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Construction of Green Space Ecological Network in Xiongan New Area Based on the MSPA–InVEST–MCR Model

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Abstract: With the rapid pace of urbanization, the integrity and connectivity of ecosystems are under serious threat, making biodiversity conservation a top priority. We use the Xiongan New Area in China as a case study to explore the significance and application of constructing urban ecological networks in the development of new cities. This study systematically applied the categorization of green space systems using remote sensing technology; MSPA was used to identify key landscape patches; InVEST was employed to assess habitat quality; and potential ecological corridors were established using the minimum cumulative resistance model (MCR). Moreover, targeted recommendations for optimizing ecological green spaces were put forward. The findings demonstrate that the Xiongan New Area has significant potential and needs for ecological network construction, and it faces the issue of ecological network fragmentation. This research highlights the significance of developing ecological networks within urban planning and proposes optimization strategies tailored to these networks. The objective is to offer scientific guidance for the design and development of emerging cities, such as the Xiongan New Area, to facilitate the alignment and integration of ecological preservation efforts with urban expansion, ultimately achieving the sustainable development goal of harmonious coexistence between the environment and urban areas.

Keywords: ecological network; spatial pattern; MSPA; InVEST model; MCR model; ecological sensitivity assessment; Xiongan New Area

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1. Introduction

In the process of accelerating urbanization, due to human interference with nature, ecosystems are facing degeneration in terms of structure and function [1]. The serious problems of habitat fragmentation and isolation have thus become major threats to biodiversity [2]. How to achieve coordination between ecological environment and urban development has become a world concern in the process of urbanization. Urban ecological networks, which are composed of an ecological source area and corridors, represent one of the most important methods for integrating landscape structure with ecological functions and processes [3]. The establishment of ecological networks is indispensable for overcoming the fragmentation of habitats, protecting biodiversity, and achieving sustainable development, which will lay a good foundation for establishing a harmonious relationship between mankind and nature [4].

Ecological networks find a wide number of applications in ecology and urban planning owing to their good connectivity [5,6]. The connections between various animal habitats help promote individual movement and dispersal, maintain population dynamics, and enhance genetic diversity [7]. Indeed, recent studies have shown that ecological fragmentation of landscapes disrupts the continuity of ecological corridors and diminishes the survival of plant and animal species [8,9]. In Jiangsu Province, China, wetland development has caused fragmentation of habitats for waterbirds, hence dramatically reducing the population of the endangered red-crowned crane from over 1200 individuals in 2002 to about 400 in recent years [10]. In the 1990s, Forman introduced the concept of the patch–corridor–substrate model, suggesting that ecological corridors serve as a crucial measure for ecological spatial planning. This model plays a very important role in urban planning because planners use it to demarcate and protect key ecological areas as "patches" while enhancing ecological urban connectivity through "corridors" like greenways. The diversity and resistance of urban ecosystems increase, while the matrix concept balances urban development with ecological protection and promotes sustainable development [11]. Henny's 2008 research on the Green River Basin corridor in the Netherlands, and the results showed that the ecological corridor not only maintained the development of natural ecology but also promoted the relationship between ecology and politics [12]. In recent studies, for example, Yi-Xuan Liang (2023) used a combination of ecological sensitivity and ecosystem service value to determine habitat sources, avoiding the interference of a single method in the judgment [13]. Certain academics employ the MCR model to develop patterns of ecological security through the creation of an ecological network system, aiming to harmonize the safeguarding of natural ecosystems with sustainable urban growth [14,15].

The construction of an urban ecological network is of great significance to urban development. First, the urban fabric disrupts the connections between ecological patches, hindering ecological flows across the region. Thus, constructing an ecological network ensures the normal migration of species and facilitates species exchange between ecological patches [16,17]. Second, the Baiyang Lake wetland, along with other connected water systems within the Xiongan New Area, contributes to environmental improvements in high-density urban areas, helps regulate the microclimate, and provides recreational opportunities for residents visiting the wetlands [18]. Moreover, the Baiyang Lake wetland has scenic beauty and offers significant aesthetic value, which can foster tourism, attract talent, and promote further industrial development, all of which are beneficial to the future growth of the Xiongan New Area [19].

Despite this, existing research often places greater emphasis on the identification of ecological source areas and corridors, while the focus on the hierarchical management of ecological networks is insufficient [20]. As urban expansion continues, identifying key nodes and regions in ecological network construction has become a research priority [21]. Prioritizing ecological issues is one of the core principles of ecological wisdom in conservation and restoration practices [22]. Ecological networks, as complex systems comprised of sources and corridors, exhibit significant differences in the area and spatial patterns of source areas, as well as in the length and cost-effectiveness of corridors [23]. By clarifying the focus of ecological network construction and management, it is possible to achieve comprehensive cost control while ensuring equivalent ecological benefits, thus reflecting ecological wisdom in urban governance.

The Xiongan New Area is a crucial node for relieving the non-capital functions of Beijing and advancing the coordination of Beijing–Tianjin–Hebei, having been concerned greatly in planning and development [24]. The Xiongan New Area belongs to Baoding City, Hebei Province, offering an advantageous geographical position and abundant ecological resources. The Baiyang Lake wetland is the biggest freshwater lake on the North China Plain, holding an important status in water source conservation and biodiversity protection [25]. In the sense of rapid urbanization, it contains an extensive area in developing the Xiongan New Area. At the same time, although ecological priority has been brought forward in its development, irreversible damage to the urban ecological baseline has taken place, such as the destruction of forests and grasslands, habitat destruction, and water pollution, which pose a threat to the sustainable development of the city and region in the future. Therefore, maintaining environmental sustainability and achieving harmonious coexistence between cities and nature during large-scale urbanization is a major challenge that planners must address. Therefore, a major challenge for planners is to maintain the sustainability of ecological development amid large-scale rapid urbanization, achieving a harmonious coexistence between urban areas and nature [26]. Constructing an ecological network, which can enhance landscape connectivity and improve urban ecological resilience, would be an important strategy. By strategically laying out sources and corridors, it helps restrain urban development, identifies the priority areas for ecological restoration, and identifies key elements, along with cost control, contributing to a cohesive ecological safety framework [27].

Therefore, the purpose of this study is divided into the following parts:

(1) Use the ecological sensitivity assessment method to evaluate the ecological sensitivity of different land use types, providing a basis for the identification of ecological sources.
(2) Identify patches with a significant impact on ecological connectivity through MSPA, including selection based on biodiversity potential, where natural elements such as water, wetlands, and trees serve as foreground elements, while cultivated land and construction land are taken as background elements to generate binary images. Then, GuidosToolbox 3.3 was used for MSPA classification and seven landscape elements were identified.
(3) Employ the InVEST model to measure ecosystem service roles, evaluate habitat quality dimensions, and assess ecosystems' capacity to offer conditions conducive to survival and reproduction.
(4) Utilize the Minimum Cumulative Resistance (MCR) model to construct potential ecological corridors, creating the lowest-cost pathways based on source areas and resistance surfaces.
(5) According to the results of MSPA and the InVEST models, targeted ecological green space optimization suggestions were put forward.

In summary, ecological networks within the city are key components for accomplishing the practice of sustainable urban development. In this case, during the development of the Xiongan New Area, balancing urbanization and natural growth harmoniously may be a great challenge for planners and decision-makers. This study aims to clarify how to balance economic development with ecological protection through the construction of ecological networks in the urban planning of the New Area. It will point out high-priority elements in the construction and management of the ecological networks, providing valuable insight and references for urban planning and ecological conservation work, not only for the Xiongan New Area but also for other areas.

2. Materials and Methods

The Xiongan New Area is located in central Hebei Province (38°42′ E–39°10′ E, 115°37′ N–116°19′ N), within the hinterland of Beijing, Tianjin, and Baoding (Figure 1). The area includes Xiongxian County, Rongcheng County, Anxin County, and some surrounding areas, with a total area of 1765.67 km^2. The site is located in the plain area to the east of Taihang Mountain and belongs to the accumulation plain landform. The terrain gradually decreases from the northwest to the southeast, with the ground elevation mostly ranging from 3 to 26 m and the ground slope less than 3.5°. The site topography is flat, which is conducive to the construction of urban areas. There is a lake in the center of the site, the Baiyang Lake wetland, which is the largest habitat on the site.

2.1. Data Sources

This study utilized 10-m resolution remote sensing images from the European Space Agency (https://www.esa.int/ accessed on 15 June 2024) taken in June 2024 as the source data for land use (Table 1). Using ENVI 5.6 for image interpretation, the analysis categorized the results into seven types of land use: wetland, cultivated, forested, grassy, watery, construction, and unutilized. Finally, the 2024 land use data for the Xiongan New Area were clipped in ArcGIS 10.8.6. Additionally, 10-m elevation data were obtained from the 91weitu (Table 1). These data were then processed through clipping, discretization, classification, and reclassification to derive site information such as slope and aspect.

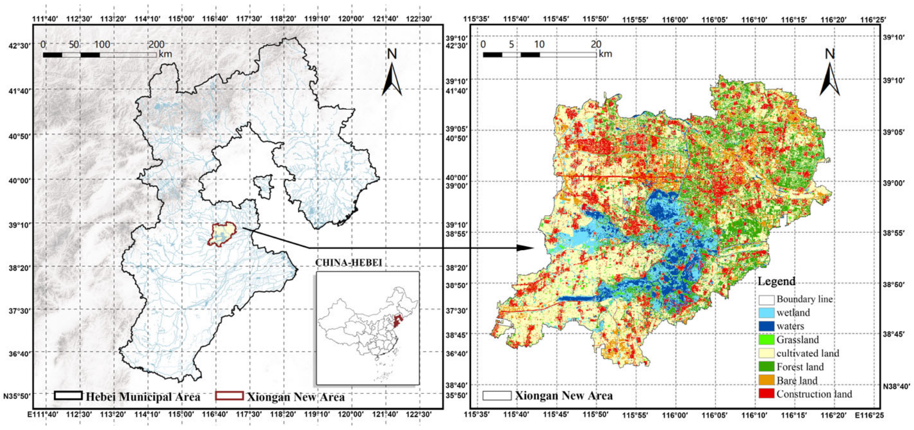


Figure 1. Geographical location of the study area.

Table 1. Data sources.

Data Types	Data Names	Resolution	Sources
Remote sensing data	Remote sensing satellite image of the Xiongan, Hebei	10 m	The European Space Agency (https://www.esa.int/, (accessed on 15 June 2024))
Geographic environmental data	Elevation data	10 m	91weitu (https://www.91weitu.com/, (accessed on 15 June 2024))
	Drainage data	10 m	91weitu (https://www.91weitu.com/, (accessed on 15 June 2024))

2.2. Research Method

The technical approach consisted of four steps (Figure 2). First, data gathering to complete an initial site information collection was performed. Then, land use overlaying was carried out for ecological sensitivity analysis. Identifying and analyzing landscape elements by using the MSPA and InVEST models were included in the third step. The final step was building an ecological network by using the MCR model.

2.2.1. Ecological Sensitivity Assessment

Based on the specific conditions of the Xiongan New Area, elevation data and remote sensing data were selected as the foundational materials. Land use data were then derived from remote sensing data [28]. By overlaying single-factor analyses, a comprehensive distribution map of ecological sensitivity within the Xiongan New Area was generated [29]. On the basis of analyzing various maps, textual information, and remote sensing images, combined with field surveys and expert opinions, the ecological sensitivity evaluation factors for the study area were categorized into three main groups: natural environment factors, ecological resource factors, and human activity factors [30]. The natural environment factors included elevation, slope, and aspect; ecological resource factors included water body buffers and vegetation cover; and human activity factors included land use types. These collectively form the six indicators used in the ecological sensitivity evaluation [31]. Next, weights were assigned to each factor, and a judgment matrix was constructed using the Analytic Hierarchy Process (AHP) to calculate the weight of each factor, resulting in a land use weight distribution table [32].

Using a raster calculator, all evaluation factors were overlaid, and natural breaks were applied to cluster the evaluation results. Based on the scoring from ten experts and informed by relevant studies [33], the clustering results were then adjusted. A raster calculator was then used to perform an overlay analysis of all evaluation factors to produce a comprehensive scoring table. To further differentiate between categories and achieve clearer classification, the natural breaks method was applied, classifying the land in the

Xiongan New Area into five levels of ecological sensitivity [34] (Table 2). These five sensitivity levels encompassed all land types within the Xiongan New Area, ultimately producing an ecological sensitivity distribution map for the area. The calculation formula is as follows:

$$MI_j = \sum_{i=1}^{n} S_i \quad (1)$$

In the formula, MI_j represents the comprehensive ecological sensitivity index for the spatial unit j, n is the number of sensitivity evaluation indicators for the spatial unit j, and S_i is the sensitivity level value for the evaluation indicator i.

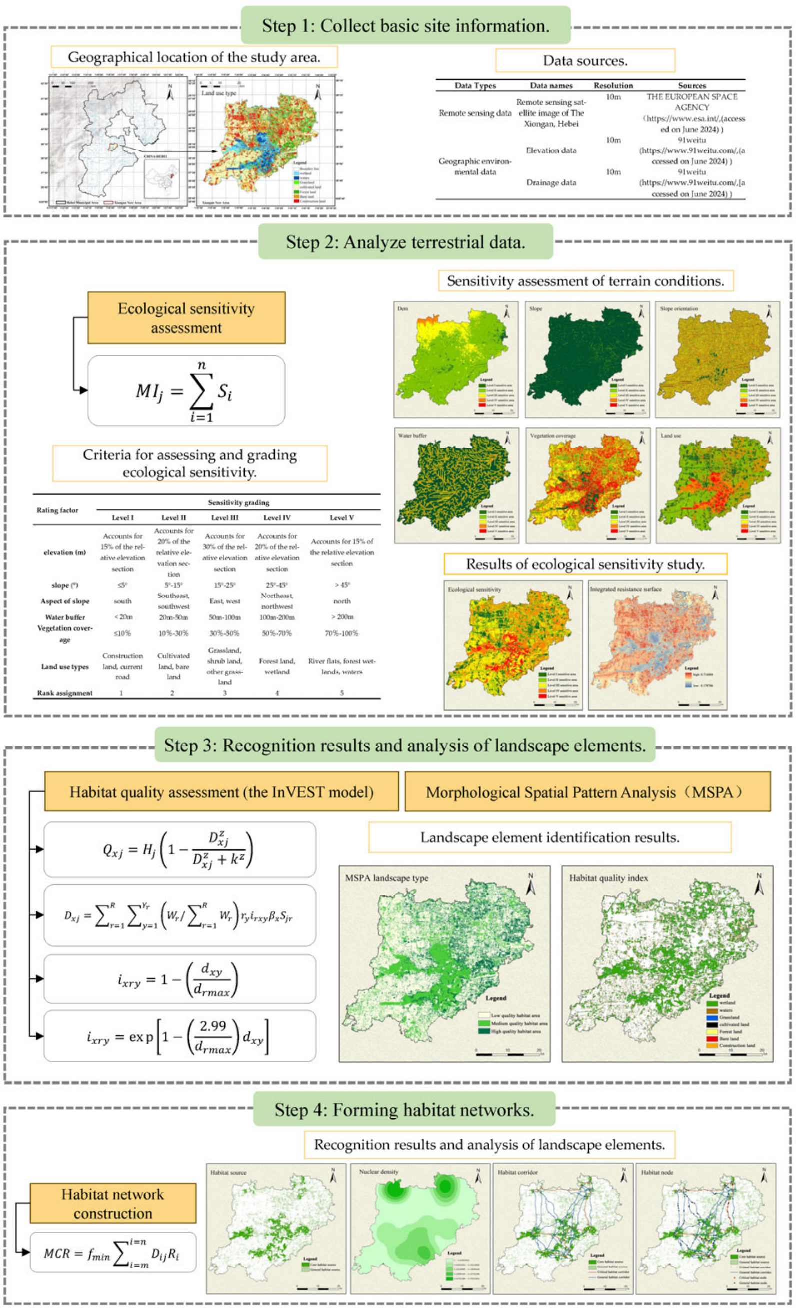


Figure 2. Technical approach of this study. Step 1. Collect basic site information. Step 2. Analyze terrestrial data. Step 3. Recognition results and analysis of landscape elements. Step 4. Forming habitat networks.

Table 2. Criteria for assessing and grading ecological sensitivity based on a single factor.

Rating Factor	**Sensitivity Grading**				
	Level I	**Level II**	**Level III**	**Level IV**	**Level V**
Elevation (m)	Accounts for 15% of the relative elevation section	Accounts for 20% of the relative elevation section	Accounts for 30% of the relative elevation section	Accounts for 20% of the relative elevation section	Accounts for 15% of the relative elevation section
Slope (°)	≤5°	5°–15°	15°–25°	25°–45°	>45°
Aspect of slope	South	Southeast, southwest	East, west	Northeast, northwest	North
Water buffer	<20 m	20–50 m	50–100 m	100–200 m	>200 m
Vegetation coverage	≤10%	10–30%	30–50%	50–70%	70–100%
Land use types	Construction land, current road	Cultivated land, bare land	Grassland, shrub land, other grassland	Forest land, wetland	River flats, forest wetlands, waters
Rank assignment	1	2	3	4	5

2.2.2. Morphological Spatial Pattern Analysis (MSPA)

MSPA is a classification technology that uses the principles of mathematical morphology to effectively identify key landscape elements that significantly influence the ecological interconnectivity of a particular research area. This method utilizes a tailored series of mathematical morphology operators designed to describe the geometric shapes and connectivity of image components [35]. The technique began at the pixel scale, employing principles of mathematical morphology to categorize binary image pixels into seven distinct MSPA groups, differentiated by aspects like landscape, spatial configurations, and their overall effect [36]. Connectivity details include core area, islet, perforation, edge, loop, bridge, and branch (Table 3). Therefore, through the input of ecological sensitivity analysis data, this study classified sensitivity grades 1–3 as prospect elements, assigning them 2 points; the sensitivity levels 4–5 were used as background elements, and a score of 1 was assigned to generate a binary image. The MSPA-based identification of seven landscape elements within the research zone was then conducted using the eight-neighborhood analysis method in GuidosToolbox 3.3 [37].

Table 3. Landscape classification and definition of MSPA.

Landscape Type	**Interpretation**
Core	Places where a large number of organisms settle and larger habitat patches can provide important help for the reproduction of organisms.
Bridge	Fragmented patches of niches that can only provide assistance to a small number of organisms and cannot communicate energy in large quantities.
Loop	The intersection of the central zone and the non-green zone, located at the habitat patch's boundary.
Edge	A transitional zone bridging the central zone and the non-green terrain.
Perforation	A bridge linking each central region, symbolizing the passageway that connects segments of the ecological network and is crucial for the processes of biological migration and landscape linkage.
Branch	Pathways linking identical, central regions, serving as expedited routes for species movement within the same central zone.
Islet	A zone where a single end links to an edge, bridge, loop, or pore.

The MSPA system employed pixels to pinpoint key areas that greatly influence the ecological network landscape's connectivity, including core zones and bridge regions [38].

Consequently, a core area might consist of a group of small patches with a significant impact on ecological interconnectivity instead of just the largest patch. Utilizing Conefor 2.6, the ecological connectivity index was analyzed to evaluate the significance of various ecological source regions [39].

2.2.3. Habitat Quality Assessment

The InVEST framework served as an all-encompassing assessment model for measuring diverse ecosystem service operations. Data on habitat quality mainly originated from the InVEST model, evaluating an ecosystem's capacity to create conducive environments for species' survival and reproduction. The index for assessing habitat quality ranged between 0 and 1, with higher index values indicating an ecosystem with greater resilience and improved habitat conditions [40]. Habitat degradation reflected the degree of change in habitat caused by human activities, specifically the level of degradation due to threat factors. A higher habitat degradation value indicated a greater level of threat to the habitat. The assessment of habitat quality could evaluate habitat degradation across different regions and serve as an indirect indicator of biodiversity. This metric was crucial in assessing an ecosystem's ability to offer appropriate living environments for different species [41]. First, we preprocessed the land use data in ArcGIS. No-data values were reclassified as 0, while the remaining land use data were categorized into seven types: wetlands, water bodies, grasslands, arable land, forests, barren land, and built-up areas. We then input land use data, threat factors, and sensitivity to those factors, calculating a habitat quality index ranging from 0 to 1 on a raster grid basis. The model parameters were set based on the suggested figures from the InVEST model manual and pertinent scholarly works [42,43], adjusted for the specific conditions of the study area (Tables 4 and 5).

Table 4. Resistance factors and their maximum influence distance, weight, and attenuation type.

Stress Factor	Maximum Impact Distance/km	Weight	Attenuation Type
Plowland	5	0.5	linearity
Construction land	8	1.0	exponent
Unutilized	6	0.5	linearity

Table 5. Resistance factor parameters of different land types.

Land Use Types	Habitat Suitability	Plowland (Stress Factor)	Construction Land (Stress Factor)	Unutilized (Stress Factor)
Wet land	0.7	0.4	0.5	0.3
Waters	0.6	0.3	0.4	0.2
Meadow	0.8	0.7	0.6	0.5
Plowland	0.1	0.2	0.8	0.5
Forest land	1	0.6	0.4	0.2
unutilized	0.4	0.5	0.4	0.2
Construction land	0	0	0	0

The specific formula for evaluating habitat quality by using habitat quality index is outlined below:

$$Q_{xj} = H_j\left(1 - \frac{D_{xj}^z}{D_{xj}^z + k^z}\right) \tag{2}$$

In Formula (2), Q_{xj} is the habitat quality of grid j in certain land use type j; k is a half-full sum constant; H_j represents the appropriateness of the habitat for land use type j; D_{xj} is the habitat stress level of grid x in a habitat type j, represented by land use. D_{xj} satisfies the following formula:

$$D_{xj} = \sum_{r=1}^{R}\sum_{y=1}^{Y_r}\left(W_r/\sum_{r=1}^{R} W_r\right) r_y i_{rxy} \beta_x S_{jr} \tag{3}$$

In Formula (3), R represents the count of stress-related factors, and W_r represents the weight of stress factor r. Y_r is the number of grids of stress factor layers in land use data. r_y represents the count of stress elements present in each category of the land use grid. β_x represents the degree of accessibility for grid x, with a maximum value of 1, indicating maximum reachability. S_{jr} is the responsiveness of type j land use to stress factor r, peaking at 1, signifying the habitat's utmost sensitivity to stress factor. The influence of stress factor r in grid y on the living environment in grid x is denoted as i_{rxy}, and its variation with distance satisfies the following formula:

$$i_{xry} = 1 - \left(\frac{d_{xy}}{d_{rmax}}\right) \tag{4}$$

$$i_{xry} = \exp\left[1 - \left(\frac{2.99}{d_{rmax}}\right)d_{xy}\right] \tag{5}$$

In Formulas (4) and (5), d_{xy} represents the straight-line separation between grid x and y, while d_{rmax} denotes the utmost impact distance of the stress factor r.

2.2.4. Green Space Ecological Network Construction

(1) Resistance factor weight calculation

Based on a combination of vegetation cover, land use, and slope factors, this study selected factors such as soil erosion sensitivity, land use type, vegetation coverage, and resistance surface patterns derived from comprehensive ecological security evaluations. Resistance values were assigned based on related studies [44]. ArcGIS 10.8.2 facilitated the grading and normalization of each impact factor, followed by assigning weights to each index based on the AHP, employing the geometric average technique for weight integration, and finally obtaining the detailed weights.

(2) Resistance factor weight consistency test

To maintain the logic behind the judgment matrix, it was necessary to determine the comparative significance of each component in the matrix in relation to its highest factor, as depicted in the formula:

$$C_I = \frac{\lambda_{max}}{m-1} \tag{6}$$

In Formula (6), λ_{max} represents the highest eigenvalue in the judgment matrix, while C_I denotes the index of consistency, and m represents the order of the target judgment matrix. If this formula were satisfied, it would pass the consistency test; otherwise, it was invalid and required revision, as shown in the following formula:

$$C_R = \frac{C_I}{R_I} < 0.1 \tag{7}$$

In Formula (7), C_I represents the index of consistency, R_I denotes the index of random consistency and C_R signifies the ratio of random consistency. In this paper, the consistency test was evaluated according to C_R and R_I. By comparing the ratio C_R to 0.1 of the consistency test of each matrix, if C_R a value of less than 0.1; the matrix was deemed to have successfully met the consistency criteria.

(3) Habitat source extraction (landscape connectivity analysis)

First, the core area patches identified by MSPA were extracted in ArcGIS. Subsequently, the core areas were allocated the habitat quality index derived from the InVEST model. Patches with higher habitat quality were identified as habitat sources [45].

The research focused on choosing the Integral Index of Connectivity (dIIC) and the Probability of Connectivity (dPC), calculating their relative importance (dI) to prioritize habitat sources. Areas with higher dI values were selected as core habitat sources [46,47]. Quantification of the indicators was conducted through Conefor 2.6, setting the patch connectivity distance limit at 500 m and the likelihood of connectivity at 0.5. The primary formula for calculation is outlined as follows:

a. Global connectivity index

$$dIIC = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \frac{a_i a_j}{1+l_{ij}}}{A_L^2} \tag{8}$$

In Formula (8), n signifies the aggregate count of patches in the terrain, with a_i and a_j indicating the respective areas of patches i and j, and l_{ij} denoting the connections between patches i and j. When $0 < dIIC < 1$, a $dIIC$ value of 0 indicates no relationship between habitat patches. Conversely, a $dIIC$ figure of 1 signifies that the total region encompassed by the calculation constitutes a habitat patch.

b. Possible connectivity index

$$dPC = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij}^{*} a_i a_j}{A_L^2} \tag{9}$$

In Equation (9), n signifies the aggregate count of habitat patches, p_{ij}^{*} denotes the highest likelihood of species dispersal between habitat patch i and j, a_i indicates the expanse of habitat patch i, and a_j denotes the area of habitat patch j. The PC value ranges between 0 and 1.

c. Relative importance of both

$$dI = 0.5dIIC + 0.5dPC \tag{10}$$

In Formula (10), dI symbolizes the potential connectivity index within the landscape, while dPC denotes the potential connectivity index after patch removal.

(4) Habitat corridor construction

The Minimum Cost Resistance (MCR) model has become a very useful approach to assessing ecological connectivity in which “cost” or “resistance” values are assigned to different elements within a landscape as a means of simulating species movement. This model identifies the paths with minimum cumulative resistance, forming the backbone of ecological corridor planning [48]. The benefits will come in the form of the MCR model, which can combine all types of landscape data, offering flexibility in its application. It generally applies in ecological corridor planning, biodiversity conservation, and urban planning [49]. The interaction between habitat sources indicated the potential for constructing habitat corridors between patches. Therefore, this study applied the MCR model to screen and extract ecological corridor paths [50]. Based on the MCR model, habitat source spatial data were input into ArcGIS 10.8.2, and resistance parameters were set according to habitat quality to identify ecological corridors (Table 6).

Table 6. Drag parameters.

Type		Resistance Value
Source area	Core source	1
	General source	5
Habitat	High-quality habitat	10
	Medium-quality habitat	50
	Low-quality habitat	100

MCR model value satisfies the following formula:

$$MCR = f_{min} \sum_{i=m}^{i=n} D_{ij} R_i \tag{11}$$

In Formula (11), D_{ij} represents the spatial separation from source point j to space unit i, while R_i denotes the resistance coefficient for unit i.

(5) Habitat node extraction

In ArcGIS, the isolated patches identified by MSPA were extracted, and the results of the habitat corridor identification were overlaid. The isolated patches intersected by the corridors were identified and extracted as habitat nodes. Based on the corridor hierarchy, isolated patches along key corridors were identified as significant nodes, whereas the rest were categorized as general nodes.

3. Results

3.1. Ecological Sensitivity Analysis

The results were obtained by combining six data types (Figures 3 and 4). It can be seen from the analysis that most of the extremely sensitive areas are concentrated in the vicinity of the Baiyang Lake wetland, which is more susceptible to disturbance due to the instability of wetland ecology. For areas with a certain vegetation foundation and large topographic relief, all development and construction activities should be prohibited and repaired through natural restoration; targeted ecological restoration measures can be implemented in areas where vegetation conditions are general but soil erosion degree is high.

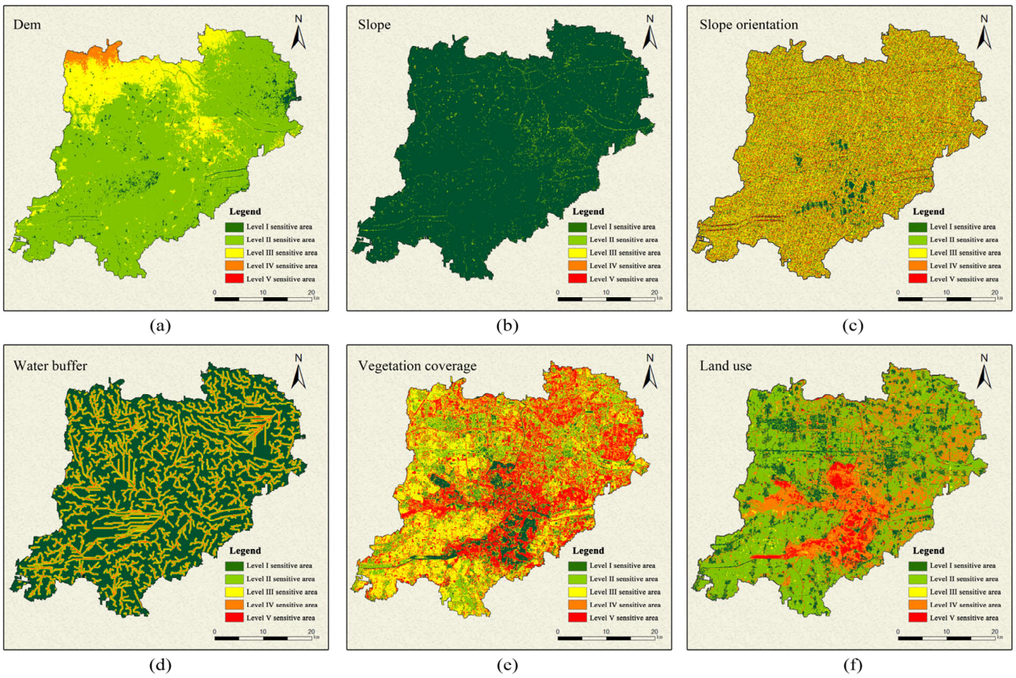


Figure 3. Sensitivity assessment of terrain conditions. (**a**) Evaluating sensitivity to altitude. (**b**) Evaluation of slope sensitivity. (**c**) Evaluation of slope sensitivity. (**d**) Evaluation of sensitivity to water buffers. (**e**) Evaluation of sensitivity to vegetation coverage. (**f**) Land use sensitivity evaluation.

The areas with moderate sensitivity are primarily concentrated in the western portion of the site. Based on the field survey, this area consists mainly of cultivated and bare land. Due to the disturbance of the original ecosystem and human occupation, it is not advisable to undertake development and construction activities. The ecological restoration approach for this area should prioritize the restoration and protection of the natural landscape and ecological environment, with a specific focus on areas with notable issues identified during the field survey. Furthermore, the moderately sensitive area can serve as an ecological buffer zone for the highly sensitive area, allowing for restoration of the ecological environment in accordance with local conditions, enhancement of habitat diversity, and reduction of ecological sensitivity levels.

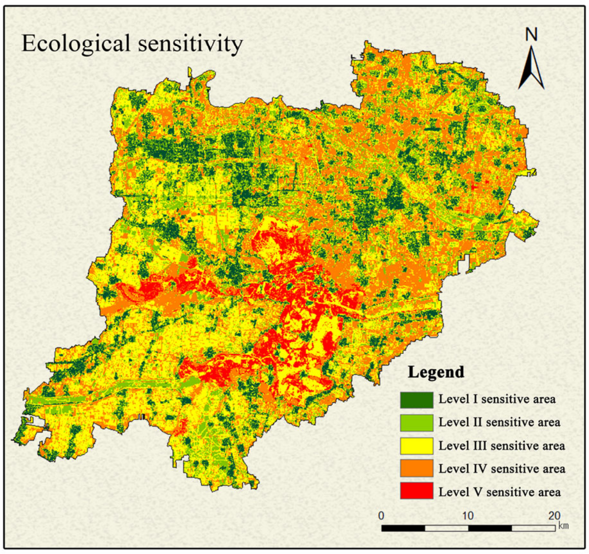


Figure 4. Overlay analysis of site ecological sensitivity.

The insensitive and mildly sensitive areas are concentrated in the north and northeast of the site, dominated by unused land, construction land, and artificial shelterbelts. Artificial shelterbelts can still consider appropriate ecological restoration, such as focusing on the vertical structure of vegetation and building a stable ecological community with trees, shrubs, and grasses. Mild and non-sensitive areas are less disturbed by soil environment, geological disasters, and water resources and can be properly developed. Plants with better landscape effects or that attract pollinators can be planted in the area to increase ecosystem services as much as possible [46].

3.2. Resistance Surface Construction

After testing the consistency of the weights of seven judgment matrices, it was found that the C_R of all seven judgment matrices was less than 0.1, as shown in Table 7. As seen in Table 8, all consistency tests were passed.

Table 7. Properties and weights of resistance factors in ecological source area [47].

Resistance Type/Resistance Value	1	2	2	4	5	Properties	Weight
Elevation						Positive	0.1225
Slope	<8°	8°–15°	15°–25°	25°–35°	>35°	Positive	0.0639
Land use types	waters	Forest land, wetland	Grassland, cultivated land	Bare land	Construction land	-	0.1973
NDVI	>0.8	0.6–0.8	0.4–0.6	0.2–0.4	<0.2	-	0.1727
Habitat Quality (HQ)	0.79–1	0.59–0.79	0.39–0.59	0.19–0.39	0–0.19	Negative	0.1896
Distance from road (DTR)	>2000 m	1500–2000 m	1000–1500 m	500–1000 m	<500 m	Negative	0.1206
Distance from water (DTW)	<500 m	500–1000 m	1000–1500 m	1500–2000 m	>2000 m	Negative	0.1131

Table 8. Summary of conformance test results.

Maximum Characteristic Root	C_I Value	R_I Value	C_R Value	Consistency Test Result
7.637	0.106	1.36	0.078	pass

Utilizing the MCR model, ArcGIS superposition analysis (Table 7) overlaid six resistance factors to derive a detailed resistance surface value (Figure 5). The figure shows that the resistance value of the built-up area in the northwest is higher, while the resistance value of the woodland area in the northeast and the surrounding the Baiyang Lake wetland is lower.

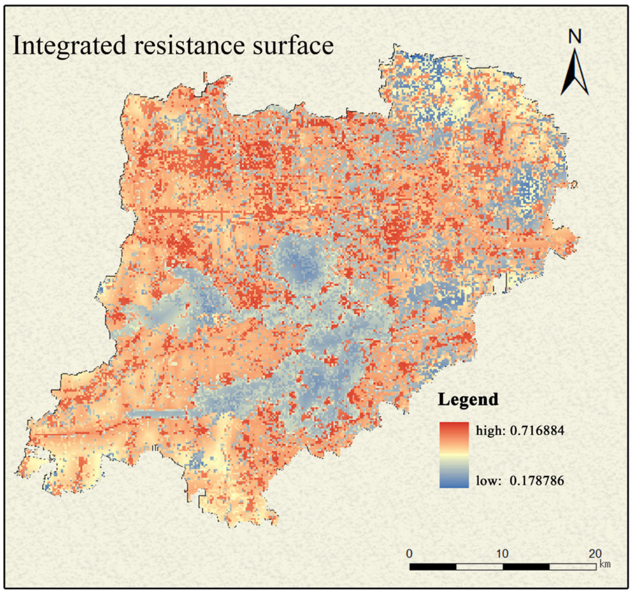


Figure 5. Composite resistance surface.

3.3. Recognition Results and Analysis of Landscape Elements

Land use data for the 2024 study area were analyzed using the MSPA tool that was used in GuidosToolbox 3.3, and the MSPA classification results of landscape elements were obtained (Figure 6). The areas of different landscape types were counted, and their proportions were calculated [51] (Table 9). The results show that the core area (432.58 km^2) is the largest among the foreground elements, constituting 70.22% of the entire surface area of the foreground components, but it only accounts for 24.5% of the study area. Combined with (Figure 6), it is evident that extensive core regions predominantly cluster around the Baiyang Lake wetland, with more in the east and less in the west and less in the south and more in the north. The total area of the islet is 17.44 km^2, accounting for only 2.83% of the total, indicating that the parcels are small and widely dispersed. This result reflects the good ecological construction achievements of the Baiyang Lake wetland in recent years. The edge (17.26% of the overall size of the foreground components) is the second largest, whereas the bridge zone, crucial for biological migration, constitutes merely 4.46% of the overall foreground element area.

To sum up, although there are large-scale core patches in the study area, such as the Baiyang Lake wetland, the overall area of the core is limited, the pattern is scattered, and the patch proportion in the edge area is high, the bridge area is limited, and the biological migration ability is weak.

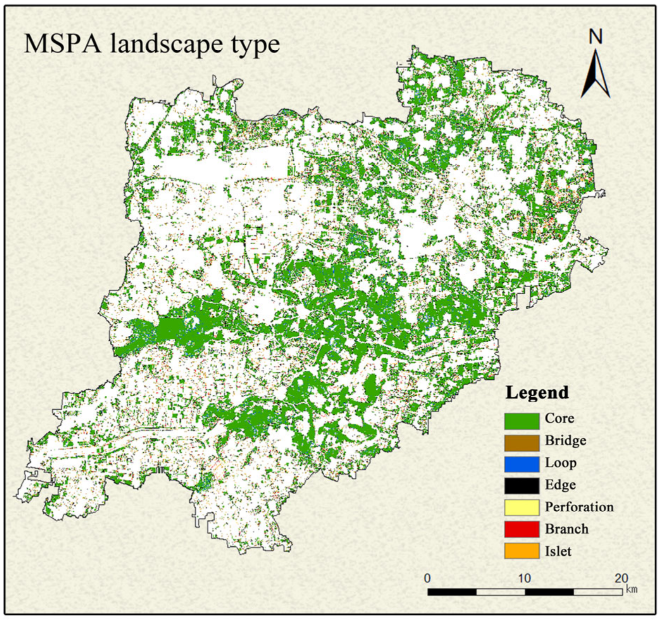


Figure 6. MSPA landscape type analysis results.

Table 9. Area and proportion of each landscape type based on MSPA.

Landscape Type	Area/km^2	Account for the Proportion of Foreground Elements	Account for the Proportion of the Study Area
core area	432.58	70.22	24.5
islet	17.44	2.83	0.99
perforation	16.88	2.73	0.95
edge	106.30	17.26	6.02
loop	4.38	0.71	0.25
bridge	11.02	1.79	0.62
branch	27.45	4.46	1.56
Total	616.05	100	34.89

3.4. Results and Analysis of Habitat Quality Assessment

Resistance factors and other data were input into the InVEST model (Table 7), employing the habitat quality module to measure the study region's habitat quality index, yielding a distribution range between 0 and 0.98. Based on the quantitative results and relevant literature references [52,53], the habitats in the study area were categorized into high-quality (0.76–0.98), medium-quality (0.43–0.75), and low-quality (0–0.42) habitats. The habitat quality analysis diagram is shown in Figure 7. Analysis of habitat quality ratios (Table 10) showed that low-quality habitats comprised 76.30%, medium-quality habitats accounted for 14.19%, and high-quality habitats accounted for the smallest proportion at 9.51%, exhibiting a polarized distribution trend. The trend could be attributed to the slow expansion of land used for construction in recent years and the overabundance of forest cultivation. Large-scale, high-quality habitats were concentrated around the Baiyang Lake wetland, with a significant aggregation in the eastern part of the wetland, resulting in a scattered overall distribution of high-quality habitats.

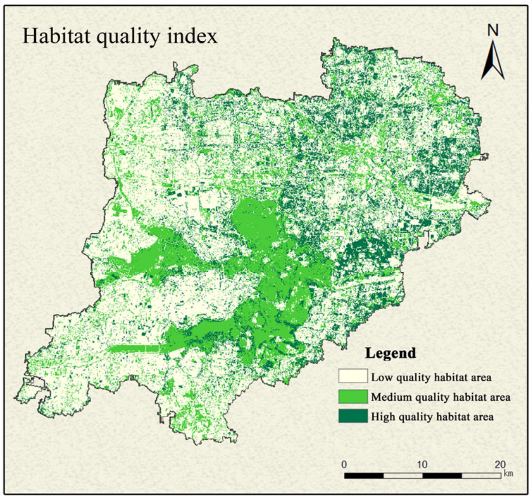


Figure 7. Results of habitat quality index analysis.

Table 10. Habitat area and proportion of different quality levels.

Habitat Category	Habitat Quality	Area/km^2	Account for the Proportion of the Study Area/%
High-quality habitat	0.76–0.98	168.05	9.51
Medium-quality habitat	0.43–0.75	250.49	14.19
Low-quality habitat	0–0.42	1347.13	76.30

The Baiyang Lake wetland is the largest macrophyte-dominated shallow freshwater wetland in the North China Plain [54]. It not only provides habitat for wildlife to support biodiversity but also interacts with surrounding green spaces to create synergistic effects (Figure 8), offering extensive ecosystem services to the adjacent areas [55]. The wetland ensures benefits for the surrounding environment [56], resulting in a distribution pattern of larger, high-quality habitats along the Baiyang Lake wetland within the Xiongan New Area.

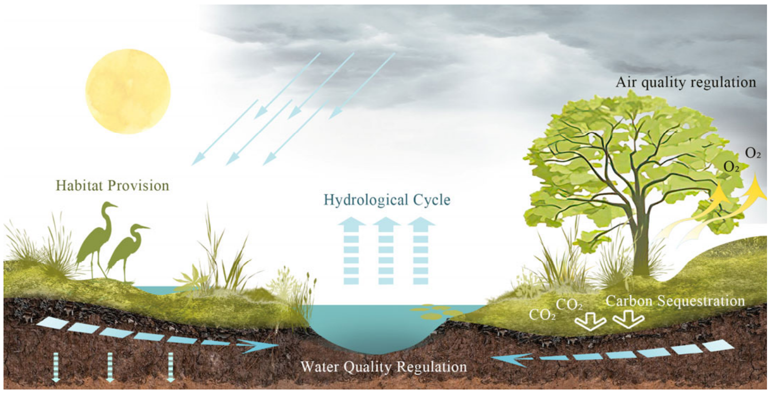
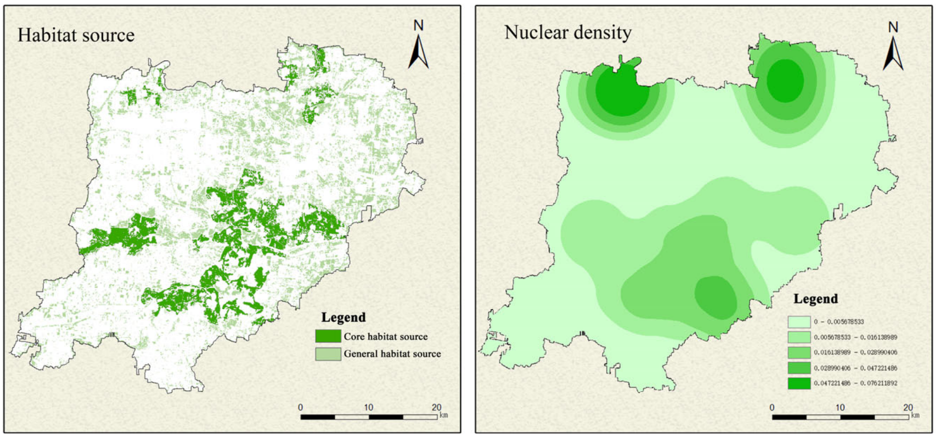


Figure 8. Schematic diagram of ecosystem services of the Baiyang Lake wetland.

3.5. Results and Analysis of Green Space Ecological Network Optimization

3.5.1. Ecological Sensitivity Assessment

Derived from the classification of landscape elements in MSPA and the outcomes of habitat quality assessments using the InVEST model, the total number of core patches as habitat sources was 28,032, with a total area of 301.55 km^2. By placing habitat sources into the Conefor intermediate connectivity index, the dI values of each source were calculated. Considering the calculated results and referring to relevant studies [57], 20 habitat sources with dI > 0.4 were selected as core habitat sources (Figure 9a), encompassing an overall expanse of 165.5 km^2, which constitutes 0.05% of all habitat sources but accounts for 54.88% of the habitat source area. The largest area of the patch is 43.53 km^2, which mainly includes the northern wetland of the Baiyang Lake wetland and some forest belt. The results show that the patches of habitat source areas in the core area are scattered, with a majority of small patches; while a few large patches exist, most are small and fragmented. Approximately 95% of the patches fail to meet the criteria for ecological source areas, indicating the necessity of comprehensively considering spatial form and functional attributes when choosing ecological source zones.



(a) (b)

Figure 9. Identification of habitat sources. (**a**) Identification results of general and important habitat sources. (**b**) Nuclear density analysis results.

The core habitat sources are basically located outside the urban area, and the area designated for future development is distributed along the Baiyang Lake wetland. The distribution trend centers around the Baiyang Lake wetland, with no core habitat sources in the south and northwest. The results of the kernel density analysis indicate that there are vacuum areas in habitat sources in the central and southwestern regions of the study area (Figure 9b). This result may be due to the good construction, the large scale and number of surrounding habitat sources, good patch connectivity, and a stronger structural role in the ecological network in the central habitat source, resulting in the lower importance of the southern and southeastern habitat sources.

3.5.2. Habitat Corridor Identification and Priority Judgment

According to the MCR model, a total of 762.72 km of habitat corridors were identified, with 96.48 km being identified as critical habitat corridors, accounting for 12.65% of the total length of corridors (Figure 10 and Table 11). The habitat corridors are woven around the Baiyang Lake wetland, connecting to the western habitat patch and linking to the northern forest land through the central forest area. The key habitat corridors branch out from the Baiyang Lake wetland, with some of them concentrating in the northern forest land. The MCR model indicates that, despite the relatively good habitat quality of the Baiyang Lake wetland, the comprehensive quality of the habitat in the research zone still presents significant resistance to biological migration within the corridors, requiring improvements in corridor connectivity.

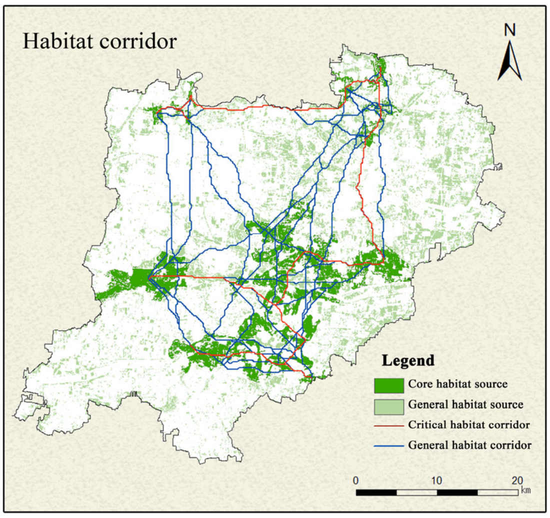


Figure 10. Habitat corridor identification results.

Table 11. Habitat quality distribution in the corridor.

Corridor Type	Corridor Length/km	The Proportion of the Total Length of the Corridor/%	Proportion of Low-Quality Habitats/%	Proportion of Medium-Quality Habitats/%	Proportion of High-Quality Habitats/%
General habitat corridor	666.24	87.35	33.03	38.38	28.59
Critical habitat corridor	96.48	12.65	34.61	34.75	30.64
total	762.72	100	33.18	38.02	28.80

3.5.3. Habitat Node Identification and Priority Judgment

Habitat corridors and islets were superimposed to form habitat nodes, which, together with habitat corridors, constitute a green ecological network [58,59]. Based on the corridor identification results, 159 habitat nodes were identified with a total area of 0.64 km^2 (Figure 11 and Table 12), accounting for only 3.67% of the isolated islet area analyzed by MSPA. This indicates that most of the isolated islets have not been integrated into the ecological network optimization pattern, limiting their ecological functions and leaving great optimization potential. The distribution of habitat nodes is more radiative in the south and less in the north. The main reason is that the corridor between habitat sources is longer in the north area, due to the small number of habitat sources, which increases the possibility of small patches passing through and reflects the characteristics of increased habitat fragmentation from south to north in the study area. There were 35 important habitat nodes located in the key corridors, constituting 22.02% of all nodes. A higher overall distribution was observed in the southern region compared to the northern, indicating that the core habitat sources mainly relied on the Baiyang Lake wetland with good natural background. The habitats were strongly isolated, with larger distances between the habitat sources and longer distances between the corridors, resulting in more nodes.

It can be seen from the node identification results that the habitat quality of the habitat nodes through which the corridor passes needs improvement. This also reflects that a large number of high-quality, isolated islet patches are difficult to enter the optimized network due to the isolation effects and need to be further integrated.

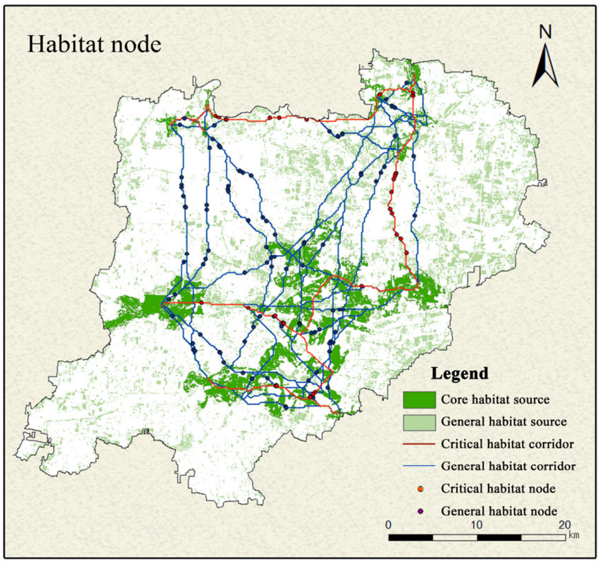


Figure 11. Habitat node identification results.

Table 12. Nodal habitat quality distribution.

Node Type	Quantity	Proportion of Low-Quality Habitats/%	Proportion of Medium-Quality Habitats/%	Proportion of High-Quality Habitats/%
General habitat node	124	50.94	46.23	2.83
Critical habitat node	35	62.23	31.03	6.90
total	159	53.33	42.96	3.71

4. Discussion

The construction of the Xiongan New Area is intended as a symbol of future development. As a densely populated city in the future, it will promote the development of nature and construction while ensuring economic development and human settlement [60]. A thorough examination was performed by the research on the current state of the prospective new town, assessing the potential value of ecological corridors based on elevation, water data, and geography data. The results show that combining landscape pattern analysis using the MSPA method with habitat quality assessment by the InVEST model and ecological sensitivity values as a comprehensive resistance surface effectively completes the task of ecological network building from many angles and directions. This approach is feasible for constructing and optimizing the ecological network of urban central areas. It is effective in supporting the improvement of urban ecological capacity and the protection of biodiversity [61]. To address the limitations of the Analytic Hierarchy Process (AHP), reliance on scoring from multiple domain experts can help mitigate these constraints [33]. For the integrated analysis of models, employing a more diverse range of model overlays can facilitate comprehensive evaluations [61].

Today's new area is being made, and for future places to live, the Xiongan New Area has big plans for development. This study starts from the present by imagining future city types, deeply looking at the natural state now, and anticipating how the Xiongan New Area might grow. It focuses on keeping nature parts and promoting sustainable growth while deeply exploring site elements. Not only would problems now be solved, but the future map of ecological pathways would also be built better, making their role in keeping cities sustainable stronger. In this study, mixing natural stuff, linking habitat hubs, building habitat pathways, and creating green space that is connected better were performed. After habitat pathways are set up in the future, adding people's views and playground resources would significantly improve the value and function of urban habitat pathways. While making urban green look nicer, putting ecological value into city planning aims to help keep ecological value during later big city buildings [62].

4.1. Ecological Sensitivity Analysis

Some researchers have already looked into making city ecological networks. Jiemin Kang (2023) said that using roads as the base and using possible ecological lands along these lines would link broken habitat spots, which would make the regional landscape pattern better [58]. Amal Najihah M. Nor (2017) innovated research methods and proposed that habitat corridors could be identified by integrating habitat patches to improve the habitat conditions of sites [63]. Zhongwei Jing (2024) innovated the research method of double superposition, not only emphasizing nature protection but also advocating the combination of natural resources and recreational functions so as to build a compound ecological corridor [64]. Han Li (2022) proposed that ecological corridors should not only be repaired and optimized but also cultural resources should be integrated to form a new ecological network pattern combining ecology and history [65].

This research integrates MSPA, InVEST, and MCR models for choosing habitat sources, calculating ecological connectivity, and making a green ecological network for the Xiongan New Area. The research reveals the Xiongan New Area has suitable habitats for good ecological network creation but also deals with issues of broken habitats. Therefore, improving ecological connections and keeping high-quality habitats like the Baiyang Lake wetland is necessary for balanced ecology in dense urban places. Compared to previous studies, this time, the research uses a unique angle by mixing MSPA, InVEST, and MCR models for a thorough check and bettering habitat sources, pathways, and nodes in many ways. This mixed model gives a broad research angle, making the ecological network building more scientific and clever. Also, stacking MSPA and InVEST models better picks habitat patches, ensuring these patches in the Xiongan New Area are not only spatially correct but also give important ecosystem services, helping in the following steps of pathways and node choosing. Compared with previous studies, the advantages of this study lie in the innovation of methods, the comprehensive application of multiple models and the selection of habitat nodes and corridors, which provide strong scientific support for the sustainable development of the Xiongan New Area.

4.2. Analysis of Research Results

4.2.1. Habitat Source Identification

In this research, the MSPA way was used to find seven types of landscape elements, choose patches affecting ecological links, and use the InVEST model for habitat quality assessment. The final decision was made to select 20 patches as habitat source sites. These chosen patches by these ways are important for keeping landscape connectivity. Given the place's terrain and water systems, areas near the Baiyang Lake wetland are good as habitat source sites. Future studies might think about adding more ecological sources in smaller patches or trying other methods.

4.2.2. Construction of Potential Corridors

Recognized habitat sources are used as a base for corridors potentially being seen. By taking advantage of ArcGIS 10.8.2 and MCR model, MSPA, and landscape connection analysis, the ArcGIS network analysis supports scientific picking out corridors. Ecology and recreation could be added in future times to make a mixed eco-logical corridor, leading to the harmonious advancement of humans with nature. As green infrastructure, forest corridors play a key role in sustainable urban development [66]. According to findings around the Baiyang Lake wetland, ecological corridors are concentrated relatively, yet distribution elsewhere, especially the northwest area, is not even. In future steps, the enhancement of indicators and method optimization will be necessary to avoid the degradation of ecology.

4.2.3. Extraction of Habitat Nodes

Most of the habitat nodes in the Xiongan New Area are located around the Baiyang Lake wetland, indicating that the area around the Baiyang Lake wetland is mostly habitat and protected area, which can increase the passage for native birds such as egrets and Honggeese and provide breeding places for rare, protected animals such as Clangula hyemalis. Habitat corridors in the eastern Baigou Cannal and Daqing River region, connecting the northern and southern habitat patches, are habitat corridors located between the construction area and the construction area. Habitat nodes in this corridor are dense, which can be used as an important channel for animal migration, and many nodes can provide places for species to rest. Central habitat sources near the Baiyang Lake wetland expand to the northwest, forming many habitat nodes that cross central urban areas, which, in future times, will be crucial zones for urban species and potential park areas within the Xiongan New Area. Such a connection will help in creating a full urban green ecological network, ensuring habitat landscape diversity is maintained in the Xiongan New Area [67].

4.3. Research Significance

This research is carried out under the background that the Xiongan New Area is under construction. The future positioning of the Xiongan New Area is a high-density and high-development new type city, and its ecological construction should also be at the forefront of the world. The research emphasizes what kind of ecological environment planning may be needed in the early construction of high-density cities in the future. In addition to having a certain understanding of the local geographical conditions of the Xiongan New Area, it is necessary to have forward-thinking control over the habitat construction of high-density cities [68]. This research is consistent with the strategic concept of Xiongan so that it can assist the future construction of human settlements in the Xiongan New Area and has clear and important significance for the future construction of new high-density cities such as the Xiongan New Area.

Furthermore, specific contributions of research identified key ecological sources, nodes, and corridors in the Xiongan New Area to provide concrete guidelines for future urban construction. Ecological passageways between high-density urban areas can be formed by habitat corridors. In the city, nodes of habitat along corridors can transform into urban parks, micro-green spaces, or pocket parks. Outside the city, larger habitat nodes, such as the Baiyang Lake wetland and Xiongan Rural Park, serve as significant ecological sites. Integration of nodes of habitat across different scales forms a cohesive network habitat, therefore enhancing the resilience landscape of density-low cities and ensuring sustainable development of the Xiongan New Area in the future [69].

4.4. Challenges and Limitations

The construction of an ecological network in the Xiongan New Area also faces certain challenges. Despite the presence of large ecological patches, such as the Baiyang Lake wetland, the construction of ecological networks in both core and islet areas of the study region faces challenges. This core area accounts for 24.5% and 70.2% of the total area and prospective area, respectively, of the study region. The findings are also fairly closely similar to those of related studies by Lian et al. [70] and Chen et al. [71]. However, the result of kernel density analysis shows that sources of habitat are dispersed to develop three focal regions FIG. Thus, such a dispersion causes the occurrence of vacuum areas in the central portion and southwest, impairing connectivity in the establishment of an ecological network with high intensity of connection Furthermore, 159 ecological nodes with a total area of 0.64 km^2 were identified by identification results of islet areas, accounting for only 3.67% of the total region. Islet areas are important stepping stones to improve the overall connectivity of the whole network, but utilizing them is inadequate to facilitate species migration and gene flow, which poses a sharp challenge to biodiversity conservation.

On the other hand, this study is based on future urban construction combined with current habitat conditions. Suppose there are changes and modifications in the construction of the Xiongan New Area in the future. In that case, it may not be fully applicable to the future urban construction, and some details will be adjusted, so it is necessary to adjust the ecological network system according to the current situation. In the future, research on Xiongan New Area will include more models for ecological assessment and recommendations to improve the accuracy and applicability of ecological network construction [72]. Moreover, given the rapid urbanization process in the Xiongan New Area, future analyses should consider the characteristics of ecological network changes over multiple time scales to identify areas with greater stability in the ecological network.

5. Conclusions

On surveying the field in the Xiongan New Area numerous times and taking into account current and planned policies, this study sorted land types in the Xiongan New Area. Six land factors were selected to build a comprehensive resistance surface for MSPA analysis, which was used to point out habitat sources in the Xiongan New Area. Furthermore, these results overlaid with habitat quality assessment obtained via the InVEST model, and these results then provide data for the final MCR model. After examining the Xiongan New Area's ecological connectivity, the potential corridors for ecology were identified. Some of these results are here written as follows:

(1) From the analysis, land types in the Xiongan New Area by 2024 include a high amount of arable land, little forest land, low levels of vegetation coverage, and habitats mostly found around the Baiyang Lake wetland.
(2) The Xiongan New Area's sensitivity to ecology is analyzed. Many parts are moderately sensitive, and only a few parts are highly sensitive. Lightly sensitive places include unused lands, wetlands, and so on.
(3) Firstly, the MSPA method was used to identify habitat sources, resulting in the habitat source area of 432.58 km^2, which is of foreground elements biggest, accounting for 70.22% of all foreground area elements in percentage-wise, but only 24.5% of the total study area. Following that, core habitat sources are selected by connectivity index analysis on ecology. It resulted in corridors of potential habitats constructed between habitat sources, identifying the total potential ecological area corridor area as 762.72 km^2, where key ecological corridors are 96.48 km^2. Finally, site information analysis was used to identify potential nodes of ecology and core habitat nodes, with the result being 159 potential habitat nodes, including 35 core habitat nodes. This study extracted the nodes to provide a needed scientific foundation for ecological importance protection in the Xiongan New Area, working towards the stability of the ecosystem and optimizing the overall ecological pattern as well.

In terms of recommendations for future research and practical applications, the implementation of this method can increase the proportion of land cover types with higher carbon storage capacity, effectively promoting an increase in regional carbon reserves and enhancing the stability of local ecosystems [73]. Through model predictions and quantitative studies, the research methodology presented in this paper can be widely applied to ecological planning in constructive land expansion across various regions. In the context of rapid urbanization, this method can proactively address the ecological threats posed by constructive land expansion, fostering sustainable ecological and economic development in the area [49].

The results finally conclude that ecological quality in the Xiongan New Area is generally good, suggesting it is fit for building habitats. Most habitat sources are mainly centralized in the middle region of the Baiyang Lake wetland area, and nearly the whole Xiongan New Area is covered by the connected ecological network. Future plans may include the addition of recreational pathways and cultural-history routes to these habitat paths. This integration aims to enhance the city's alignment within the ecological framework, fostering harmony between urban development and ecological growth, thereby facilitating urban improvements. Besides, given the Xiongan New Area's rich historic environment, adding cultural-history routes along well-made habitat paths might also benefit tourism, pushing local economic and industrial growth. To sum up, future city projects should emphasize distributing habitat sources and pathways smartly and consider how to build a sound, lasting ecological network. This study of the Baiyang Lake wetland not only backs the Xiongan New Area planning but also delves into how future city habitat networks might be formed, with hopes this research model applies to upcoming city projects as a guide for developing ecological networks in new cities coming up.

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