanqiao, etc. In 2011, Jiawang District was identified as the only city in Jiangsu Province with exhausted resources, and all coal mines in the district closed by 2016. The coal resources were gradually depleted over a century of development, and many mines have been abandoned without ecological rehabilitation work after resource exhaustion. The long-term mining of mineral resources has triggered a series of geological disasters, including aquifer destruction, soil and water pollution, and other geological and environmental problems. Among them, the total amount of collapsed land is about 8820 km^2, the rate of increase is about 1 km^2 per year, and the depth of collapsed land generally varies from 1.6 m to 7.6 m [63].

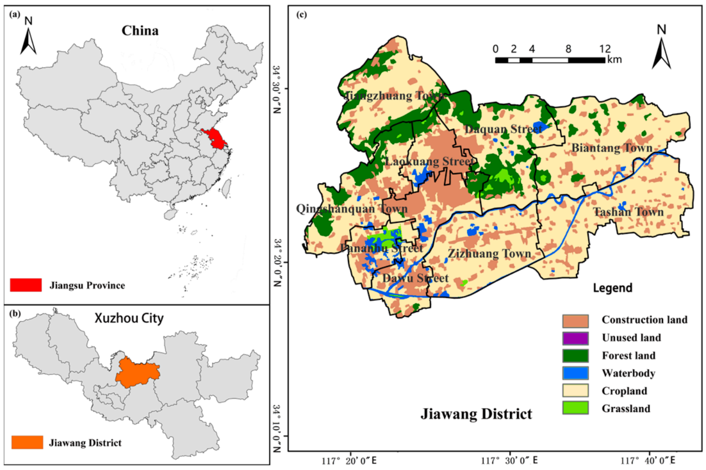

Figure 1. (**a**) Location of China; (**b**) location of Xuzhou; (**c**) location of Jiawang District. (Source: The Resource Environment and Science Data Center of the Chinese Academy of Sciences https://www.resdc.cn/ (accessed on 1 July 2022)).

2.2. Data Sources

Main data sources of this study: (1) The remote sensing images were downloaded from the geospatial data cloud (https://www.gscloud.cn/ (accessed on 1 July 2022)). The 2000 and 2010 land use maps of Jiawang District were interpreted from Landsat-5 images, and the 2020 land use maps were interpreted from Landsat-8 OLI images. The raster data resolution was 30 m $\times$ 30 m. According to the actual situation of the study area and the needs of the research purpose, the land use types were divided into cropland, grassland, waterbody, forest land, construction land, and unused land. (2) Using ENVI 5.3 software, the normalized vegetation index (NDVI) was processed and extracted from satellite image data in 2000, 2010, and 2020. (3) Coal mining subsidence data from the Jiawang area of the Natural Resources and Planning Bureau (http://zrzy.jiangsu.gov.cn/xzjw/ (accessed on 1 July 2022)) and related scholars' research in the literature were used [17,64,65], and the Arc-GIS 10.2 software was used after projection. (4) Administrative boundaries, DEM, precipitation, and evapotranspiration data were from the Resource Environment and Science Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/ (accessed on 1 July 2022)). (5) The traffic data, including the distribution data of expressways, provincial roads, national roads, and railways in Jiawang District, originated from the Open Street Map data platform (http://www.openstreetmap.org/ (accessed on 1 July 2022)) and were used to build a network data set, together with the ecological corridor to identify ecological fracture points in key areas. (6) Soil data were from the World Soil Harmonisation Database (https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/ (accessed on 1 July 2022)).

3. Research Methods

This research needs to determine the key areas of territorial ecological restoration through the construction of an ESP in Jiawang District, so this research mainly includes three main steps. The first step was to determine the ecological source by constructing a comprehensive evaluation system of ecological security by selecting the importance of ecosystem services, ecological sensitivity, and landscape stability. The second step is to correct the basic resistance surface using the ecological sensitivity evaluation data. The ESP was constructed by identifying ecological corridors based on circuit theory, and ecological pinch points, obstacle points, and fracture points were identified. Finally, key areas of territorial ecological restoration were identified, and relevant strategies were proposed according to land use types (Figure 2).

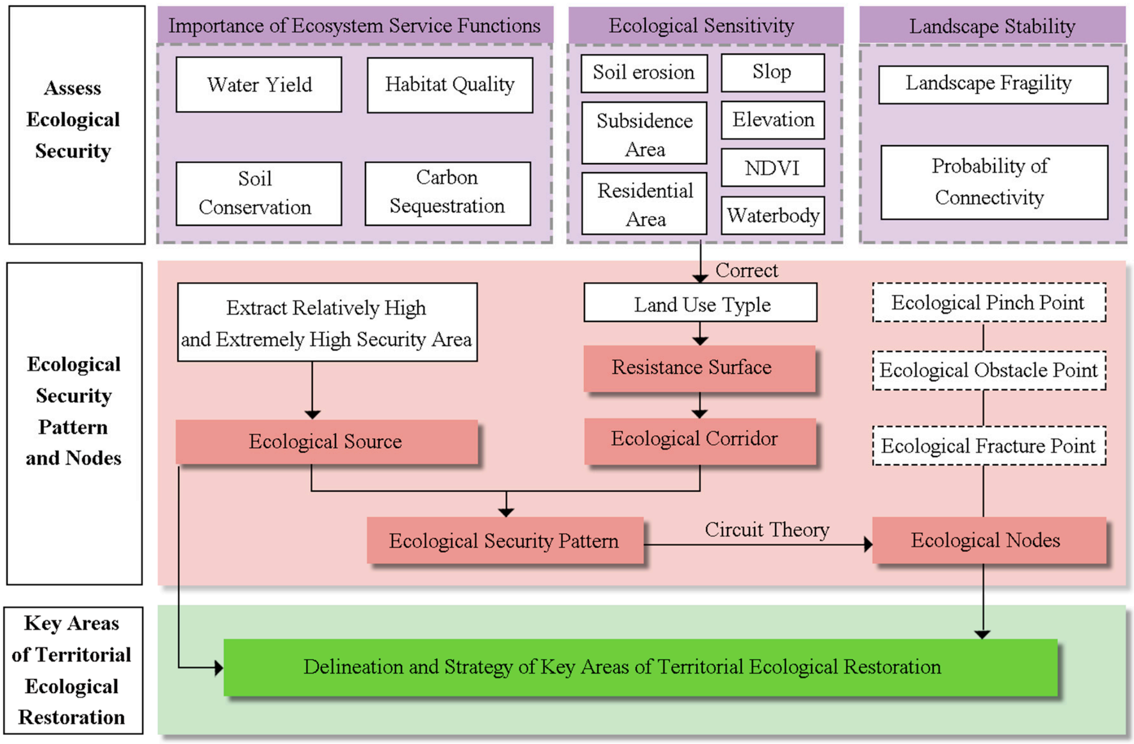

Figure 2. Logical framework and technical route. (Source: the research team).

3.1. *Identify Ecological Sources through Ecological Security Assessment*

Ecological source areas are important patches that can provide ecosystem services and maintain the stability of landscape ecological structure, which is the basis for building an ESP [4]. The selection of ecological source areas not only needs to consider the ecosystem service value of the patches themselves, but should also have the ability to prevent ecological degradation and maintain landscape connectivity [66]. Thus, this study constructed a comprehensive evaluation method based on ecosystem importance, ecological sensitivity, and landscape stability. The specific assessment methods and calculation procedures are shown in Tables 1 and 2. By superimposing the three results with equal weights and dividing them into five levels using the natural breakpoint method, the patches with relatively high safety levels and extremely high safety levels were selected as ecological sources.

Table 1. Methods and processes for calculating the importance of ecosystem services, ecological sensitivity, and landscape stability.

Type of Evaluation		Formula	Variable Description
Ecosystem services importance	Water yield	$Y_{xj} = \left(1 - \frac{AET_{xj}}{P_x}\right) \cdot P_x$	Y_{xj} is the water yield of raster x in land use type j; P_x is the annual average precipitation of raster x; and AET_{xj} is the evapotranspiration of raster x in land use type j.
	Carbon sequestration	$C = C_{above} + C_{soil} + C_{dead} + C_{below}$	C is the total carbon stock; C_{above} is the aboveground carbon stock; C_{soil} is the soil carbon stock; C_{dead} is the dead carbon stock; and C_{below} is the belowground carbon stock.
	Soil conservation	$A_c = K \times L \times S \times P \times C$	A_c is the amount of soil conservation (t/hm^2·a); R is the rainfall erosivity factor; K is the soil erodibility factor; L is the slope length factor; S is the slope gradient factor; C is the vegetation cover factor; and P is the soil conservation measures factor.
	Habitat quality	$Q_{Xj} = H_j \left[1 - \frac{D_{xj}^z}{D_{xj}^z + K^z}\right]$	Q_{xj} is the habitat quality of raster x in land use type j; H_j is the habitat suitability of land use type j; D_{xj}^z is the total habitat threat level of raster x in land use type j; k is the half-saturation constant, which is often regarded as 0.5; and z is the normalization constant ($z = 2.5$).
Ecological sensitivity	Multifactor integrated evaluation	$P_i = \sum_{i=1}^{n} F_j \times W_j$	P_i is the ecological sensitivity comprehensive evaluation score; F_j is the ecological sensitivity index of the ith factor; and W_j is the impact weight of the ith factor.
	Soil erosion	$A = \sqrt[4]{R \times K \times LS \times C}$	A is the erosion sensitivity; R is the rainfall erosivity factor; K is the soil erodibility factor; LS is the topographic relief factor; and C is the vegetation cover factor.
Landscape stability	Landscape fragility	$PD = \frac{N}{A}$	PD refers to the degree of landscape pattern fragmentation; N refers to the total number of landscape patches; and A refers to the total landscape area (m^2).
	Landscape connectivity	$dPC = \frac{(PC - PC_{remove})}{PC} \times 100\%$	dPC demonstrates the importance of plaques, and the possible connectivity index of a particular patch is demonstrated by PC. PC_{remove} represents the possible connectivity index after removing the patch. The distance threshold was set to 1000 m, and the probability of connectivity was set to 1

The evaluation of the importance of ecosystem services aims to identify the important natural ecological spaces that ensure a virtuous cycle and dynamic balance of regional ecosystems [35]. According to the ecological status of Jiawang District, four types of factors, namely water yield, habitat quality, soil conservation, and carbon sequestration, were selected for the importance assessment [67,68]. The evaluation of ecological sensitivity refers to the diagnosis of potential areas where regional ecosystems may have generated ecological problems and caused ecological degradation under the influence of human activities and natural environment changes [43,69]. This study selected five geological–geomorphological factors, namely slope, elevation, NDVI, distance from subsidence area, and distance from residential area [70,71], as well as two hydrological factors, namely distance from waterbodies and soil erosion [40,72], in order to reflect the characteristics of the internal attributes of the resource-exhausted city region and the types of potential risks (Table 2). Landscape stability refers to the intensity of the influence of ecological patches on ecological flow activities, and it is affected by landscape fragmentation and landscape connectivity [60,73]. The patch density can characterize the degree of landscape fragmentation, as well as the degree of landscape spatial heterogeneity [45]. Landscape connectivity is an indicator of the degree of occurrence of regional ecological processes [74]. In this study, two indicators, landscape fragmentation and landscape connectivity, were selected to evaluate the stability of the landscape pattern so as to quantify the extent to which the natural environment patches and landscape connectivity in the study area were affected [75].

Table 2. Evaluation of ecological sensitivity.

Evaluation Factors		Grades of Ecological Sensitivity Low 1	Relatively Low 2	General 3	Relatively High 4	Extremely High 5	Weight
Geomorphological factors	NDVI	>0.6	0.45–0.6	0.3–0.45	0.15–0.3	0–0.15	0.26
	Elevation (m)	<70	70–140	140–210	210–280	>280	0.04
	Slope (°)	0–6	6–12	12–18	18–24	>24	0.07
	Distance from subsidence area (m)	>7000	5000–7000	3000–5000	1000–3000	<1000	0.2
	Distance from residential area (m)	>800	600–800	400–600	200–400	<200	0.1
Hydrological factors	Soil erosion	Low erosion	Relatively erosion	General erosion	Relatively high erosion	High erosion	0.18
	Distance from waterbody (m)	>3000	1500–3000	1000–1500	500–1000	<500	0.15

3.2. Construction of Ecological Resistance Surface and Corridor

Resistance surfaces aim to quantify the extent to which species are hindered from spreading and migrating in ecological patches [76]. In this study, we used the MCR model to construct basic ecological resistance surfaces and assigned corresponding resistance values to different land types: 70 for cropland, 30 for forest land, 50 for grassland, 10 for waterbodies, 80 for unused land, and 100 for construction land [77]. The spatial heterogeneity within the landscape would be neglected if the values were assigned only by landscape type. Long-term high-intensity mining of coal resources and urban construction cause ground subsidence and water pollution, which, to a certain extent, will exacerbate regional ecosystem sensitivity and biocirculation resistance [1]. Therefore, this study considers the use of ecological sensitivity data to revise the landscape resistance surface [51,52], and the specific revisions are shown in Table 3.

Ecological corridors are bridges between ecological sources and are key ecological components for maintaining ecological flows and ecosystem connectivity [33]. Circuit theory draws on the physics of electrons randomly traveling in a circuit to model the process of migration and diffusion of individual species or genes across the landscape. By using the current intensity between source sites to reflect the relative importance of ecological patches and corridors, thereby predicting species dispersal and migration patterns and identifying movement pathways, this approach is more consistent with real species movement [78]. In this study, based on circuit theory, we used the Linkage Pathways Tool module to calculate cost-weighted distances (CWDs) among multiple pairs of source sites to create a CWD surface for identifying least-cost pathways (LCPs) and to determine the location and shape of ecological corridors [79,80].

Table 3. Methods of constructing and correcting resistance surfaces.

Correct Indexes	Formula	Variable Description
Minimum cumulative model	$MCR = f_{min} \sum_{j=n}^{i=m} L_{ij} \times R_i$	f is the positive correlation between the cumulative resistance value and the flow of ecological factors; min represents the minimum cumulative resistance; L_{ij} is the spatial distance between spatial landscape unit i and ecological source j; and R_i is the resistance coefficient of landscape element i to the motion diffusion of a target element.
Degree of ecological sensitivity	$R_i = \frac{SL_i}{SL_a} \times R$	R_i is the ecological resistance coefficient of grid i corrected on the basis of ecological sensitivity; SL_i is the ecological sensitivity of grid i; SL_a is the average ecological sensitivity of grid i corresponding to land use type a; and R is the basic resistance coefficient of grid i corresponding to land use type.

3.3. Ecological Node Identification

3.3.1. Ecological Pinch Points

Ecological pinch points are important nodes in ecosystems that reflect landscape connectivity, and their protection can prevent serious ecological damage and loss in a region [37]. In circuit theory, the current density represents the amount of electricity that passes through a single pixel in raster data. Areas with higher current densities indicate a higher likelihood of biological transfer and migration through the area or irreplaceability, and these areas can be used as ecological pinch points [78]. The study uses the Pinchpoint Mapper module of the Linkage Mapper plug-in and selects the "All-to-one" and "All-pairs" modes for iterative calculations. Considering that the core positions of pinch points would not be affected by the change in corridor width, the weighted distance of the corridor was finally set to 1000 m after many tests. The region with high current was extracted from the two modes by the natural breakpoint method and combined with the region with high resistance on the ecological resistance plane, and the final pinch point region was determined by superposition.

3.3.2. Ecological Obstacle Points

Ecological obstacle points can be viewed as bottlenecks in the migration of species, which, when repaired, will help to strengthen ecosystem linkages [29]. The Barrier Mapper module of the Linkage Mapper 2.0 Toolbox was used to identify the ecological obstacle points, and the percentage of improvement score relative to the least-cost distance (LCD) was selected for calculation [80]. This study determines whether the location of obstacle points has changed by adjusting the search radius. Combining the actual results, 200 m was selected as the search radius in this study, the high current area was extracted by the natural obstacle point method as the obstacle point area of the study area, which was superimposed with the land use status, and targeted ecological measures were proposed.

3.3.3. Ecological Fracture Points

When important traffic arteries, such as railways and highways, cross ecological corridors, ecological fracture points are formed. They will not only hinder the continuity of the landscape, but also seriously harm the stability of the ecosystem. In this study, expressways, provincial roads, national roads, and railways are selected as important traffic arteries and superimposed to form the network data set. The intersection of the two was selected as the ecological fracture point, which was also the fragile point of the ecosystem under the influence of traffic.

4. Results

4.1. Identification Results of Ecological Sources

4.1.1. Ecological Security Assessment

In terms of the spatial pattern of ecosystem service importance, ecological sensitivity, and landscape stability, the more important and extremely important zones of ecosystem services were mainly concentrated in the north-west and south-east of the study area in Jiawang District (Figure 3). These areas were characterized by nature reserves, forest nature parks, and parts of areas dominated by vegetation cover, with higher terrain and lower human development activities. The highly sensitive areas were mainly located in the built-up and subsidence areas in the south (Figure 4). The built-up areas themselves had been subjected to high levels of interference from human activities. The coal mining subsidence areas had also suffered serious ecological degradation under the double influence of human interference and ecological damage, and the natural ecological recovery capacity was low. The low-value areas of landscape pattern stability were mainly distributed in the built-up areas of towns (Figure 5). The intensity of economic activities and the large area of town construction in these places led to a low ecosystem service value and a high degree of patch fragmentation.

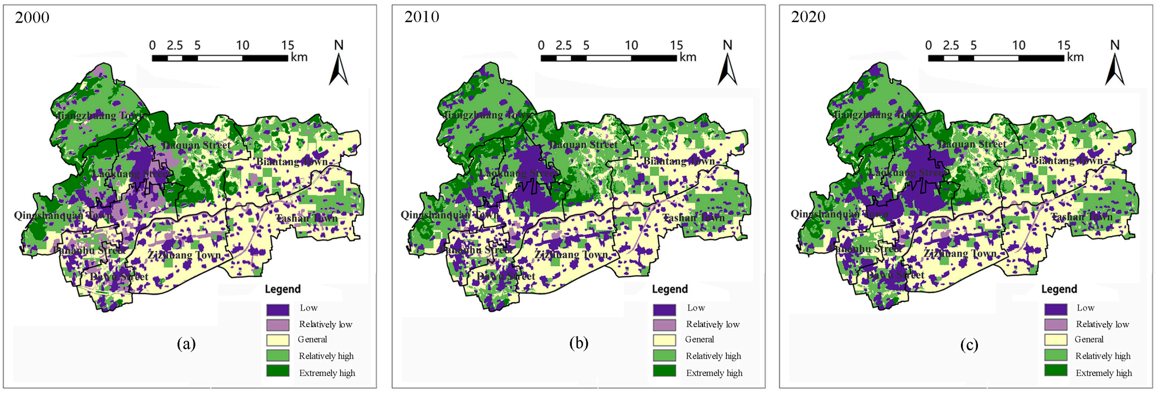

Figure 3. (**a**) The distribution of importance of ecosystem services in 2000; (**b**) the distribution of importance of ecosystem services in 2010; (**c**) the distribution of importance of ecosystem services in 2020. (Source: the research team).

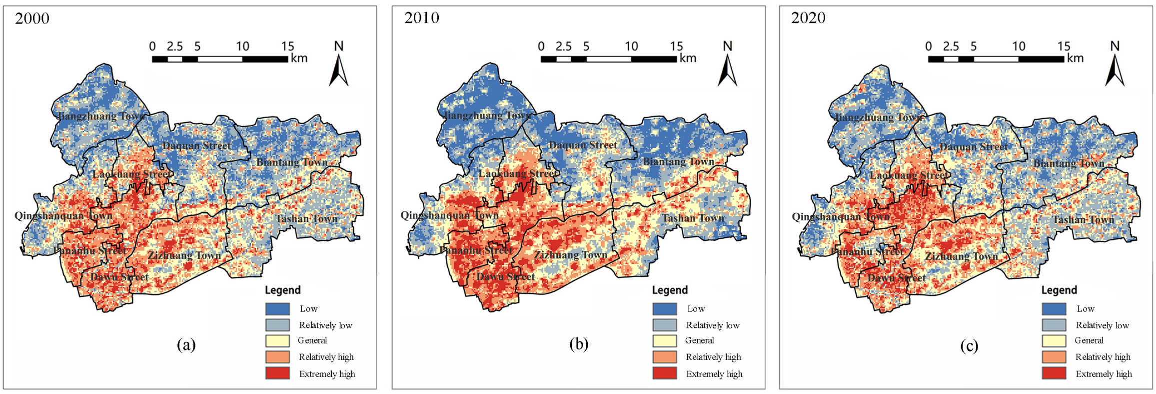

Figure 4. (**a**) The distribution of ecological sensitivity in 2000; (**b**) the distribution of ecological sensitivity in 2010; (**c**) the distribution of ecological sensitivity in 2020. (Source: the research team).

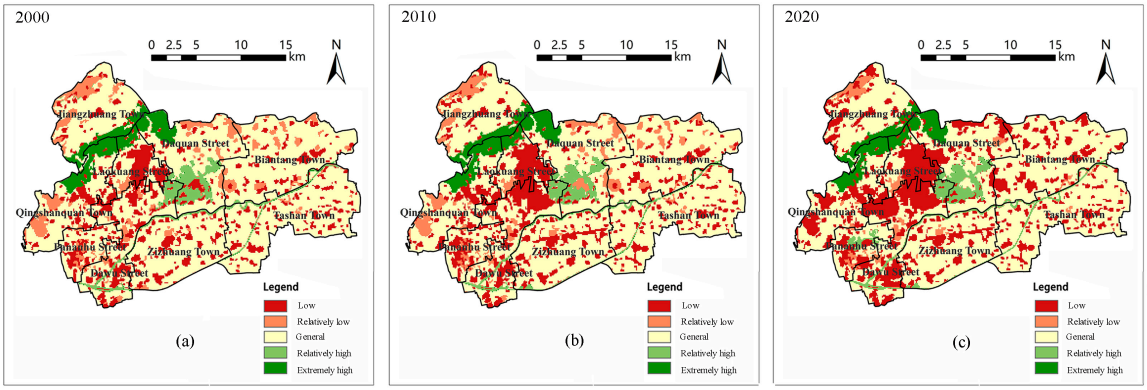

Figure 5. (**a**) The distribution of landscape stability in 2000; (**b**) the distribution of landscape stability in 2010; (**c**) the distribution of landscape stability in 2020. (Source: the research team).

From the ecological security grading and spatial layout of Jiawang District (Table 4, Figure 6), it can be seen that the areas of relatively high security and extremely high security were 123.59 km^2, 116.18 km^2, and 125.25 km^2 in total, accounting for 19.93%, 18.74%, and 20.20% of the whole spatial area of ecological protection grading. These areas were mainly some water sources and areas with high forest coverage, which were of primary importance in maintaining the ecological security of Jiawang District and needed to undergo strict ecological protection. The general security areas were 14.97 km^2, 36.10 km^2, and 14.91 km^2, accounting for 2.41%, 5.82%, and 2.40% of the spatial area of the ecological security grading, which were mainly forest land. Spatially interspersed with the relatively low-security areas, they were distributed within the township boundaries in the north and south of the study area. The relatively low-security area covered 385.30 km^2, 359.79 km^2, and 355.33 km^2, accounting for 62.15%, 58.03%, and 57.31% of the ecological protection classification space in Jiawang District, and it was mostly cropland. This area had not been subject to full urban development and retained some of its natural ecological conditions. The low-security areas covered areas of 96.14 km^2, 107.93 km^2, and 124.51 km^2, accounting for 15.51%, 17.41%, and 15.83% of the ecological protection classification space in Jiawang District. It was mainly distributed in the central location of each township, most obviously in the central urban location of Laokuang Street. This area was composed of a large amount of construction land and some cropland, with low importance of ecosystem services, but high ecological sensitivity. Enhancing the land use efficiency and greening coverage of such areas can effectively improve the efficiency of the overall ecological protection work in Jiawang District.

Table 4. Area graded by ESA from 2000 to 2020.

Year	Low (km^2)	Relatively Low (km^2)	General (km^2)	Relatively High (km^2)	Extremely High (km^2)
2000	96.14	385.30	14.97	39.95	83.64
2010	107.93	359.79	36.10	68.83	47.35
2020	124.51	355.33	14.91k	73.15	52.10

From 2000 to 2010 (Figure 6a,b), the rapid development of urbanization and industrialization in the study area led to an imbalance between land supply and demand, coupled with the disturbance of coal mining activities, which have caused serious damage to the ecosystem. The concentration of ecological patches in the southern part of the study area was poor, resulting in a large reduction in extremely high-security areas. From 2010 to 2020 (Figure 6b,c), Jiawang District was committed to gradually shifting from a resource-based city to ecological city development. The fragmentation of ecological security patches was alleviated, and the high-ecological-security-value areas were improved.

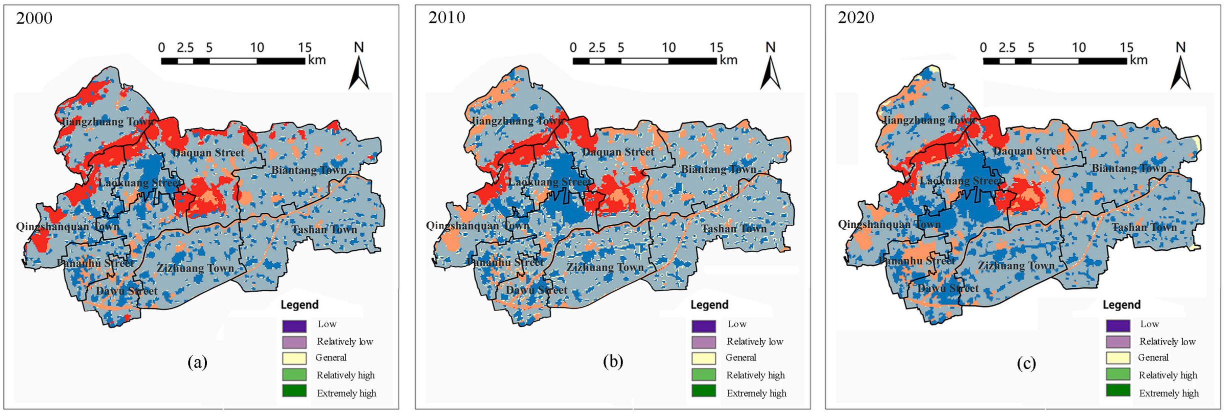

Figure 6. (**a**) The distribution of ecological security assessment in 2000; (**b**) the distribution of ecological security assessment in 2010; (**c**) the distribution of ecological security assessment in 2020. (Source: the research team).

4.1.2. Extraction of Ecological Sources

This study selected relatively high-security and extremely high-security patches as ecological source areas based on the results of the ecological security assessment. Superimposing the ecological source area with the ecological protection red line and nature protection area in Jiawang District, it was found that the vast majority of the ecological protection red line and nature protection areas were within the ecological source area. This indicates that the delineation method of the ecological source area in this paper had high rationality and accuracy. As can be seen from Table 5, the ecological source areas in 2000, 2010, and 2020 were 123.59 km^2, 116.18 km^2, and 125.25 km^2 respectively. These sources accounted for 13.57%, 18.74%, and 20.20% of the total area of Jiawang District. In terms of temporal distribution, the total area of ecological source areas first decreased and then increased, with small fluctuations in the changes.

Table 5. Distribution table of ecological source area in Jiawang District from 2000 to 2020.

Name of Township	Ecological Source Area in 2000/km^2	Ecological Source Area in 2010/km^2	Ecological Source Area in 2020/km^2
Qingshanquan Town	21.96	21.77	19.62
Daquan Street	36.88	35.18	38.25
Jiangzhuang Town	18.67	18.55	19.33
Biantang Town	8.55	8.50	8.94
Laokuang Street	5.29	5.25	5.37
Dawu Street	12.28	10.33	12.25
Tashan Town	6.76	6.76	6.76
Zizhuang Town	6.48	6.38	6.53
Pananhu Street	6.72	3.46	8.20
Total	123.59	116.18	125.25
Proportion of the study area/%	19.93	18.74	20.20

From the perspective of spatial distribution (Figure 7), the ecological source areas of Daquan Street, Jiangzhuang Town, Qingshanquan Town, and Dawu Street were more distributed (Table 5), with forest land, grassland, and other vegetation and water areas having high coverage. Erlang Mountain, Shigu Mountain, Dadong Mountain Scenic Spot, and Dugong Lake Scenic Area constituted the main parts of these ecological source areas. In contrast, the ecological source area was less distributed in Laokuang Street and Pananhu Street. The former is a densely populated built-up area with a lack of connectivity in its ecological landscape, while the latter is a mining area with a long history and complex terrain. All these factors seriously damaged the integrity of the natural environment and the stability of the ecosystem. With the active ecological measures taken in Jiawang District in the past ten years, the ecological patch areas of Dugong Lake Scenic Area and Pan'an Lake Wetland Park have increased significantly.

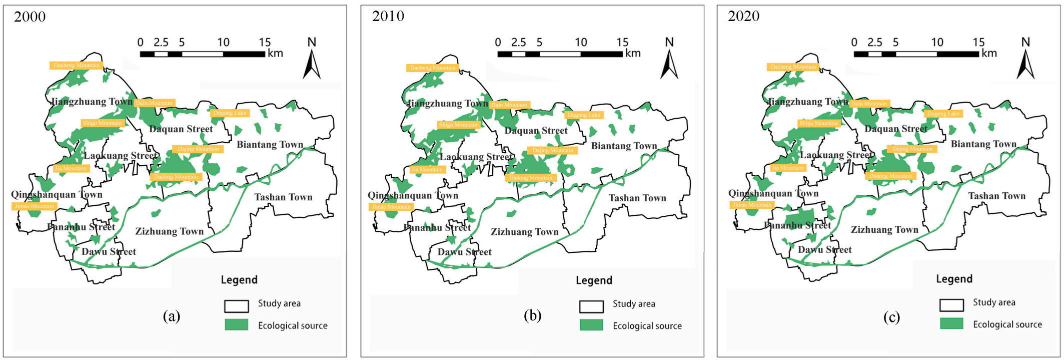

Figure 7. (**a**) The distribution of ecological sources in 2000; (**b**) the distribution of ecological sources in 2010; (**c**) the distribution of ecological sources in 2020. (Source: the research team).

4.2. Results of Ecological Resistance Surface Construction

As shown in Figure 8, the distributions of ecological resistance values in 2000, 2010, and 2020 were 6.03–158.76, 7.68–177.45, and 5.36–150.96, with the high- and low-value areas of resistance values increasing and then decreasing. In terms of spatial and temporal distribution, the high-value areas from 2000 to 2010 were mainly concentrated in Laokuang Street, Dawu Street, and Zizhuang Street, which were the main construction areas of the city and the concentration areas of coal mining and were more affected by human activities. Compared with the distribution of resistance values in 2000, the spatial change in the high-resistive—value area in 2010 was small, but the range was obviously enlarged. The concentration of urban human activities and mining subsidence zones led to a sensitive and fragile regional ecology and an increase in the overall resistance to biological migration, causing many low-value zones to become high-value zones in the southern part of the study area. From 2010 to 2020, there was a spatial pattern in which Laokuang Street was the center of high values, decreasing to the periphery in a circular manner. Due to the ecological rehabilitation of the collapsed area and the increase in regional vegetation cover, some areas changed from a medium–high value to a low value. However, with the increasing area of impervious surfaces in cities, it was difficult to form large green patches in urban built-up areas. As a result, the resistance coefficient in built-up areas remained high, increasing the difficulty of ecological rehabilitation. This could be seen to indicate that human activities and natural disasters could affect the sustainable development of regional ecosystems.

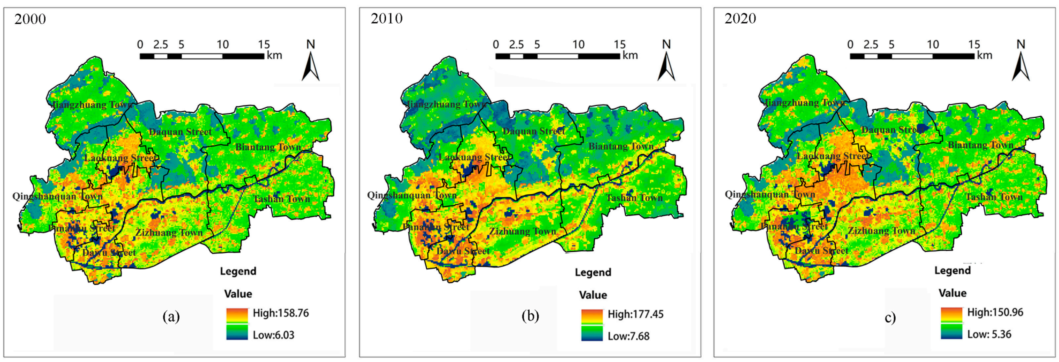

Figure 8. (**a**) The distribution of combined resistance surface in 2000; (**b**) the distribution of combined resistance surface in 2010; (**c**) the distribution of combined resistance surface in 2020. (Source: the research team).

4.3. Ecological Corridor Identification Results

Table 6 shows that there were 53, 51, and 49 ecological corridors in 2000, 2010, and 2020, with total lengths of 129.25 km, 118.57 km, and 112.25 km, respectively. The number and length of ecological corridors decreased year by year. In terms of temporal and spatial distribution, there was a clear spatial similarity in the distribution of ecological corridors within the overall study area, while there was a clear spatial variability within the towns (Figure 9). Jiangzhuang Town, located in the northwestern part of the study area, had significantly fewer ecological corridors due to the encroachment of construction land into ecological source areas. Zizhuang Town and Tashan Town had sparser corridor distributions due to the lack of ecological patches and connectivity with other source lands. There were several ecological sources of different sizes distributed in Bianchang Township, and the ecological corridor corridors were usually short and distributed in a network. The corridors in Laokuang Street and Dawu Street were less distributed. Frequent and intensive human activities in the area damaged the connectivity of the original ecological corridors and threatened the security of the ecosystem.

Table 6. Classification table of length of ecological corridor from 2000 to 2020.

Year	Number of Corridors < 2 km	Number of Corridors of 2–5 km	Number of Corridors of >5 km	Total
2000	23	28	2	53
2010	24	24	3	51
2020	23	24	2	49

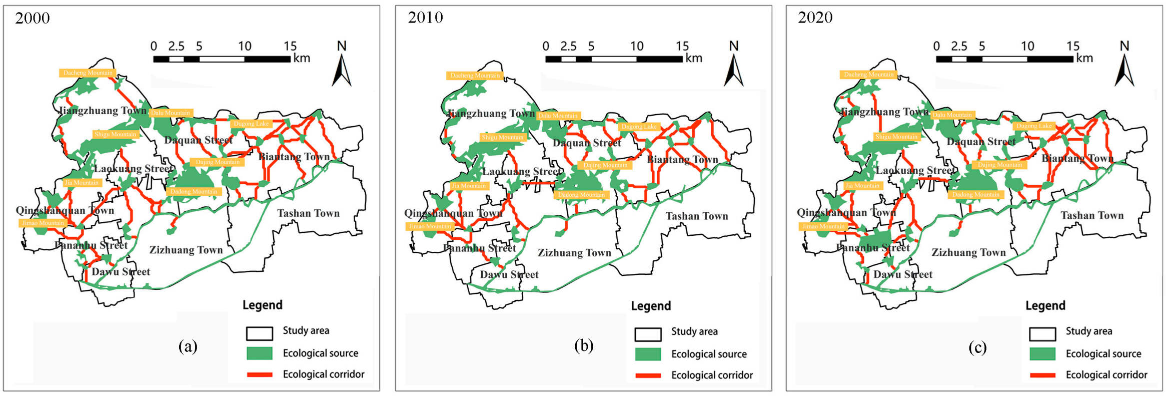

Figure 9. (**a**) The distribution of ecological corridors in 2000; (**b**) the distribution of ecological corridors in 2010; (**c**) the distribution of ecological corridors in 2020. (Source: the research team).

As can be seen from Table 6, the number of ecological corridors in the range of <2 km and >5 km increased from 2000 to 2010 (Figure 9a,b), and they were mainly distributed along the sides of rivers and scenic spots, such as the Grand Canal and the Big Dawngdao Mountain Scenic Area. Numerous ecological corridors in the range of 2–5 km were mainly distributed on the northern side of the study area; the number decreased and the change in length was thus polarized. This was due to the more serious fragmentation of ecological source areas as coal mining and urbanization led to the expansion of subsidence areas and construction land. From 2010 to 2020 (Figure 9b,c), the overall density of corridors in the northeastern and northwestern parts of the study area was higher, but the number decreased significantly, and the lengths of ecological corridors showed a decreasing trend in all three intervals.

4.4. Ecological Node Identification

4.4.1. Ecological Pinch Point

As shown in Figure 10, 17, 13, and 19 ecological pinch points were identified and screened in 2000, 2010, and 2020, totaling 9.53 km^2, 6.07 km^2, and 10.70 km^2, respectively. In terms of temporal and spatial distribution, the number of pinch areas changed little between 2000 and 2010 (Figure 10a,b), but the overall area decreased. The number and area of pinch areas increased from 2010 to 2020 (Figure 10b,c), and the area of pinch points decreased compared with that in 2000. It is mainly because of the closure of mines and the treatment of coal mining subsidence areas that part of the ecological land has been managed, especially on Pananhu Street.

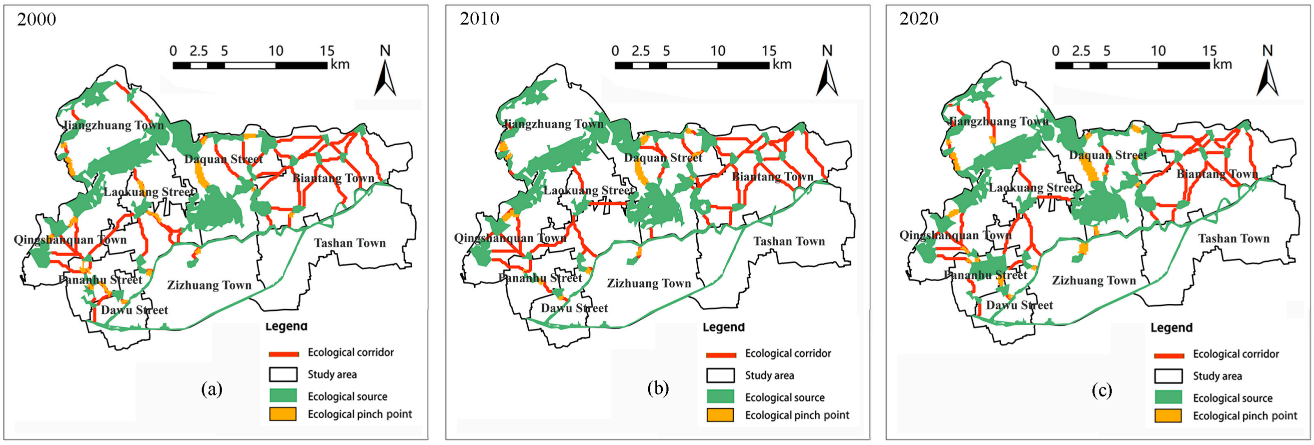

Figure 10. (**a**) The distribution of ecological pinch points in 2000; (**b**) the distribution of ecological pinch points in 2010; (**c**) the distribution of ecological pinch points in 2020. (Source: the research team).

In terms of spatial distribution (Figure 10), the area north of the Beijing–Hangzhou Grand Canal in the study area showed obvious fragmentation of ecological pinch point patches, with a gradual increase in the number and area, while the changes in the ecological pinch point area south of the Grand Canal were opposite to this. As can be seen from Table 7, Daquan Street (33.65–49.91–48.12%), Qingshanquan Town (10.34–14.80–9.92%), and Jiangzhuang Town (12.86–14.97–16.19%), which are located on the north side of the Beijing–Hangzhou Grand Canal, accounted for a larger proportion of pinch point patches. In contrast, Zizhuang Town (3.00–4.82–9.69%) and Biantang Town (2.52–1.38–0%), which are close to the south side of the Grand Canal, and Laokuang Street (8.65–0–0%), which is densely populated with human activities, accounted for a smaller share of the pinch point area. The pinch point areas were mainly located in the center or edge of ecological source areas connected by ecological corridors, and these overlapping areas had high ecological value.

Table 7. The proportions of the total area of pinch points in Jiawang District from 2000 to 2020.

Year	Jiangzhuang Town/%	Qingshanquan Town/%	Pananhu Street/%	Laokuang Street/%	Daquan Street/%	Dawu Street/%	Zizhuang Town/%	Bian Tang Town/%
2000	12.86%	10.34%	16.11%	8.65%	33.65%	12.86%	3.00%	2.52%
2010	14.97%	14.80%	6.02%	0	49.91%	8.09%	4.82%	1.38%
2020	16.19%	9.92%	10.83%	0	48.12%	48.12%	9.69%	0

In terms of land use types, cropland, construction land, and waterbodies accounted for 77.4%, 8.29%, and 8.05%, respectively, and waterbodies accounted for a relatively small proportion in 2000. In 2010, the pinch points were mainly cropland and waterbodies, accounting for 81.41% and 7.75%. In 2020, cropland, construction land, and forest land accounted for 80.39%, 8.21%, and 7.07%. As an important node of animal migration, pinch areas are easily affected by human activities, such as construction land and lake filling, which pose a high potential ecological risk to the surrounding areas. Therefore, ecological conservation for ecological pinch point areas is urgent.

4.4.2. Ecological Obstacle Points

As shown in Figure 11, this research identified 16, 20, and 15 ecological obstacle points in 2000, 2010, and 2020, respectively. The area of obstacle increased sharply from 11.09 km^2 in 2000 to 13.08 km^2 in 2010 and decreased to 12.70 km^2 in 2020. From the perspective of time distribution, the number of obstacle points showed a decreasing trend over the past two decades, but the area increased sharply. The Jiawang District government made a decision to gradually stop coal mining in 2010 and carry out industrial transition and upgrading. At the same time, various mining area rehabilitation and ecological management projects were undertaken, and these measures alleviated the fragmentation degree of the obstacle area in the south of the study area in 2020. However, the impacts of urban development and human activities on biomobility are still significant.

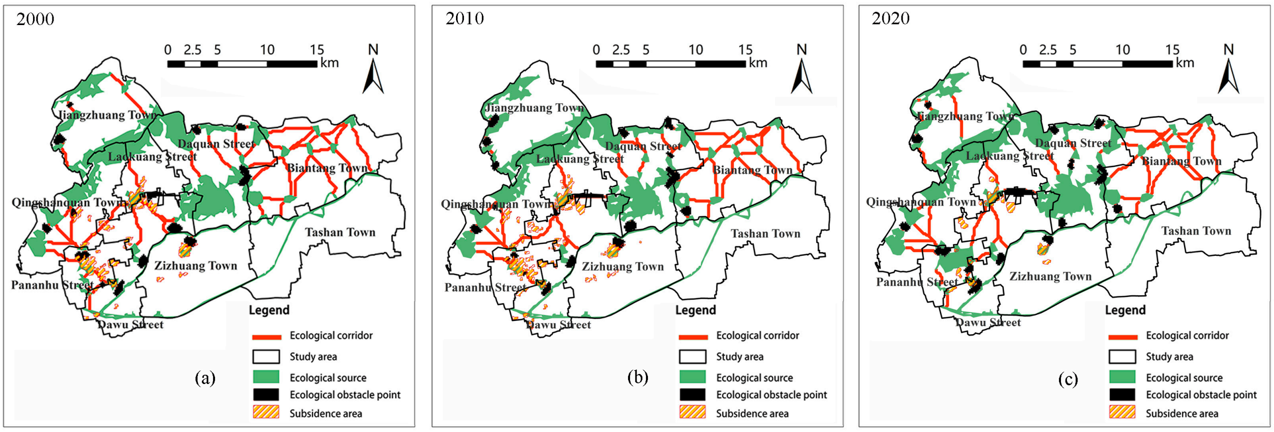

Figure 11. (**a**) The distribution of ecological obstacle points in 2000; (**b**) the distribution of ecological obstacle points in 2010; (**c**) the distribution of ecological obstacle points in 2020. (Source: the research team).

From the perspective of spatial distribution, most of the obstacle areas are located in the area north of the Beijing–Hangzhou Grand Canal, along the ecological corridor, or at the edge of the ecological source area. As can be seen from Table 8, the proportions of the area of obstacle sites in Pananhu Street (11.54–5.20–11.57%), Daquan Street (19.12–28.06–26.61%), and Dawu Street (31.38–16.82–22.60%) were larger. The migration of species was mainly hindered by problems such as accelerated surface collapse due to coal mining and urban construction, which led to traffic lines cutting off ecological corridors. Zizhuang Town (9.29–8.26–6.14%) and Biantang Town (4.24–11.24–8.43%) had smaller proportions of obstacle areas. Zizhuang Town was located at the edge of the study area, with poorer connectivity to the surrounding counties. The obstacle point in Biantang Town was mainly due to the fragmentation of ecological source patches in low hilly areas.

Table 8. The proportion of the total area of obstacle points in Jiawang District from 2000 to 2020.

Year	Jiangzhuang Town/%	Qingshanquan Town/%	Pananhu Street/%	Laokuang Street/%	Daquan Street/%	Dawu Street/%	Zizhuang Town/%	Bian Tang Town/%
2000	10.01%	9.11%	11.54%	5.14%	19.12%	31.38%	9.29%	4.24%
2010	13.91%	7.72%	5.20%	6.35%	28.06%	16.82%	8.26%	11.24%
2020	8.98%	5.67%	11.57%	10.00%	26.61%	22.60%	6.14%	8.43%

From the perspective of land use type, in 2000, 2010, and 2020, construction land accounted for 22.54%, 15.90%, and 27.87%, and cropland accounted for 66.91%, 69.80%, and 60.55%, respectively. Owing to the serious interference of human activities and the huge resistance of the ecosystem, a large area of obstacle points appeared in the construction land, cropland, or its surrounding radiation area, leading to the separation of landscape connectivity. Repairing or removing the obstacle points is crucial to improving landscape connectivity. Different ecological measures should be proposed according to land use type.

4.4.3. Ecological Fracture Point

As shown in Figure 12, the numbers of ecological fracture points in 2000, 2010, and 2020 were determined to be 8, 24, and 33. The construction of the G310, G206, and other highway lines increased the number of ecological fracture points and extended them to the north, south, and east of Dadongshan. They were mainly distributed in Qingshanquan Town, Laokuang Street, Dawu Street, and Biantang Town. The urban construction areas and traffic trunk lines in these areas were relatively dense. The number of fracture points in the Pananhu area increased first and then decreased, which was mainly due to the improvement in the integrity of the ecological source area and the decrease in the ecological corridor. Roads, as important transportation facilities, cannot be directly removed. In order to avoid conflict between human activities and the ecosystem, engineering measures, such as flyovers and culverts dedicated to biology, can be built to repair the ecological fracture points and leave enough ecological space.

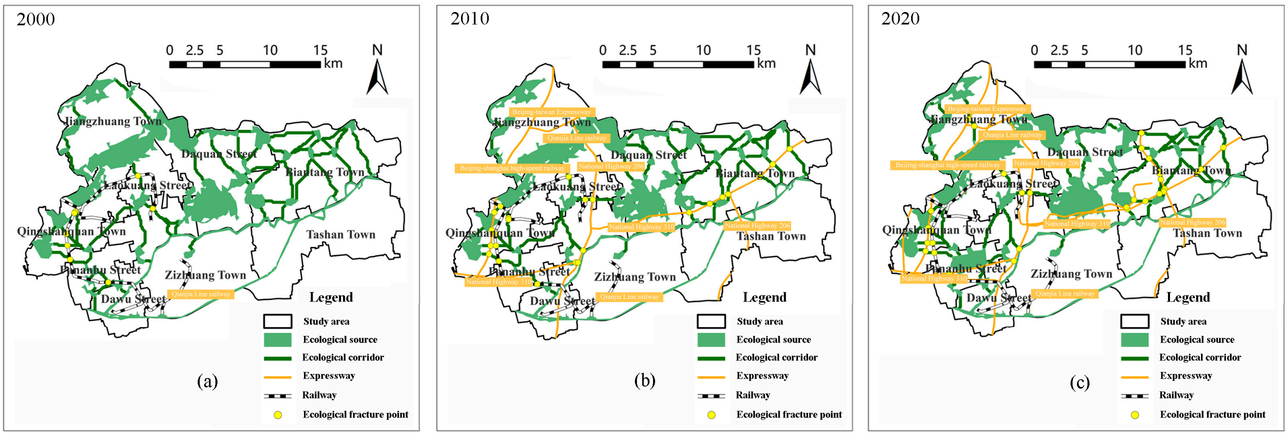

Figure 12. (**a**) The distribution of ecological fracture points in 2000; (**b**) the distribution of ecological fracture points in 2010; (**c**) the distribution of ecological fracture points in 2020. (Source: the research team).

4.5. Identification of Key Areas of Territorial Ecological Restoration

From the spatio-temporal evolution of key areas of territorial ecological restoration in 2000, 2010, and 2020, it can be seen that, in the urban construction of Jiawang District over the past 20 years, land use change, road network construction, and coal mining subsidence areas were the leading factors affecting the ecosystem change in Jiawang District. Therefore, optimizing urban planning and construction and controlling coal mining subsidence areas are an important direction to improve the ecological environment of Jiawang District [75].

The key area in Jiawang District in 2020 was composed of ecological source areas and ecological nodes. The ecological nodes included ecological pinch points, ecological obstacle points, and ecological fracture points. As shown in Figure 13 and Table 9, this paper identified 27 ecological sources, 49 ecological corridors, 19 ecological pinch points, 15 ecological obstacle points, and 33 ecological fracture points. Among them, the ecological source area was 125.25 km^2, accounting for 20.20% of the total area of the study area, which was composed of forest land, grassland, and waterbodies. Ecological restoration activities should focus on improving and maintaining them while controlling urban expansion.

The ecological pinch area was 8.77 km^2, accounting for 1.41% of the total area, mainly construction land and cropland. Ecological restoration activities were mainly to improve the greening rate. The area of ecological obstacle points was 12.70 km^2, accounting for 2.05% of the total area. It was dominated by cropland and forest land, and the control of cropland and construction of forest land should be strengthened. The distribution and safety of wild animals should be emphasized in the fracture area. The targeted implementation of ecological measures based on key areas of territorial ecological restoration can strengthen the stability of the ecological space matrix and ecosystem service capacity of Jiawang District [44].

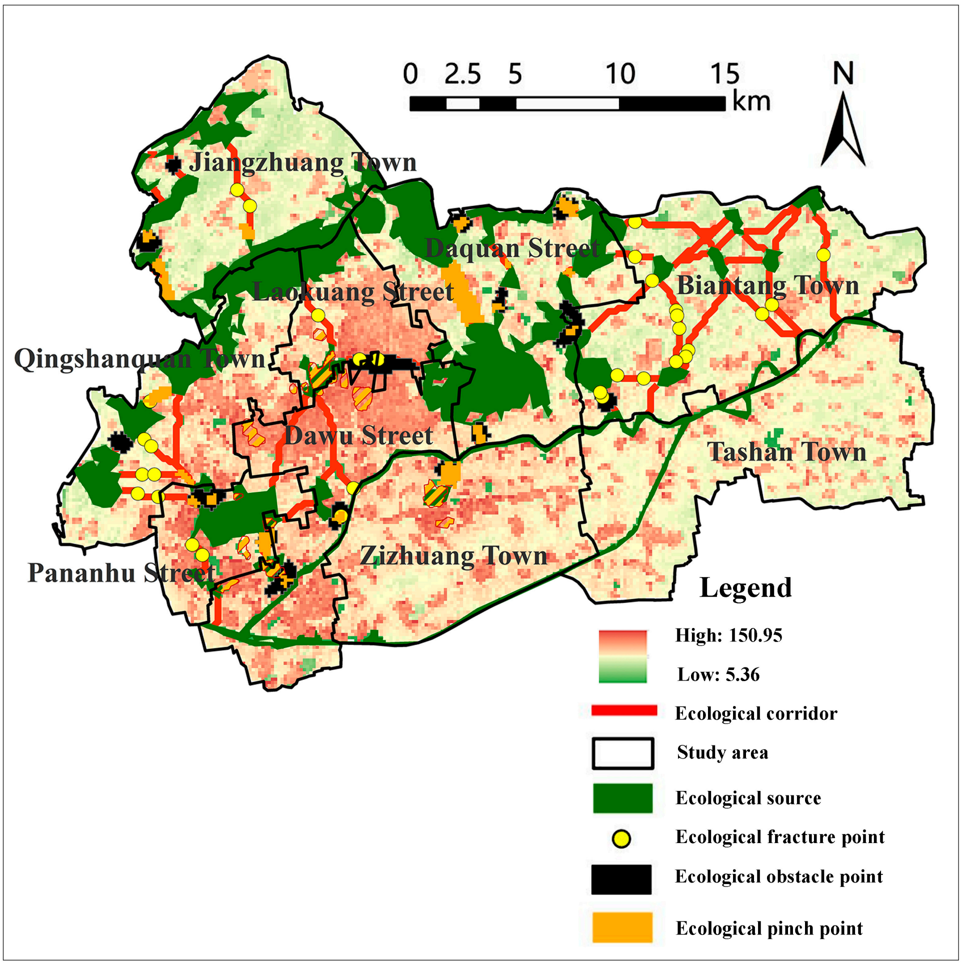

Figure 13. Distribution of key areas of territorial ecological restoration in Jiawang District in 2020. (Source: by the research team).

Table 9. Key areas of territorial ecological restoration in Jiawang District in 2020.

Rehabilitation Area	Land Use Status	Area/km^2	Main Distribution Position	Suggested Restoration Direction
Ecological source	Forest land	80.66	Jiangzhuang Town, Qingshanquan Town, Daquan Street, and Biantang Town	Protect ecological sources and control urban expansion
	Grassland	8.33	Pananhu Street and Daquan Street	
	Waterbody	23.17	Pananhu Street, Dawu Street, Laokuang Street, Zizhuang Town, Tashan Town, and Biantang Town	
	Construction land	4.30	Daquan Street, Pananhu Street, Dawu Street, and Laokuang Street	
	Cropland	8.79	Daquan Street, Dawu Street, Tashan Town, and Pananhu Street	

Table 9. *Cont.*

Rehabilitation Area	Land Use Status	Area/km^2	Main Distribution Position	Suggested Restoration Direction
Ecological pinch point	Cropland	6.44	Jiangzhuang Town, Daquan Street, Qingshanquan Town, Pananhu Street, Dawu Street, and Zizhuang Town	Improve greening rate Protect forest lands and return farmland to forests
	Forest land	0.51	Zizhuang Town, Daquan Street, and Qingshanquang Town	
	Waterbody	0.77	Pananhu Street and Dawu Street	
	Construction land	0.79	Zizhuang Town, Daquan Street, and Dawu Street	
	Grassland	0.26	Pananhu Street	
Ecological obstacle point	Cropland	7.69	Zizhuang Town, Daquan Street, Dawu Street, Pananhu Street, Jiangzhuang Town, and Biantang Town	Return farmland to forests and lakes Comprehensive control of soil erosion
	Forest land	0.75	Daquan Street and Biantang Town	
	Construction land	3.54	Laokuang Street, Dawu Street, and Zizhuang Town	
	Waterbody	0.58	Dawu Street and Pananhu Street	
	Grassland	0.14	Pananhu Street	
Ecological fracture point	Railway	-	Qingshanquan Town, Laokuang Street, Biantang Townt, Jiangzhuang Town, and Dawu Street	Create wildlife walkways or place warning signs
	Highway	-	Qingshanquan Town, Laokuang Street, Biantang Town, Jiangzhuang Town, and Dawu Street	

5. Discussion

5.1. Strengths and Limitations

Compared with the traditional ecological protection and restoration work of single elements, such as water and soil, this study pays more attention to its global, systematic, and comprehensive nature. Firstly, the ecological security of the study area was evaluated multidimensionally in terms of ecosystem importance, ecological sensitivity, and landscape stability, and areas with high values were selected as ecological source areas [40,80]. The scientific and precise identification of ecological source areas is of great significance for the construction of ESPs and territorial ecological restoration. In the construction of the resistance surface, the impacts of both natural environmental changes and human activities brought to the region by resource development were considered comprehensively. The use of ecological sensitivity evaluation data to modify the basic resistance surface can reflect the ecological resistance status of resource-exhausted cities better than general studies [51]. Finally, the ecological source, ecological pinch point, ecological obstacle, and ecological fracture point were taken as the key areas of territorial ecological restoration, and effective ecological strategies were proposed in combination with land use types [50,78]. It was found that, unlike previous static studies, regional ecological restoration or protection activities can be better coordinated by analyzing the changes in ESP during different periods in resource-exhausted cities. Distributed in the area of obstacle points and fracture points around coal mining collapse zones and urban construction activities, the relationship and distance to urban space was also in dynamic change.

Although this study can provide some reference for the ecological recovery of similar resource-based cities, it still has some limitations. The different geographical locations, resource types, and stages of urban development make each city's ecosystem suffer from different degrees of damage. For different types of resource-exhausted cities, locally adapted modifications of evaluation parameters and strategies can better fit the actual development of regional ecosystems. Although this study included the ecological resistance coefficient of ecological sensitivity in the construction of the ecological resistance surface, there were still some socio-economic factors that had not been included, and future studies should fully consider the influence of natural and social factors [40]. At present, there is no scientific standard to adopt on how to determine the sequence of the implementation of different key areas of territorial ecological restoration. Therefore, the focus of future research should be on the social, economic, and ecological conditions of the region to rationally determine the sequence of implementation so as to achieve more efficient ecological management effects.

5.2. Characteristics of Spatial and Temporal Evolution of Territorial Ecological Restoration Critical Areas

Through studying the changes in key areas of territorial ecological restoration in Jiawang District over the past 20 years, the results show that there was a dynamic relationship between environmental rehabilitation and destruction in resource-exhausted cities.

In terms of changes, the ecological source area, ecological pinch points, ecological obstacle points, and ecological fracture points in 2000 were 123.59 km^2 (Table 5), 8.32 km^2, and 11.09 km^2, respectively. In 2010, the distribution of ecological source areas and ecological pinch points decreased to 116.18 km^2 and 5.81 km^2. The area of ecological obstacle points increased to 13.08 km^2, and the number of ecological fracture points increased to 24. This indicates that the ecological environment is deteriorating, with fewer resting areas for migrating organisms, more areas to prevent migration, and a worsening in the ESP. In 2020, the proportion of ecological source areas increased to 125.25 km^2 (Table 5), the proportion of ecological pinch points increased to 8.77 km^2, and the ecological obstacle point area decreased to 12.70 km^2. The number of ecological fracture points increased to 33. The increase in the number of ecological source areas and ecological pinch points indicated an increase in regional landscape connectivity and the flow of materials and energy. The presence of obstacles and fracture points suggests that, although areas favorable to biological migration increased, areas that impede migration and show high ecological resistance still require persistent ecological treatment. Overall, ecological source areas and ecological pinch points increased in Jiawang District from 2000 to 2020, and ecosystem connectivity and stability improved and developed.

In terms of spatial distribution, the territorial ecological restoration area in 2000 was interwoven and densely distributed in the northern part of the Beijing–Hangzhou Grand Canal in the form of bands and patches. The northern part of the study area relies on natural conditions, such as scenic spots and forests, which constitute most of the ecological source sites in Jiawang District (Figure 7a). In the southern part of the study area, pinch points and source areas are sparsely distributed and scattered, and organisms take a long time to cross this area (Figure 10a). Ecological obstacle zones are mainly distributed in coal mining collapse zones and high resistance zones near urban built-up areas (Figures 11a and 12a). In 2010, the density of ecological rehabilitation zones in the central and southern parts of the study area increased, but the overall spatial distribution remained unchanged. The expansion of urban built-up land in the south led to the gradual degradation of ecological carrying capacity. Ecological problems, such as ecological pollution and ground subsidence, were caused by the development of coal resources. This made a large area of ecological obstacle point area appear in the study area (Figure 11b). The spatial extent of ecological pinch points and ecological source areas also decreased (Figure 10b). Ecological fracture points are centrally distributed in the western part of the study area in the densely populated areas of traffic arteries and ecological corridors, and the development of traffic drove local economic development while impeding ecological connectivity (Figure 12b). In 2020, the territorial ecological restoration area was mainly distributed in the northern part of the Beijing–Hangzhou Grand Canal. The spatial extent of the ecological pinch point area expanded, but the fragmentation of the pinch point patches increased (Figure 10c). This was mainly due to the expansion of built-up areas in the northern and central parts of the study area, which caused anthropogenic disturbance and damage to the ecological environment. In 2010, Jiawang District officially stopped the mining of coal resources and took active measures to strengthen ecological governance and control of coal resource development. As a result, the ecological obstacle point area was repaired and improved, and its spatial extent was reduced (Figure 11c). The remaining obstacle points were mostly distributed in the untreated coal mining subsidence areas or the edge of the ecological source near the built-up areas. The fracture points in the western part of the study area had no obvious changes in spatial distribution, but had a tendency to develop to the east, with the construction of the road network in the east (Figure 12c). In summary, from 2000 to 2020, the key areas of territorial ecological restoration in Jiawang District showed dense and sparse spatial patterns in the north and south of the Beijing–Hangzhou Grand Canal, respectively. The ecological pinch points and ecological obstacle point areas distributed near construction land and coal mining subsidence areas changed frequently, and the expansion of construction land and coal mining subsidence areas were the most critical factors leading to regional ecological degradation.

5.3. Optimization Measures for Key Areas of Territorial Ecological Restoration

Improving the ecological environment of resource-exhausted cities and realizing the transition and upgrading of resource-exhausted cities have always been among the national development priorities. Although some control measures have been taken and positive results have been achieved, the ecological problems of resource-exhausted cities are still serious. Therefore, in order to ensure the smooth implementation of future ecological restoration goals, appropriate protection should be given to resource-exhausted cities according to the actual situation. This study comprehensively identified four key areas for territorial ecological restoration in 2020, namely ecological source areas, ecological pinch points, ecological obstacle points, and ecological fracture points, and put forward the following ecological restoration suggestions according to land use types.

(1) Strengthening the protection of ecological source land to achieve equal emphasis on development and ecological protection. For nature reserves with beautiful scenery and good tourism resources in the study area, the continuity of habitats and species diversity can be maintained by strengthening the construction of facilities and the protection of woodlands. (2) Appropriate development and construction of small source areas dominated by eco-tourism and the investment of economic gains in ecological infrastructure [77]. The construction of ecological protection forests on both sides of the river and around reservoirs has been strengthened, and river ecological protection zones have been established. At the same time, ecological protection and restoration projects, such as sewage treatment and water quality monitoring, have been carried out [66].

Ecological pinch points are important ecological obstacles for regional development that are conducive to ensuring the smooth construction of ecological corridors [80]. They mainly include cropland and construction land. In order to improve the ecological environment of cultivated areas, measures can be taken to return farmland to forests. On the premise of ensuring the quality of farmland, comprehensive farmland improvement work is being actively carried out [69]. If it is close to a waterbody, the conversion of cropland into wetland can be considered. With regard to construction land, the construction of parks, green spaces, and small wetlands should be strengthened. For residents' domestic waste and daily sewage, appropriate engineering measures should be taken to treat them to promote the sustainable development of construction sites [62].

Ecological obstacle points are areas that impede the movement of species from ecological sources to other sources. Ecological obstacle points are mainly construction land and forest land. Although coal mining has ceased in the study area, urban construction is still affected by historical legacy problems. Priority can be given to improving the areas where ecological obstacle points overlap with coal mining subsidence sites through a comprehensive approach that emphasizes both artificial rehabilitation and natural protection, such as land reclamation, vegetation planting, and the reconstruction of coal mining subsidence landscapes [3,4]. For forested land, measures such as afforestation and soil and water conservation will be increased to build a green ecological network.

The ecological fracture point area is affected by both road traffic and ecological corridors. Roads, as important transport facilities, cannot be removed directly. Soundproofing facilities and protective forests on both sides of the road will be strengthened to reduce the disturbance to organisms [69]. In order to avoid conflicts between human activities and ecosystem conservation, the migration corridors of wild animals should be reasonably planned and laid out, and any form of destruction or predation of wild animals should be severely suppressed [28]. With regard to the air-mining collapse zones traversed by transport routes, measures, such as wetland management and soil and water conservation, should be taken to alleviate the conflict between ecological space and living space.

6. Conclusions

Resource-exhausted cities have caused many non-negligible ecological and environmental problems due to large-scale resource development, seriously threatening regional ecological security. Exploring the dynamics of ecological damage and restoration in resource-exhausted cities is conducive to the coordinated development of cities and ecosystems. In this study, we assessed the ecological security of Jiawang District in 2000, 2010, and 2020 based on the importance of ecosystem services, ecological sensitivity, and stability of landscape patterns, and determined the ecological source. The ecological sensitivity data were used to correct the resistance surface. In addition, ecological corridors, pinch points, obstacle points, and fracture points were identified by circuit theory methods. Finally, the priority areas for ecological protection and rehabilitation of the national territory were diagnosed and identified, and corresponding measures were proposed for each priority area.

The results showed that: (1) From 2000 to 2020, the ecological source areas of Jiawang District were 123.59 km^2, 116.18 km^2, and 125.25 km^2, showing a trend of first decreasing and then increasing. The distribution of ecological source areas was uneven, with more in the north and fewer in the south. There were 53, 51, and 49 ecological corridors, mainly located in the northern and central areas of the study area, which were distributed in the shape of roots or spider webs. (2) Ecological pinch points 17, 13, and 19 were mainly distributed in the northern and central areas of the study area and appeared along the center or top of the ecological corridor. Ecological obstacle points 16, 20, and 15 were located on the ecological corridor in the north and middle of the Beijing–Hangzhou Grand Canal and at the intersection of the ecological source and ecological corridor. Ecological fracture points 8, 24, and 33 had a concentrated distribution in the central and southern Jiawang Districts of the main traffic arteries. (3). Combined with the characteristics of land use types and spatial distribution in 2020, targeted strategies for territorial ecological restoration have been proposed. This study can provide a reference for promoting the sustainable development of resource-exhausted cities.

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