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Integrated Evaluation of the Ecological Security Pattern in Central Beijing Using InVEST, MSPA, and Multifactor Indices

Xiaodan Li [1,2,†], Haoyu Tao [1,2,*,†], Jing Wang [3], Bo Zhang [4], Zhen Liu [1,2], Zhiping Liu [1,2] and Jing Li [1,2]

[1] State Key Laboratory for Tunnel Engineering, China University of Mining and Technology (Beijing), Beijing 100083, China; lixiaodan@cumtb.edu.cn (X.L.); bqt2000605053@student.cumtb.edu.cn (Z.L.); bqt2100620051@student.cumtb.edu.cn (Z.L.); bqt2100605039@student.cumtb.edu.cn (J.L.)
[2] School of Mechanics and Civil Engineering, China University of Mining and Technology (Beijing), Beijing 100083, China
[3] Beijing Institute of Architectural Design, Beijing 100083, China; wangjing4@biad.com.cn
[4] School of Architecture and Art, North China University of Technology, Beijing 100144, China; abaodoc@ncut.edu.cn
* Correspondence: bqt1900603023@student.cumtb.edu.cn; Tel.: +86-188-3200-8180
† These authors contributed equally to this work.

Abstract: Scientific identification of ecological sources and corridors is crucial in constructing an ecological security pattern (ESP). To develop an ESP tailored to the scale of central urban areas in megacities, this study takes Central Beijing as the research object. It innovatively integrates the integrated valuation of ecosystem services and tradeoffs (InVEST), the morphological spatial pattern analysis (MSPA), and the Conefor software to identify ecological sources. Seven indicators related to topographic, natural conditions, and human disturbance factors are selected to build the ecological resistance surface, which is then combined with circuit theory to construct the ESP. The results show the following: (1) Central Beijing contains 157 ecological sources, primarily distributed in the western, northern, and eastern regions, with woodland as the dominant land type. (2) A total of 439 ecological corridors were extracted, including 317 key ecological corridors and 122 inactive ecological corridors. (3) The identified ecological pinch points are mainly the Jingmi Diversion Canal and the West Moat. (4) The identified ecological barriers are spread throughout the entire study area. The results of this study are highly significant for improving the quality of ecological security and protecting biodiversity in the study area and other urban centers.

Keywords: ecological security patterns; morphological spatial pattern analysis (MSPA); integrated valuation of ecosystem services and tradeoffs (InVEST); circuit theory; Central Beijing

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1. Introduction

Ecological security patterns (ESPs) represent a vital approach to ensuring regional ecological security while balancing socio–economic development and ecological conservation [1]. They hold significant importance in achieving regional sustainable development [2,3]. ESPs are considered the basis for obtaining these goals by establishing and providing ecosystem services to people. They have received extensive attention and ESP-related theories have been well developed [4,5].

Currently, ESP-based research is mainly conducted according to the mode of "ecological sources identification—ecological resistance surface construction—ecological corridor extraction" [6–9], among which ecological sources identification and resistance surface construction are the most critical steps. The scientific components of ecological sources' identification and the comprehensiveness of resistance surface construction directly affect the accuracy of the resulting ESPs.

This current study on identifying ecological sources has been divided into three main stages: (1) Preliminary Stage: The direct selection of areas with good ecological quality as the ecological sources, such as nature reserves, rivers, forests, etc. [10,11]. Although this method is straightforward and intuitive, its selection criteria are narrow, and the assessment framework lacks scientific rigor, which makes it difficult to comprehensively reflect the demands for ecological services. (2) Advanced Stage: The construction of a quantitative identification system of ecological sources based on ecosystem services, ecological sensitivity, and ecological supply/demand ratio [12]. This research is more scientific and systematic, with more comprehensive considerations and quantitative methods, providing more abundant results. At present, this is the mainstream research direction. For instance, Jia et al. (2023) incorporated the ecosystem service supply–demand relationship to establish a new ecological framework [13], while Gao et al. (2021) integrated ecosystem services and ecological sensitivity to identify ecological sources [14]. (3) Professional Stage: The utilization of more specialized identification software, such as the integrated valuation of ecosystem services and tradeoffs (InVEST) [15] and morphological spatial pattern analysis (MSPA), to screen ecological sources with more specific screening criteria and more specialized quantification methods. For instance, Cao et al. (2024) integrated four modules in InVEST with food production services to identify ecological sources [16], whereas Wei et al. (2022) utilized MSPA to extract core areas for constructing ecological sources [17]. However, limitations remain when using these tools in isolation: InVEST lacks capabilities for spatial morphological analysis, while MSPA excels in spatial topology but cannot quantify Habitat Quality or ecological services. Most studies have relied on single-method applications, with limited attempts to integrate the strengths of both tools. This study aims to synergize InVEST and MSPA to construct a more comprehensive and scientifically rigorous identification of ecological sources.

Ecological resistance surfaces, which reflect the influence of landscape heterogeneity on ecological flows [18], are essential tools in ecological security research. The accuracy of these surfaces depends on the scientific selection of indicators but is often influenced by the biophysical and socio–economic conditions of specific regions [19]. Current research approaches include the following: (1) Resistance Based on Land Use Types: Resistance values are assigned according to land use types [5]. Although straightforward, this method considers only a single factor, overlooking critical indicators such as elevation and slope, thereby limiting its accuracy. (2) Habitat Quality module in InVEST: This method utilizes InVEST's Habitat Quality module to define resistance surfaces [20], which can partially reflect Habitat Quality, although it remains constrained by single-factor limitations. (3) Integration of Multiple Indicators: A more comprehensive approach integrates multiple indicators, such as elevation and slope, to construct resistance surfaces [21]. While scientifically robust, the lack of standardized criteria for indicator selection leads to significant variability in results. Consequently, this study proposes a multidimensional approach, selecting seven key indicators to construct more precise and reasonable ecological resistance surfaces.

Ecological corridors, which connect ecological sources, play a crucial role in maintaining ecosystem connectivity and facilitating the internal flow of ecological services [22]. Key methods for corridor extraction include the following: (1) Minimal Cumulative Resistance (MCR) Model: The MCR model, based on the principle of minimal cumulative resistance, is commonly employed to identify ecological corridors. For instance, Qin et al. (2024) employed the MCR model to extract ecological corridors in Qujing City and construct an ecological network [23]. Similarly, Yang et al. (2023) built a comprehensive conservation and management system linking ecological sources, corridors, and nodes [24]. However, the MCR model overlooks species' random movement behaviors, cannot determine corridor width or critical nodes [25], and fails to effectively evaluate the importance and hierarchy of corridors [26]. (2) MSPA Method: The MSPA method identifies corridors through spatial morphological analysis. For example, Wang et al. (2022) applied MSPA to rapidly identify corridors in urbanized areas [20], while Rosot et al. (2018) used MSPA to prioritize riverbank protection and landscape restoration [27]. However, MSPA struggles to define corridor boundaries and hierarchy. (3) Circuit Theory: This method models species movement as random walks of electrical charges within a circuit, enabling the identification of multiple potential pathways with defined widths and relative importance [28–31]. It overcomes the limitations of traditional methods, providing a more scientific approach to corridor hierarchy and evaluation. Therefore, this study adopts circuit theory to extract ecological corridors, offering a more rigorous analysis of their importance and classification.

Most ESP studies have focused on macro-scale regions, such as municipal, provincial, or national urban clusters. While these studies are valuable for maintaining large-scale ecological processes, they face limitations in addressing issues at the micro-scale, such as central urban areas. Beijing, as China's capital and a quintessential mega-modern city, exemplifies such challenges. Its central urban areas are characterized by high population density, intensive built-up land use, limited green spaces, and poor ecological environments, necessitating a comprehensive and systematic assessment of ESPs. This study, focusing on Central Beijing, aims to improve ecosystem services and ecological quality at the urban micro-scale, proposing targeted planning recommendations.

This study hypothesizes that by integrating professional tools such as InVEST and MSPA, along with scientifically selected indicators for resistance surface construction, ecological sources, resistance surfaces, and ecological corridors in Central Beijing, can be comprehensively and accurately identified. These findings will optimize ESPs, enhancing ecosystem connectivity and stability.

This study addresses the following research questions: (1) How can an ESP be constructed for the scale of central urban areas in mega-cities? (2) How can the advantages of InVEST and MSPA be combined to comprehensively and scientifically identify ecological sources? (3) How can key indicators for Central Beijing be selected from multiple dimensions to construct an ecological resistance surface? (4) How can ecological corridors be extracted scientifically and their importance and hierarchy evaluated?

By addressing these questions, this study seeks to provide scientific support for the construction of ESPs in Central Beijing and similar cities, offering optimization strategies for future urban planning.

2. Materials and Methods

2.1. Study Area

According to the Beijing Municipal Master Plan, the Haidian District, Shijingshan District, Fengtai District, Xicheng District, Dongcheng District, and the Chaoyang District together form Central Beijing (116°2′33″–116°38′22″ E, 39°45′37″–40°9′35″ N) (Figure 1). As of 2022, the study area had a permanent population of 10.95 million, accounting for 50.1% of Beijing's total population, while covering only 8.4% of the city's total area, resulting in an extremely high population density.

The area is characterized by concentrated and dense construction land, with a total area of 1009 km^2, accounting for 73% of the study area. Water systems cover approximately 1.5% of the area, including Kunming Lake, Yongding River, and Tonghui River. Green spaces are distributed in isolated patches, dominated by woodlands and urban parks such as the Summer Palace, the Temple of Heaven Park, and Chaoyang Park. However, the lack of connectivity among these green spaces has led to severe habitat fragmentation.

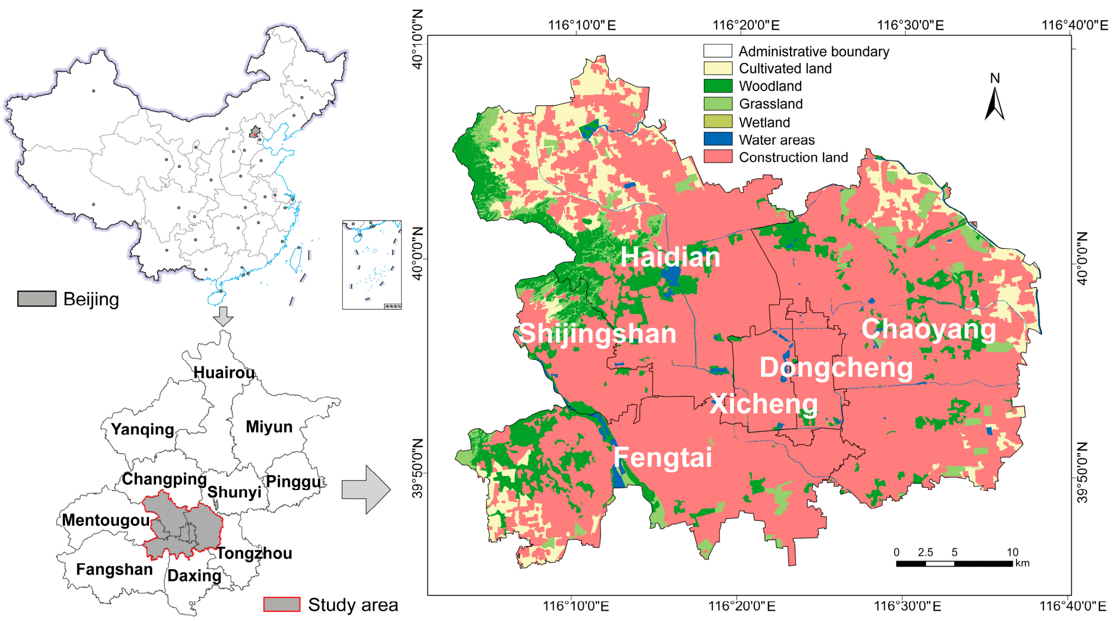

Figure 1. Geographical location and land cover types of Central Beijing.

In summary, Central Beijing has a high population density, concentrated urban built-up land with a high area percentage, and point-like distribution of unconnected parks and water systems, which have led to a decline in connectivity and increasing habitat fragmentation, seriously threatening the conservation of urban biodiversity.

2.2. Data Source

The dataset for this study originates from authoritative databases, as detailed in Table 1.

Table 1. The data types and sources used in this study.

Data Types	Data Time	Resolution	Data Sources
Land use type	2020	30 m	https://www.webmap.cn/commres.do?method=globeIndex (accessed on 2 December 2022)
DEM	-	30 m	www.gscloud.cn (accessed on 2 March 2023)
Precipitation	2011–2020	1 km	www.geodata.cn (accessed on 2 March 2023)
Soil data	2009	-	https://data.tpdc.ac.cn/home (accessed on 24 May 2023)
NDVI	2020	30 m	www.nesdc.org.cn (accessed on 24 May 2023)

2.3. Research Methodology

The research framework for ESPs consists of three parts: identification of ecological sources, construction of ecological resistance surfaces, and extraction of ecological corridors (Figure 2). First, the intersection area of the InVEST high-value areas and the MSPA core area was determined. The high-value areas within the intersection part were selected as the final ecological source using the Conefor software. Second, based on a comprehensive review of existing studies in this field and considering the actual conditions of the study area, seven factors from three categories—topographic factors, natural conditions, and human disturbances—were selected to construct the ecological resistance surface for the study area [32–34]. Finally, the ecological corridors, ecological pinch points, and barriers in the study area were extracted by applying the circuit theory, and the ESPs for the study area were finally established.

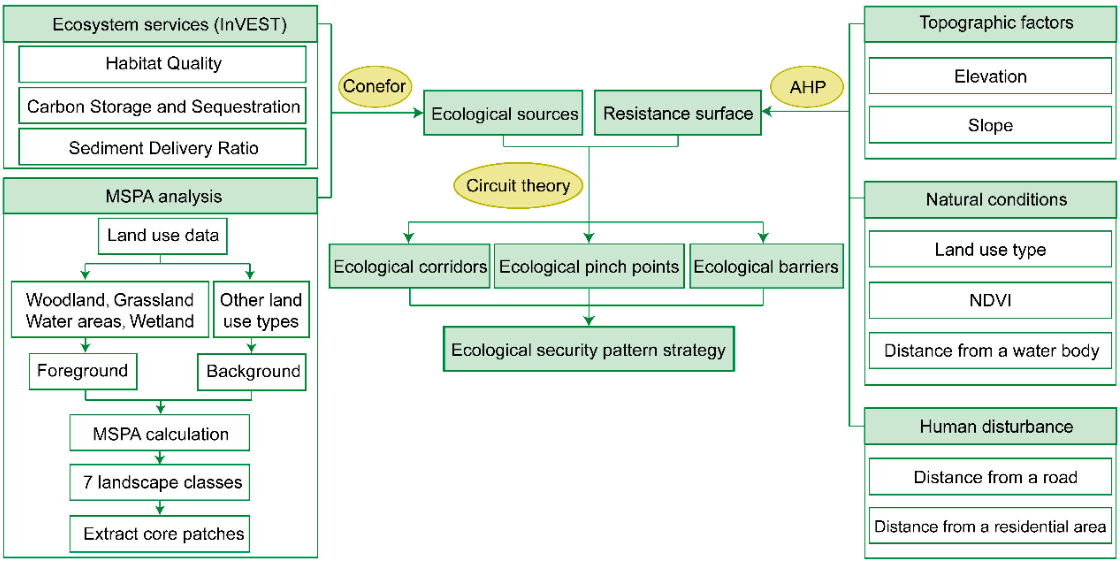

Figure 2. Research flowchart design.

2.3.1. Identification of Ecological Sources

This study innovatively integrates InVEST, MSPA, and Conefor to identify ecological sources. The methodological steps are as follows: (1) The InVEST model is utilized to evaluate the ecological service functions of the study area and extract high-value regions. (2) The MSPA method is applied to delineate core areas within the study region. (3) The intersection of the high-value areas from InVEST and the core areas from MSPA is defined as the candidate area for ecological sources. (4) A landscape connectivity analysis is performed using Conefor software, with regions within the candidate areas where the delta Probability of Connectivity (dPC) is $\geq$0.01 being screened, thereby ultimately identifying the ecological sources. The dPC metric quantifies the significance of individual patches or nodes to overall connectivity, rendering it an essential tool for ecological network analysis [35–37].

(1) ESP Evaluation Based on InVEST

For this study, three specific modules, Habitat Quality, Carbon Storage and Sequestration, and Sediment Delivery Ratio of the InVEST model, were selected for the assessment of ecological service functions. Given the lack of sufficient data in previous studies to determine the weights of these modules, a neutral and impartial equal-weight overlay method was employed for the preliminary evaluation, following thorough discussions among five experts in the field. This approach was adopted to minimize human bias and ensure that all factors were treated equitably and fairly during the initial analysis. The overlay results were subsequently classified into five levels using the natural breaks (Jenks) classification method. After comparative analysis, the highest levels, 3, 4, and 5, were finally taken as the high-value areas of the ecological service function. Detailed calculations for the three modules can be found in related studies [38–41], and the data used in the model are presented in Tables A1–A4.

(2) Landscape Pattern Analysis based on MSPA

MSPA can analyze the geometric shape and connectivity of raster images [42]. This method reveals raster image geometry and patch associations and identifies categories of landscape spatial patterns at the pixel level, which is important for connecting specific ecological features [33].

Based on the actual conditions of the study area and existing research, woodland, grassland, wetlands, and water areas were set as the foreground, while cultivated land and construction land were set as the background [43]. The analysis conducted using the Guidos

Toolbox 3.1 tool (https://forest.jrc.ec.europa.eu/en/, accessed on 13 June 2024) identified seven landscape elements and extracted core area data for subsequent data analysis.

2.3.2. Construction of Resistance Surface

In this study, the ecological resistance surface was categorized into three aspects: (1) topographic factors, including elevation and slope; (2) natural conditions factors, including land use type, NDVI, and distance from a water body; and (3) human disturbance factors, including distance from a road or a residential area. Each factor was divided into five groups and given resistance values of 1, 250, 500, 750, and 1000, ranging from low to high.

AHP is widely used for weight determination, and the specific steps are briefly outlined. During the process of determining weights with AHP, five experts with extensive experience in ecology and environmental science were invited to collaboratively finalize the evaluation matrix through discussions. The evaluation matrix successfully passed the consistency test. Subsequently, the ecological resistance surface of the study area was generated through a weighted overlay based on the determined factor weights. The details for each index of ecological resistance surface are shown in Table 2.

Table 2. Weights and classification of resistance factors.

Criterion Layer	Index Layer	Unit	Resolution	Weight	Resistance Value				
					1	250	500	750	1000
Topographic factors	Elevation	m	30 m	0.0142	<80	80–200	200–400	400–650	>650
	Slope	(°)	30 m	0.0710	<4	4–8	8–16	16–27	>27
Natural conditions	Land use type	-	30 m	0.4104	woodland	grassland	cultivated land	wetland, water areas	construction land
	NDVI	-	30 m	0.1664	>0.7	0.6–0.7	0.4–0.6	0.3–0.4	<0.3
	Distance from a water body	km	30 m	0.0675	<1	1–3	3–5	5–10	>10
Human disturbance	Distance from a road	km	30 m	0.0541	>5	2–5	1–2	0.5–1	<0.5
	Distance from a residential area	km	30 m	0.2164	>2.5	1.5–2.5	1–1.5	0.5–1	<0.5

2.3.3. Extraction of Ecological Corridors

McRae (2006) pioneered the application of circuit theory from physics to landscape ecology and genetics, utilizing the movement of electrons in a circuit to model species migration patterns within landscapes [44].

The individual species, ecological sources, and ecological resistance surface are modeled like electrons in a circuit, the focal nodes of the circuit, and the resistance map, respectively. Important ecological corridors, ecological pinch points, and ecological barriers are identified according to the strength of the current in the simulated circuit. The greater the current, the stronger the connection between ecological sources, while resistance is the degree of obstruction to ecological flows within a landscape. When resistance values are low, ecological movements through terrestrial ecosystems are facilitated. In this study, we used the Linkage Mapper 3.1.0 software to conduct the circuit theory-based analysis.

3. Results

3.1. Identification Results of Ecological Sources

3.1.1. Distribution of the Ecosystem Services

The functional assessment of ecological services based on InVEST showed significantly different spatial patterns for single and integrated ecological services (Figure 3). Habitat Quality scores for the study area were generally low (Figure 3a). The low-value area (Relatively low and Low) was 1214.72 km^2, accounting for about 87.77% of the studied total area, and widely distributed, except the northwestern mountainous region. The land types are mainly construction land, cultivated land, and grassland. The high-value area (High and Relatively high) is 40.23 km^2, accounting for about 2.91% of the total area, mainly distributed in the northwestern mountainous region, and the land types are mainly woodland and green park land.

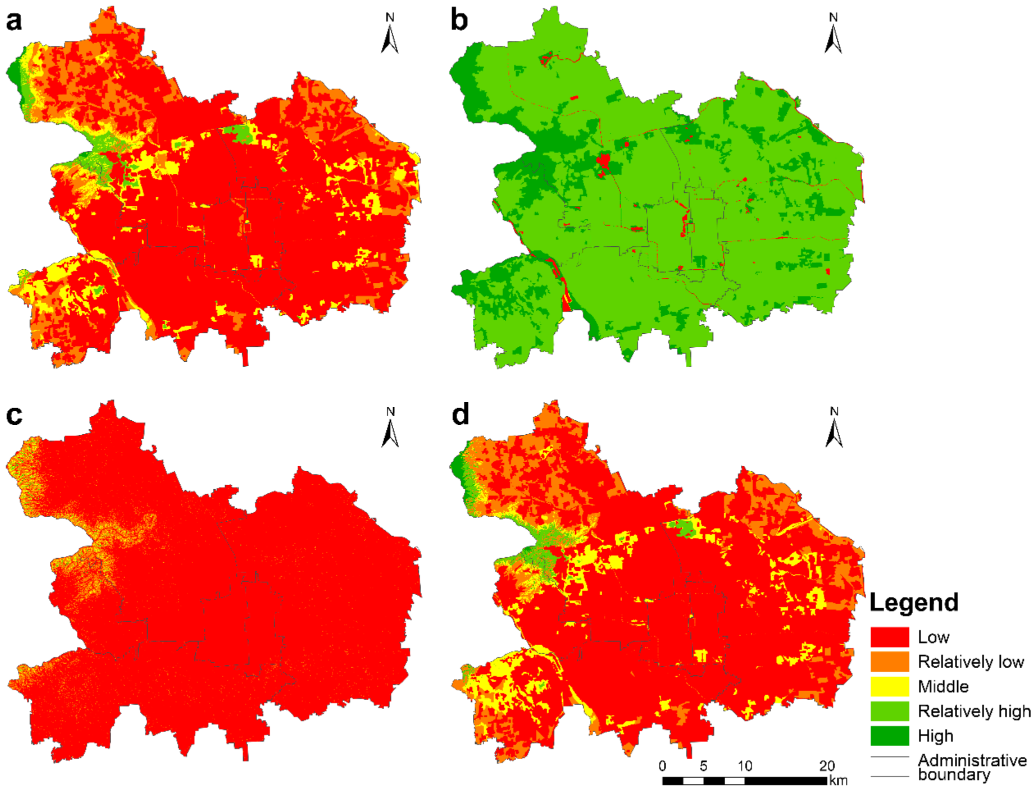

Figure 3. Spatial distribution of ESs. (**a**) Habitat Quality; (**b**) Carbon Storage and Sequestration; (**c**) Sediment Delivery Ratio; (**d**) Spatial distribution of ESs.

Carbon Storage and Sequestration scores are generally high (Figure 3b). The high-value area (High and Relatively high) spans 1363.23 km^2, accounting for 98.50% of the total and covering nearly the entire study area; the low-value area (Relatively low and Low) covers only 20.15 km^2, about 1.46% of the total, and is sporadically distributed, with water bodies as the dominant land type.

The Sediment Delivery Ratio of the study area did not show any obvious regional differences; the scores were generally low (Figure 3c). The high-value area (High and Relatively high) covers just 2.99 km^2, making up 0.22%, and is primarily located in the northwestern mountainous region; the land type is woodland; and the low-value area (Relatively low and Low) is 1368.97 km^2, which is about 98.91% of the total, spatially distributed across almost the entire study area.

Habitat Quality, Carbon Storage and Sequestration, and the Sediment Delivery Ratio were normalized for equal-weighted superposition analysis and classified into five levels to obtain the ecological service function map for Central Beijing (Figure 3d). For the purpose of incorporating areas with good ecological quality as much as possible into ecological sources, the three highest levels (High, Relatively high, Middle) were set as ecological service function high-value areas. The high-value area is 164.74 km^2, approximately 11.9%, reflecting the relatively low ecological service quality of the region. These areas are fragmented, not connected, and mainly distributed in the western and eastern parts.

3.1.2. Landscape Pattern Analysis Based on MSPA

An MSPA map (Figure 4) was obtained by analyzing the 2020 land use-type data using the Guidos Toolbox 3.1 software. The core area is fragmented and dispersed across the region, covering 213.59 km^2, approximately 15.4% of the total. The larger patches in the core area are concentrated in the western part, and the land type is woodland, mainly in the Yangtaishan Natural Scenic Area, the Beijing Jiufeng National Forest Park, the Baiwangshan Forest Park, Fragrant Hills Park, Beijing Xishan National Forest Park, the Badachu Park, etc. The smaller patches are distributed in the eastern part in a point-like manner; the land type is woodland and grassland, primarily used as small urban parks and greenspaces.

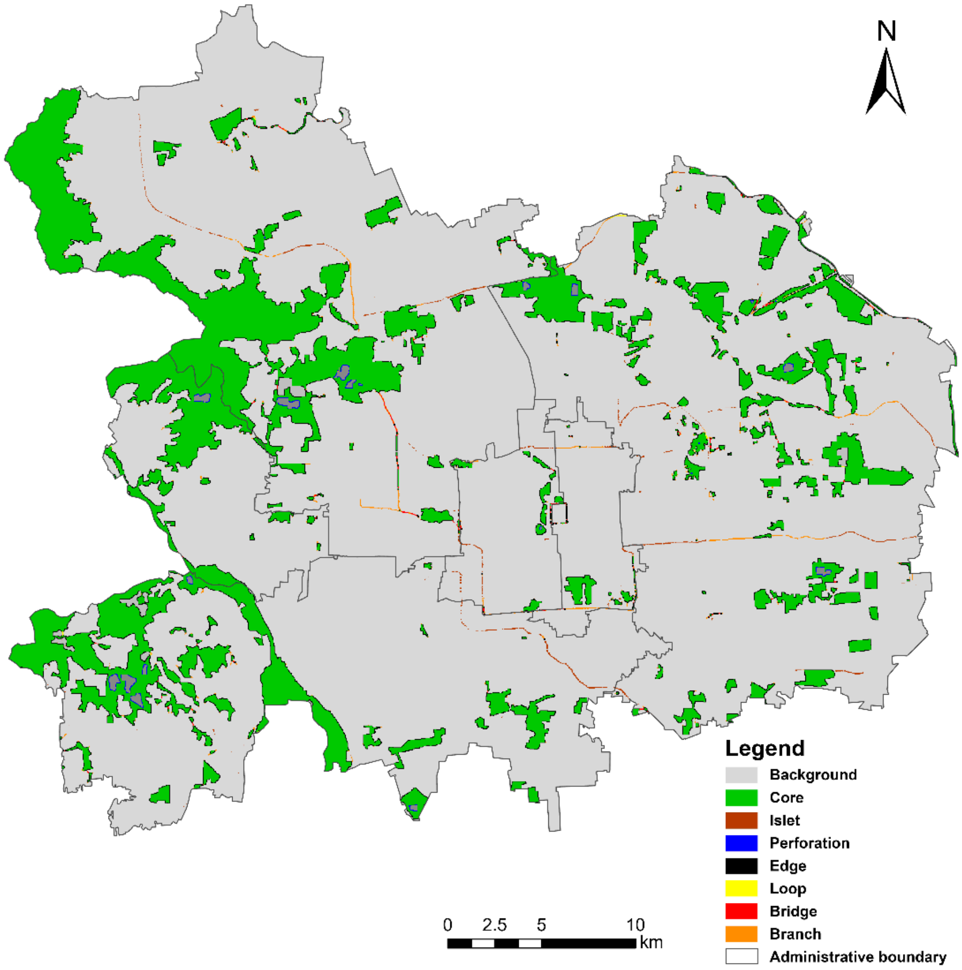

Figure 4. Spatial distribution of MSPA.

3.1.3. Results of the Ecological Source Identification

The intersection of the InVEST high-value and MSPA core areas was taken as ecological source candidates using ArcGIS Pro 3.0.0. The areas with dPC $\geq$ 0.01 in the ecological sources' candidate areas were taken as the final ecological sources using the Conefor software for landscape connectivity analysis (Figure 5). A total of 157 ecological sources were screened. The main reason for the high number of individual ecological sources is that these high-quality areas are located within the urban construction zone. They are not connected due to the blockage by construction land, which is one identification characteristic of ecological sources from the perspective of the urban center scale. The area of ecological sources is 131.60 km^2, about 9.5% of the total.

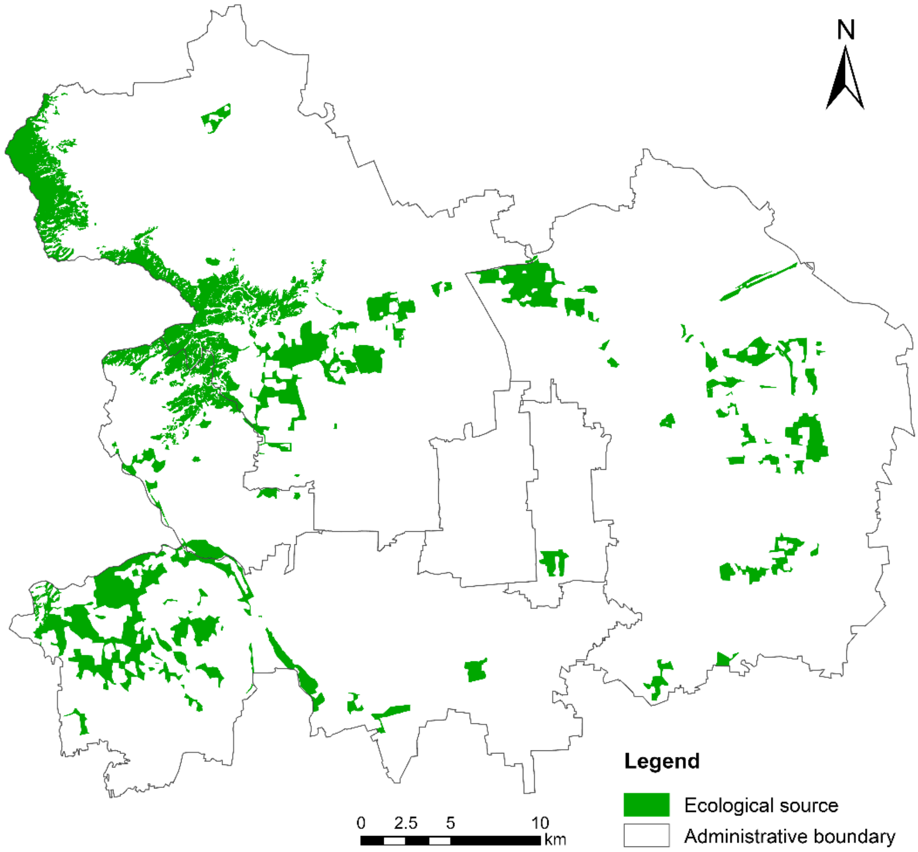

Figure 5. Spatial distribution of ecological sources.

The ecological sources are distributed in a sporadic point-like manner, in which the larger patches are mainly distributed in the western part. The land type is woodland, mainly in the Yangtaishan Natural Scenic Area, the Beijing Jiufeng National Forest Park, Baiwangshan Forest Park, Fragrant Hills Park, Beijing Xishan National Forest Park, Badachu Park, Beigong Forest Park, and the Qianlingshan Park, which have lush vegetation and are very conducive to species migration and help to maintain urban biodiversity; smaller patches are mainly distributed in the northern and eastern regions. The land type is also woodland, mainly in the Yuanmingyuan Ruins Park, Olympic Forest Park, Chaoyang Park, Jiangfu Park, Beijing Acacia Park, Jintian Park, etc. These areas are mainly inner-city parks and golf courses, which are rare green space resources in the city. There is only one ecological source in the central part of the study area, i.e., the Temple of Heaven Park, which was the place of the emperors of the Ming and Qing Dynasties to "offer sacrifices to the sky" and "pray for the grain"; this source is also a large garden landscape in the city of Beijing. The entire park, except for the buildings, is covered by cypress trees. It is one of the most important ecological sources in this region.

3.2. Resistance Surface Construction

The study area's ecological resistance surface map (Figure 6) was obtained by analyzing the weighted superposition of seven factors at three levels: topographic, natural condition, and human disturbance factors. The ecological resistance surface scores ranged from 66.5473 to 935.189, with a highly polarized score distribution. The high-resistance areas are concentrated, accounting for most of the study area, and are primarily construction land. The low-resistance areas are fragmented, located mainly in the western mountainous region, urban parks, and the city's green spaces.

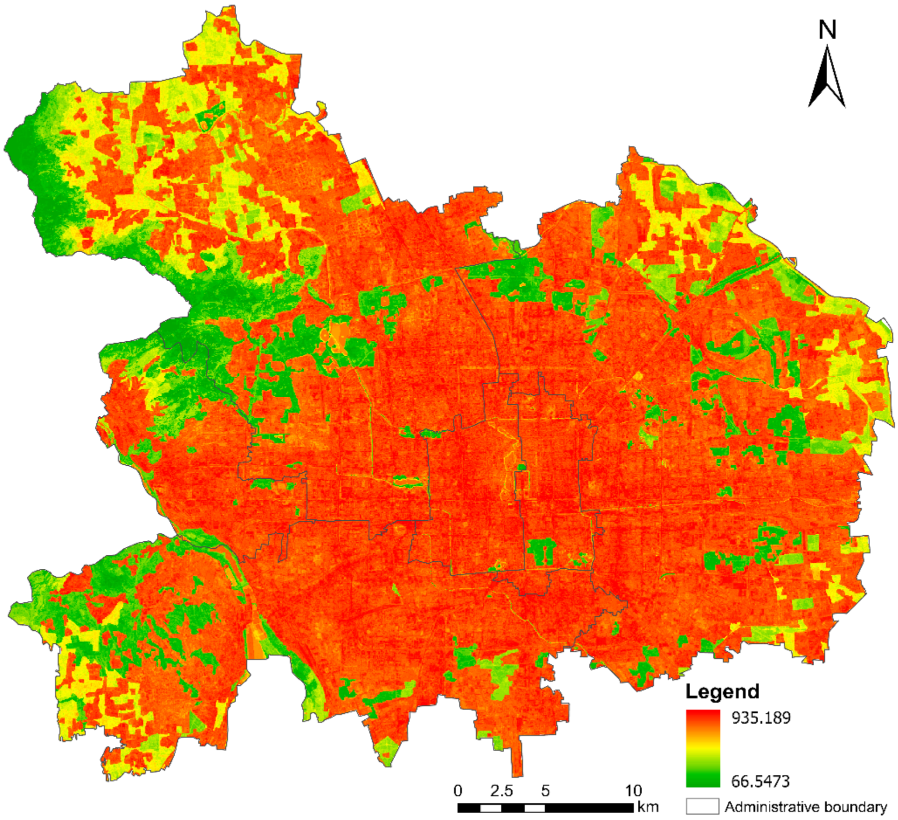

Figure 6. Resistance surface of Central Beijing.

3.3. Spatial Distribution of CWD and Ecological Corridors

The minimum cost-weighted distance (CWD) is indicative of the obstacles to species migration; the higher the score, the more difficult the species migration. According to the results of circuit theory calculations, the high CWD score value is concentrated in the central part of the study area and gradually decreases outward (Figure 7). The score is the lowest in the western and eastern parts, where the species migration is most favorable. This is because construction land is concentrated in the central part with extremely high building density. In contrast, the western and eastern regions are woodland or parkland, which facilitate species migration and retention of biodiversity. Moreover, the high CWD score in the central region indicates that the biological pathway from the northwest to the southeast is obstructed, hindering species migration and energy flow across the region.

A total of 439 ecological corridors were extracted by the Linkage Mapper tool, including 317 key ecological corridors and 122 inactive ecological corridors (Figure 8). The total length of the key ecological corridors was 496.21 km, with an average length of 1.57 km, a maximum length of 20.53 km, and a minimum length of 0.03 km. Among them, eight key ecological corridors, with a length of more than 10 km and a total length of 120.09 km, form a series of north–south and northwest–southeast ecological corridors. These are the most important ecological corridors for maintaining connectivity over the entire study area, such as connecting the Summer Palace with the Temple of Heaven Park, and the Olympic Forest Park with the Temple of Heaven Park.

There are 97 key ecological corridors between 1 km and 10 km in length, with a total length of 311.43 km. These corridors are located in the western and eastern parts. They are important ecological corridors connecting ecological sources between regions. There are 212 key ecological corridors less than 1 km in length, totaling 64.69 km, which are also mainly distributed in the western and eastern regions. They serve as vital ecological corridors linking smaller, adjacent ecological sources.

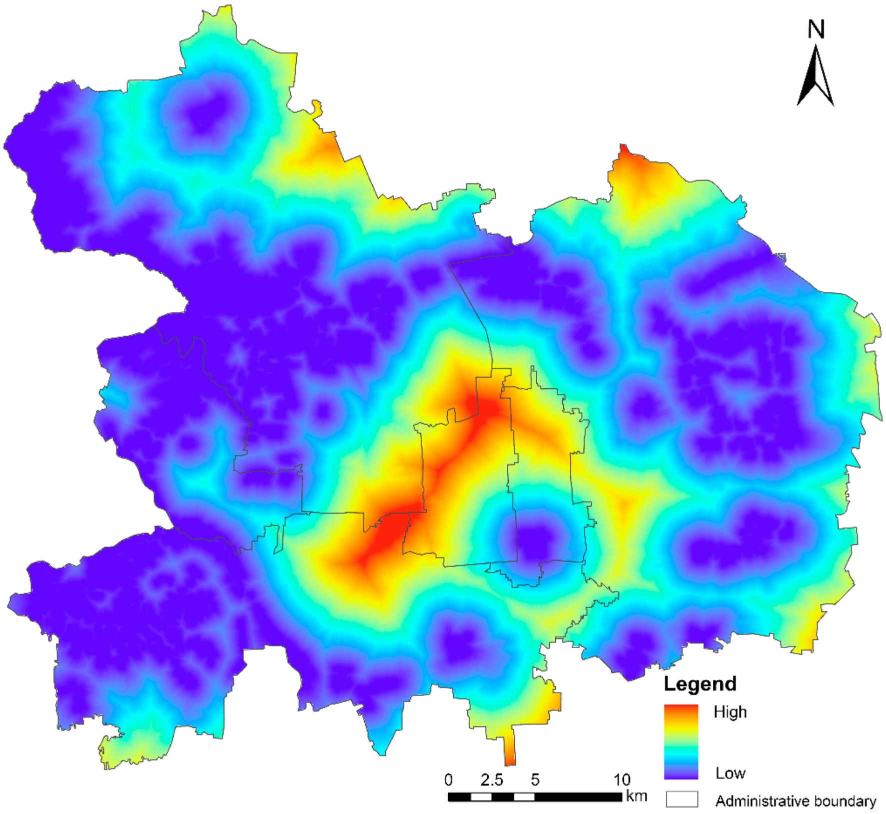

Figure 7. Spatial distribution of CWD.

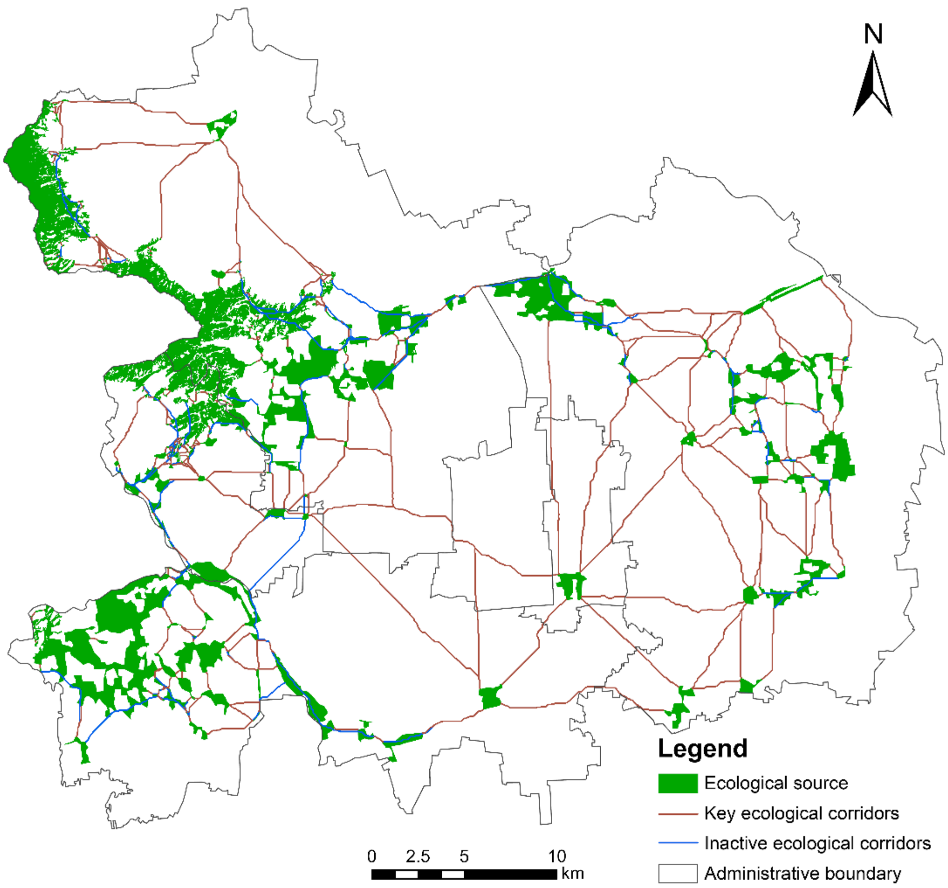

Figure 8. Spatial distribution of ecological corridors.

In addition, the total length of inactive corridors is 510.07 km; they partly overlap with the key ecological corridors; the non-overlapping part is mainly distributed in the western and eastern parts. Although these inactive corridors have a limited role in the retention of biodiversity in the central urban areas, they still provide supplementary value to the overall ecological network.

3.4. Identification of Ecological Pinch Points and Barriers

Ecological pinch points refer to ecological corridors that play a significant role in ecological processes among ecological sources and are located in the weakest part of the corridor. Ecological pinch points that are "stepping stones" can transform structural linkages into functional connectivity. They have a strategic node value for maintaining ESPs and the exchange of matter and energy among components during the construction of ecological networks [45]. The total area of ecological pinch points in the study area is 3.02 km^2, accounting for about 0.22% of the total area, and the main land type is water systems (Figure 9).

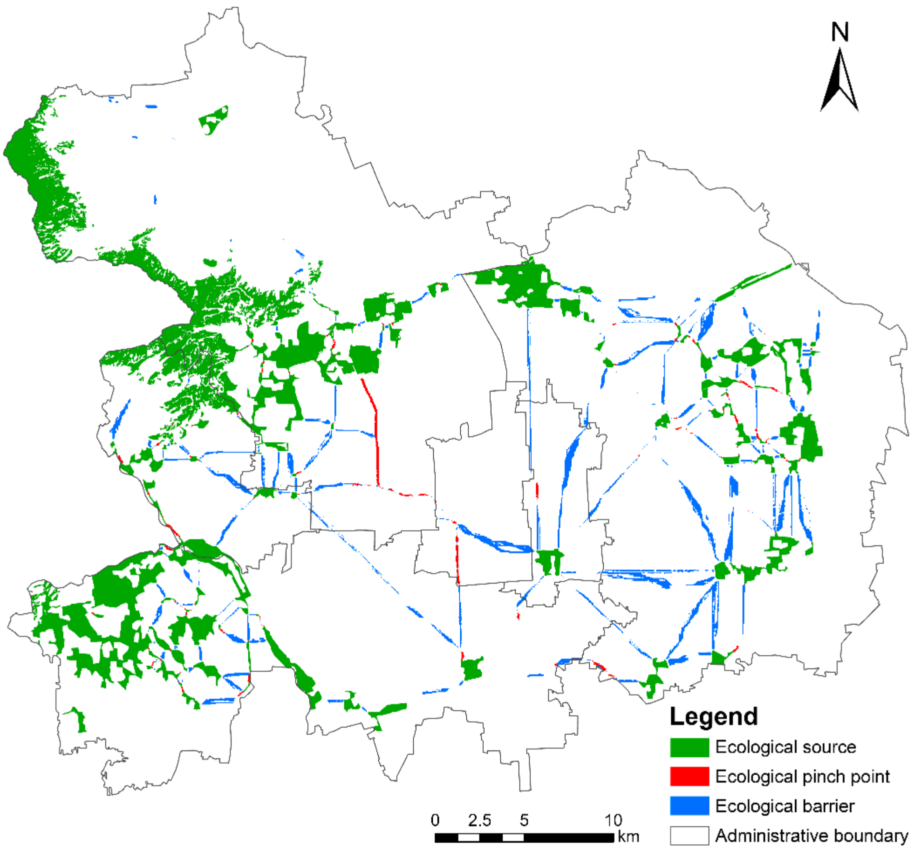

Figure 9. Spatial patterns of ecological pinch points and barriers.

The two most important ecological pinch points are the Jingmi Diversion Canal in Haidian District and the West Moat in Xicheng District. The central part represents the core area of the city's construction land, with a high construction land density and few green spaces and water systems. The constructed ecological corridors can only be connected through limited water system; due to the limited urban water system width, the two rivers become the most important ecological pinch points in the study area.

Ecological barriers are crucial locations in ecological corridors that impede biological migration, energy flow, and connectivity between ecological sources. Removing or reducing barriers helps to improve landscape connectivity and thus enhance the ecological security of the region. The total area of ecological barriers in the study area is 27.47 km^2, about

1.98% of the total area, and the main land type is construction land. The ecological barriers are numerous and distributed over an extensive area. The central area of the study area is the core area of urban construction land; with its high construction land density, few green spaces, and water systems, it severely restricts biological migration and energy flow and is the direct cause of the general deviation of the ESPs in the central area of this mega city. The removal or reduction of these ecological barriers in future urban construction would be of great benefit for the landscape connectivity and the city's ESPs.

4. Discussion

4.1. Analysis of Ecological Source Identification Based on InVEST, MSPA, and Conefor

Identifying ecological sources is a crucial step in ESP studies, as the scientific validity of the method directly influences ESP accuracy. The method of identifying ecological sources is a critical academic issue; the extent of research has gone from superficial to deep, from the initial direct use of ecologically sound areas as ecological sources to the comprehensive consideration of ecological service functions, ecological sensitivity factors, and the current use of MSPA and InVEST for scientific identification with gradually improving accuracy. However, any method has certain limitations. For example, MSPA can provide guidelines for the identification of ecological sources based on spatial morphological attributes such as patch area and spatial topological relationship but has certain limitations in identifying ecological sources individually because it does not reflect functional attributes such as Habitat Quality of the patches. InVEST proves effective in evaluating Habitat Quality and ecological service functions; however, it falls short in capturing spatial aspects such as area, structural connectivity, and other morphological attributes.

This study innovatively combines InVEST, MSPA, and Conefor, integrating the advantages of all three models to comprehensively identify ecological sources. The three modules of Habitat Quality, Carbon Storage and Sequestration, and Sediment Delivery Ratio were selected from the InVEST model to characterize the ecological services of the study area. These three modules were chosen for the following reasons: (1) Habitat Quality reflects the condition of regional ecosystems and serves as a key factor in assessing the ecological environment. It integrates the sensitivity of the study area to landscape types with the intensity of external threats to produce the Habitat Quality distribution, thereby evaluating the region's biodiversity status [46]. (2) The Carbon Storage and Sequestration module is used to assess the quality, intensity, and spatial heterogeneity of the regional ecological environment. Carbon is stored and sequestered in terrestrial ecosystems, helping to alleviate climate change and enhance ecosystem services; this process is a crucial environmental factor during urbanization [47]. (3) The Sediment Delivery Ratio module effectively assesses the amount of soil erosion in the study area, quantifying and mapping sediment built-up on land and its transport to rivers.

Ecological sources' identification methods based on InVEST, MSPA, and Conefor evaluate the spatial morphological attributes such as patch area and spatial topological relationship, assess the quality of ecological service functions, and, finally, identify high-quality ecological sources using the Conefor 2.6 software.

4.2. Analysis of the Regional Scope of the Study

As the main sites of human activities, urban areas frequently face problems such as dense construction land layout, high population density, little ecological green space, poor ecological environment, etc. This present study on ESPs focuses on the macro-scale, such as municipal areas, provincial areas, or national urban agglomerations to promote the coordinated development of macro-regional ecological security and biodiversity. Due to the large scale of the research scope, it is limited to give effective guidance on the construction of ESPs at the micro-level, such as in urban areas. Therefore, it is necessary to carry out research on the ESPs of urban areas at the micro-scale. This study takes Central Beijing as an example and explores urban ESPs at the micro-scale. The objectives are to address ecological and environmental problems caused by rapid urbanization, improve the overall quality of urban ecosystem services, and maintain structural security of the ecosystem.

4.3. Fragmentation Characteristics of Ecological Sources

Macroscale ESP analysis at the provincial or city cluster level identifies ecological sources that tend to be clustered and connected in relatively small numbers. In contrast, small-scale ESPs such as mega-city centers tend to be unconnected due to the blocking of ecologically sound areas by construction land, resulting in a more obvious fragmentation of identified ecological sources in significantly larger numbers, which is one of the characteristics of ecological sources identified from the urban center scale perspective.

5. Conclusions

Rapid urbanization and human interference have intensified land fragmentation, leading to the decline of biodiversity and ecological services, seriously limiting the development of a sustainable ecological environment. In this study, we identified ecological sources by integrating InVEST, MSPA, and Conefor; screened seven indicators, including topographic factors, natural condition factors, and human disturbance factors for superposition analysis to construct ecological resistance surfaces; and applied circuit theory to construct ESPs. The theoretical and practical significance of this study is as follows:

(1) Identification of Ecological Sources: A total of 157 ecological sources were identified in the study area, with a total area of 131.60 km^2, accounting for about 9.5% of the total. The larger patches are mainly located in the western part. In comparison, the smaller patches are mainly located in the northern and eastern regions of the study area, and the land type is mainly woodland.

(2) Extraction of Ecological Corridors: In the study area, 439 ecological corridors were identified, consisting of 317 key corridors and 122 inactive ones. The key corridors spanned a total of 496.21 km, with an average length of 1.57 km, a maximum of 20.53 km, and a minimum of 0.03 km. The most important ecological corridors in the entire region are oriented along the north–south and northwest–southeast directions. These findings underscore the necessity of preserving and enhancing key ecological corridors to mitigate the impacts of habitat fragmentation and ensure ecological flow.

(3) Identification of Ecological Pinch Points and Barriers: The ecological pinch points in the study area are mainly the Jingmi Diversion Canal in Haidian District and the West Moat in Xicheng District, with a total area of 3.02 km^2, accounting for about 0.22% of the total area. The primary land type is water systems. A large number of ecological barriers are spread throughout the entire study area, with a total area of 27.47 km^2, accounting for about 1.98% of the total; the main land type is construction land. These pinch points and barriers represent critical bottlenecks and obstacles to ecological connectivity, emphasizing the need for targeted mitigation measures.

(4) Practical Implications for Central Beijing: Based on the ESP results for Central Beijing, targeted protection is feasible by combining the main functions of the ecological resources in Beijing, increasing the area and quantity of ecological resources, focusing on environmental protection around ecological corridors, increasing the ecological green belts, decreasing the resistance around the ecological pinch points and ecological barriers, and stabilizing the ESP.

Our findings are highly significant for the construction of ecological corridors, biodiversity conservation, territorial space planning, and sustainable utilization of land resources in Central Beijing. This research contributes to the broader goal of sustainable urbanization and provides a replicable model for cities globally.

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Appendix A

Table A1. The threat factors and related coefficients.

Threat Factor	$d_{r\text{-}max}$ (km)	Weight w_r	Distance–Decay Function
Cultivated land	6	0.7	linear
Construction land	11	1	exponential
Railway	9	0.9	exponential
Motorway	10	1	exponential
Primary roads	8	0.9	linear
Secondary roads	5	0.8	linear
County roads	3	0.7	exponential

Table A2. Sensitivity of habitat types to each threat factor.

Habitat Type	Habitat Suitability	Cultivated Land	Construction Land	Railway	Motorway	Primary Roads	Secondary Roads	County Roads
Cultivated land	0.5	0.3	0.5	0.1	0.25	0.28	0.22	0.16
Woodland	1	0.4	0.6	0.1	0.1	0.12	0.18	0.24
Grassland	0.55	0.35	0.6	0.25	0.25	0.28	0.29	0.3
Wetland	0.8	0.4	0.7	0.3	0.3	0.3	0.28	0.25
Water areas	0.9	0.5	0.8	0.4	0.4	0.35	0.3	0.25
Construction land	0	0.5	0.8	0.3	0.3	0.32	0.31	0.3

Table A3. Parameter assignment for carbon fixation assessment of different land use types.

Land Use Type	C_{above}	C_{below}	C_{soil}	C_{dead}
Cultivated land	17	87.7	92.9	9.82
Woodland	42.4	115.9	158.8	14.11
Grassland	35.3	86.5	99.9	7.28
Wetland	7	3	25	0
Water areas	2.29	0	17.16	0
Construction land	7.61	4.51	42.17	0

Table A4. P and C values of different land use types.

Land Use Type	Cultivated Land	Woodland	Grassland	Wetland	Water Areas	Construction Land
P	1	0.15	1	0	0	0
C	0.23	0.02	0.043	0	0	0

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