# CONSTRUCTION OF ECOLOGICAL SECURITY PATTERN BASED ON MINIMUM COST DISTANCE MODEL – A CASE STUDY IN KENLI DISTRICT OF DONGYING CITY, CHINA

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**Abstract.** Taking Kenli District of Dongying, China as an example, the ecological source area was determined through the analysis of land use type, habitat quality, ecosystem service value, in 2020. The resistance surface was constructed by stacking DEM data (Digital Elevation Model, DEM) and NDVI data (Normalized Differential Vegetation Index, NDVI) and corrected by night light data. The ecological corridor was constructed by using the minimum cost distance method, and the ecological sandwich point was determined according to the location relationship of each corridor. According to the relationship between the ecological corridor and the road, the ecological obstacle points are determined, and the ecological security pattern is finally constructed. The results showed that there were 263 ecological source areas in the study area in 2020, of 220.6 km$^2$. According to the research needs, 14 wetland patches with an area larger than 10 km$^2$ and greater contribution to ecosystem service value, and habitat quality evaluation were selected as ecological source areas. A total of 91 ecological corridors have been built, with a total length of about 1532.44 km, the longest corridor was about 33.04 km, and the shortest corridor was about 30.8 m. A total of 521 ecological pinch points were identified, including 1 primary node, 115 secondary nodes and 405 tertiary nodes. A total of 424 ecological obstacles were identified.
**Keywords:** *land use/cover change, ecological security pattern, Kenli District, Yellow River delta*

## Introduction

Ecological security stands as the cornerstone for safeguarding ecosystem health and propelling sustainable economic and environmental development. Broadly, it hinges on the foundational role of ecosystems in supporting human livelihoods while preserving societal harmony and stability (Ma et al., 2022). In a narrower context, ecological security pertains to the ecological function and integrity of natural and semi-natural ecosystems, ensuring their health remains uncompromised (Ma et al., 2022). The ecological security pattern, a regional landscape blueprint, aims to optimize ecological, social, and economic benefits by addressing specific environmental concerns. This entails arranging natural and human elements through technical means, yielding a multi-tiered spatial layout (points, lines, planes, and networks) that upholds the functional and structural integrity of the regional ecosystem (Liang et al., 2018). Yu’s (1999, 1996) landscape security pattern concept, based on Forman’s theory, outlines a three-step approach: identifying existing species dispersal sources (source areas), establishing a resistance surface, and subsequently assessing the safety pattern based on this surface (Wu et al., 2013; Zhang et al., 2019). This model has been widely adopted by scholars globally for ecological security assessments, yielding fruitful outcomes and promoting


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the method's scientific maturity and application (Teixeira et al., 2021). In recent years, the Party Central Committee and The State Council have prioritized ecological civilization, embedding it within the national five-year development plan, thus garnering attention across various sectors of society and yielding substantial research results that underpin the foundation for ecological security pattern construction. The Yellow River, the Chinese nation's mother river and the cradle of its civilization, plays a pivotal role in China's economic, social, and ecological security, serving as an essential ecological barrier and an economic hub (Tong et al., 2020).

This paper takes Kenli District of Dongying, China which situated at the Yellow River's estuary, as an example. The ecological source area determination comprises an analysis of land use types, habitat quality, and ecosystem service values. To construct the resistance surface, we overlay DEM data (Digital Elevation Model, DEM) and NDVI data (Normalized Differential Vegetation Index, NDVI), subsequently refining it with night light data. The minimum cost distance method guides the development of ecological corridors. Finally, the ecological pinch points are identified based on the relationship between these corridors and road networks, culminating in the establishment of an ecological security pattern. This case study aims to provide valuable research insights and reference for ecological protection and restoration not only in Kenli District but also in similar estuarine wetland regions.

## Data and methods

### *Overview of the study area*

Kenli District falls under the administrative jurisdiction of Dongying, China, situated within Shandong Province. The district acquired its name from its past designations as the reclaimed area and Lijinwa. Positioned at the estuary of the Yellow River and the heartland of the Shengli Oilfield, its geographical coordinates range from 118°15' to 119°19' East Longitude and 37°24' to 38°10' North Latitude. The district spans a southwest-to-northeast direction, measuring 96.2 km horizontally from east to west and 55.5 km vertically from north to south. Its eastern boundary fronts the Bohai Sea, while its northwest section borders Lijin County along the Yellow River. The total land area encompasses 2204.07 $km^2$.

Kenli District plays a significant role as a crucial ecological protection zone in Eastern China. Concurrently, it grapples with the severe issue of soil salinization. Furthermore, it serves as the backdrop for the Shengli Oilfield, a quintessential location characterized by the intricate interplay between natural and human factors. This interaction of river, sea, land, and human activities, while bearing ecological significance, does pose certain threats to ecological security, leading to the emergence of diverse ecological challenges. This research carries immense importance in maintaining the ecological security framework of the lower Yellow River region and propelling the sustainable development of this area (*Fig. 1*).

### *Data sources*

The data used in this study mainly include land use/cover data, DEM data, NDVI data, basic geographic data and in Kenli District of Dongying, China. In this paper, WGS 1984 coordinate system is adopted, and the spatial resolution is 30 m. The data source areas were the following:


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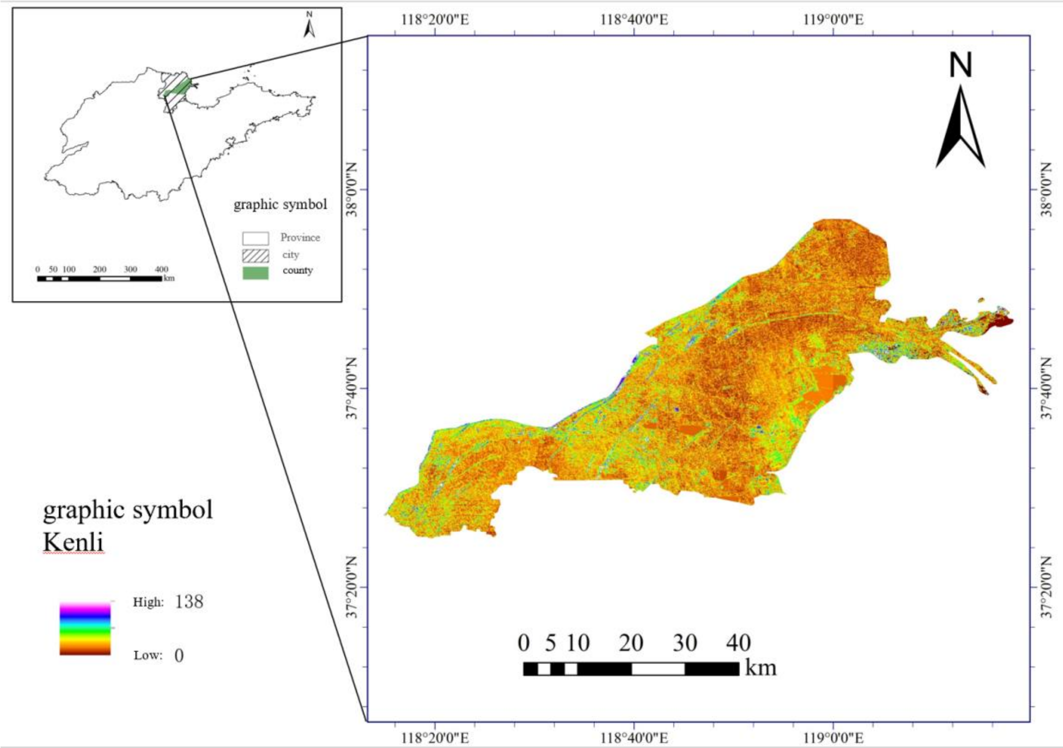


***Figure 1.*** *Overview of the research area*

The data of Land Use/Cover Change (LUCC) in Kenli District are derived from the 2000, 2010 and 2020 datasets of globeland30 Global Geographic Data product (http://globeland30.org/). The data includes 10 first-level classes with a spatial resolution of 30 m. The data of DEM comes from the geospatial data cloud (http://gscloud.cn). Slope and slope direction are extracted from ArcGIS with a spatial resolution of 30 m.

NDVIis from National Earth System Science Center (http://henu.geodata.cn/), with the spatial resolution of 30 m.

Basic geographic data such as administrative boundaries and roads are obtained from Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (https://www.resdc.cn/).

The wetland data was derived from National Data Center for Earth System Science – Geographic Resources Sub-Center, National Platform for Basic Condition of Science and Technology (http://gre.geodata.cn).

The night light data is from Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (https://www.resdc.cn/).

## Research methods

### *Habitat quality service assessment model*

In this study, we used physical measures to evaluate habitat quality by utilizing the habitat quality module within the InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) model. This module quantifies regional habitat quality primarily based on factors such as land cover type, extent, and the degree of degradation within a specific area. The calculation formula is outlined as follows:


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$$Q_{xj} = H_j \left[1 - \frac{D_{xj}^2}{D_{xj}^z - K^z}\right] \quad \text{(Eq.1)}$$

In *Equation 1*, $Q_{xj}$ is the habitat quality index of grid x in habitat type j; $H_j$ is the habitat suitability of habitat type j, the range is [0,1]; k is the semi-saturation sum constant, taking half of the maximum habitat degradation degree, and the default value is 0.05; z is a normalized constant with a default value of 2.5. The parameters in this model are determined according to the study and case site characteristics of Huang et al. (2018). Since only six land use types and oceans are involved in the study area, only seven threat sources are listed in this study (*Tables 1*, *2* and *3*).

***Table 1.*** *land use classification*

| Arable land | Forest | Grassy | Shrubland | Wetlands |
|---|---|---|---|---|
| Water | Tundra | Artificial surface | Bare ground | Glaciers and permanent snow |

***Table 2.*** *Threats weight value and maximum influencing distance*

| Threat sources | Maximum coercion distance (km) | Weights | Spatial decay mode |
|---|---|---|---|
| Arable Land | 3 | 0.6 | Linear |
| Grassy | 5 | 0.8 | Index |
| Wetlands | 4 | 0.6 | Index |
| Water | 4 | 0.5 | Linear |
| Artificial surface | 8 | 0.3 | Index |
| Bare ground | 2 | 0.4 | Linear |
| Ocean | 5 | 1 | Linear |

***Table 3.*** *Habitat suitability and sensitivity to threat sources*

| Land use types | Habitat suitability | Threat factors | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Arable land | meadow | Wetlands | Water | Artificial surface | Bare ground | Ocean |
| Arable land | 0.3 | 0 | 0.7 | 0.7 | 1 | 0.6 | 0.3 | 0.3 |
| Grass | 0.7 | 0.6 | 0 | 0.6 | 0.8 | 0.6 | 0.4 | 0.4 |
| Wetlands | 0.75 | 0.5 | 0.7 | 0 | 0.2 | 0.6 | 0.3 | 0 |
| Water | 0.7 | 0.45 | 0.6 | 0.2 | 0 | 0.8 | 0.4 | 0 |
| Artificial surface | 0 | 0 | 0.5 | 0.1 | 0 | 0.2 | 0.1 | 0.6 |
| Bare ground | 0 | 0 | 0 | 0 | 0 | 0.2 | 0 | 0 |
| Ocean | 0 | 0 | 0 | 0 | 0.2 | 0.2 | 0 | 0 |

### *Ecosystem service value*

The calculation of the equivalent factor for Ecosystem Service Value (ESV) in the study area relied on the adaptation of Xie Gaodi's factor table, as modified by Wu et al. (2019), with a correction coefficient specific to Shandong Province (1.38) in China.


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Notably, this approach focuses exclusively on terrestrial ecosystems, and as such, does not incorporate the ecosystem service value of the ocean. Therefore, the consideration of oceanic ESV is excluded from this analysis (*Table 4*).

***Table 4.*** *The value equivalent of ecosystem services*

| The ecosystem services function | Cultivated | The ecosystem services function | Cultivated | The ecosystem services function | Cultivated | The ecosystem services function | Cultivated |
|---|---|---|---|---|---|---|---|
| Gas conditioning | 610.5 | 976.9 | 1592.7 | 0 | 0 | 0 | 0 |
| Climate regulation | 1086.8 | 1099.3 | 15130.9 | 561.7 | 0 | 0 | 0 |
| Water conservation | 732.6 | 976.9 | 13715.2 | 24885.8 | -9215.6 | 36.6 | 0 |
| Soil formation and protection | 1782.8 | 2381.2 | 1513.1 | 12.1 | 0 | 24.4 | 0 |
| Waste disposal | 2002.7 | 1599.7 | 16086.6 | 22199.5 | -3000.3 | 12.1 | 0 |
| Biodiversity conservation | 866.9 | 1331 | 2212.2 | 3040.6 | 0 | 415.1 | 0 |
| Food production | 1221.2 | 366.4 | 265.5 | 122.1 | 0 | 12.1 | 0 |
| Ingredients | 122.1 | 61 | 61.9 | 12.1 | 0 | 0 | 0 |
| Entertainment culture | 12.1 | 48.9 | 6383.0 | 5299.5 | 0 | 12.1 | 0 |
| Total | 8437.7 | 8841.3 | 56961.1 | 56133.4 | -12215.9 | 512.4 | 0 |

Calculate the service value of each land use type, the value of each service function and the total value of ecosystem services according to *Equations 2*, *3* and *4.*

$$ESV_k = \sum_f A_k \times VC_{kf} \quad \text{(Eq.2)}$$

$$ESV_f = \sum_k A_k \times VC_{kf} \quad \text{(Eq.3)}$$

$$ESV = \sum_k \sum_f A_k \times VC_{kf} \quad \text{(Eq.4)}$$

where $ESV_k$, $ESV_f$ and ESV are respectively the service value of type k, the service function value of item f and the total service value; $A_k$ is the land area of type k; $VC_{kf}$ (value coefficient) is the service value of the service unit area of item f of type k.

### *Construction of ecological security pattern*

#### Determination of ecological source areas

Ecological source areas denote critical patches (Hang et al., 2021) where species proliferate, offering notable ecological advantages. Based on the specific conditions in the Kenli area, this study has found that the ecosystem’s high-value services predominantly stem from grassland and wetland. However, the grassland coverage within the study area is limited and dispersed, leading to a minor overall ecological impact. Consequently, wetland patches exceeding an area of 10 $km^2$ have been identified and selected as the core ecological source areas.

#### Construction of the resistance surface

The resistance surface reflects the energy and flow cost expended by species during migration across heterogeneous landscapes. The resistance surface is influenced by multiple factors, including land use type, elevation, slope, location, and human activities, among others. Its construction must be aligned with the actual conditions of


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the study area. In this investigation, ArcGIS 10.2 software was utilized to integrate land use data, DEM data, and NDVI data. Specifically, land use data was applied to determine land use types, DEM data was used to extract elevation information, and NDVI data was utilized to obtain data on vegetation coverage and habitat quality, essential for analyzing the resistance factors. The weight assigned to each factor was determined through factor analysis. A raster calculator was employed for spatial overlay, and the ecological resistance surface was refined through night light correction, resulting in the foundational resistance surface essential for the study (*Table 5*).

***Table 5.*** *Resistance and resistance coefficient of index weights*

| Resistance factor | Dividing criteria | Resistance values | Weight |
|---|---|---|---|
| Land use type | Cultivated land | 3 | 0.479 |
| | Grass | 1 | |
| | Wetlands | 2 | |
| | Water | 4 | |
| | Artificial surface | 5 | |
| | Bare ground | 6 | |
| | Ocean | 7 | |
| Elevation | [100m,138m] | 4 | 0.122 |
| | [50m,100m) | 3 | |
| | [20m,50m) | 1 | |
| | [0m,20m) | 2 | |
| Vegetation cover | [80%,100%] | 1 | 0.273 |
| | [60%,80%) | 2 | |
| | [40%,60%) | 3 | |
| | [20%,40%) | 4 | |
| | [0%,20%) | 5 | |
| Habitat quality | [0.6,0.75) | 1 | 0.126 |
| | [0.45,0.6) | 2 | |
| | [0.3,0.45) | 3 | |
| | [0.15,0.3) | 4 | |
| | [0,0.15) | 5 | |

Night light data can comprehensively characterize the intensity of human activities, so this paper uses night light data to modify the resistance surface to improve the accuracy and rationality (Wang et al., 2022a) of corridor simulation.

In *Equation 5,* R* is the corrected resistance coefficient of the grid; $TLI_i$ is the night light intensity value of grid i; $TLI_a$ is the average night light intensity value of land type a; Ro is the foundation resistance value for grid i.

$$R^* = \frac{TLI_i}{TLI_a} \times R_o \qquad \text{(Eq.5)}$$

Ecological corridor construction and node identification

*1. Minimum cost distance model:* The minimum cost distance model is a widely used, efficient landscape connectivity evaluation model. It identifies corridors and


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strategic points by calculating the direction and path with the lowest consumption cost and closest distance between source points. While multiple paths exist between sources, this model pinpoints the path with the least cost, streamlining the process among the alternatives. When employing the minimum cost distance method to extract corridors, the general steps involve creating cost consumption surface (resistance surface) raster data, calculating the minimum cumulative cost distance (Yuan et al., 2018) of each patch raster data, and subsequently extracting the corridor from the raster data of two green patches.

*2. Construction of ecological corridor:* Landscape connectivity is a pivotal representation of the functional integrity of regional ecosystems, bearing immense significance for ecosystem management and conservation planning (Wu et al., 2022). The ecological corridor acts as a low-resistance ecological channel, linking fragmented habitat patches, and plays a crucial role in maintaining the continuity and circulation of ecological flow and processes within the region. In this study, the cost distance tool in the ArcGIS software facilitated the generation of the lowest cost path between each ecological source area, while the cost path tool combined the ecological source area with the resistance surface in the core area to establish the ecological corridor in the Kenli area.

*3. Ecological pinch points:* Ecological pinch points serve as connecting hubs between various ecological patches, maintaining the connectivity, stability, and integrity of the ecosystem (Feng et al., 2022). Identification methods for ecological pinch points encompass several strategies, such as identifying the tangent point of the iso-resistance line between ecological source areas, extracting the "ridge line" of the ecological resistance surface, identifying the intersection point of the maximum consumption path and the ecological corridor, or locating areas with high current density based on the circuit theoretical model as the ecological pinch point (Megn et al., 2012).Utilizing advanced editing tools within the ArcGIS platform, this study analyzed the intersection status of diverse ecological corridors in Kenli District to determine the ecological pinch points. By evaluating the number and grade of ecological corridors in ecological sandwiches, the grade of ecological sandwiches was established. Comprehensive analysis of the ecological pinch density in different levels for each small watershed unit within Kenli District allowed for the selection of key areas for ecological pinch protection and restoration.

*4. Ecological obstacle points:* Ecological obstacle points signify areas between ecological sources that exhibit greater resistance to biological movement. The elimination of ecological obstacle points substantially reduces ecological resistance between regions, enhancing landscape connectivity among ecological sources and contributing significantly to maintaining the stable development of ecosystems (Liu et al., 2023). Leveraging advanced editing tools within the ArcGIS platform, this study assessed the intersection status of various ecological corridors and roads in Kenli District of Dongying, China to identify ecological obstacle points.

## Analysis of results

### *Ecological source identification*

The ecological source area, a region of elevated ecological value, serves as the bedrock for species survival, exerting a pivotal role in their continued existence and development (Wang et al., 2019). A comprehensive tally reveals 263 such ecological


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source areas spanning approximately 220.6 km² in 2020, constituting 11.72% of the total area under consideration. From a land use perspective, wetlands and grasslands dominate the landscape of ecological source areas. However, the contribution of grasslands to the ecosystem within the study region is limited due to their small size and discontinuous spatial distribution. In contrast, the area boasts a profusion of wetland patches. Among the 254 sizable ecological source areas, encompassing about 204.37 km², they cover roughly 9.27% of the total area and exhibit wide spatial distribution.

Consequently, we meticulously selected 14 wetland patches exceeding 10 km², significantly enhancing habitat quality within the study area, as pivotal ecological sources. Wetlands exhibit a multifaceted role, encompassing support, regulation, and provision within the ecosystem, exemplifying their pivotal contribution to ecosystem services and the preservation of biodiversity. These extracted ecological source areas underwent overlapping analysis with the 30 m resolution spatial distribution dataset of Chinese wetlands. The regions exhibiting substantial overlap were predominantly concentrated within the Yellow River estuary wetlands, while other regions displayed a lower degree of overlap (*Fig. 2*).

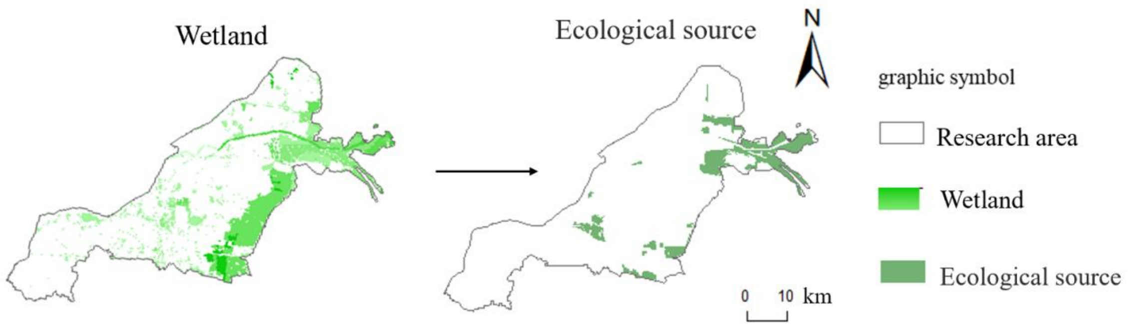


***Figure 2.*** *Distribution of wetland in Kenli and ecological source*

### *Resistance surface construction*

A resistance surface quantifies the impediment a species faces while traversing distinct landscape units. Given the study's Yellow River Estuary locale, the influence and degree of each resistance factor are ascertained through a combination of pertinent research and factor analysis, culminating in the creation of the resistance surface.

From a spatial distribution perspective, areas of high resistance value are chiefly concentrated within the northeastern coastal zone of Huanghekou Town, with scattered occurrences in select regions of Kenli Street and Xinglong Street in Shengtuo Town. Conversely, low resistance value areas exhibit a more extensive coverage, predominantly spanning the central and western regions of Kenli District, eventually converging along the Yellow River's course.

Leveraging the advanced editing tools within the ArcGIS platform, this study undertook a comprehensive examination of the intersection statuses among various ecological corridors within Kenli District, Dongying, China leading to the identification of ecological pinpoints. Corridors containing more than three nodes are classified as primary, while those with fewer than three nodes are deemed auxiliary corridors. (*Figs. 3*, *4* and *5*).


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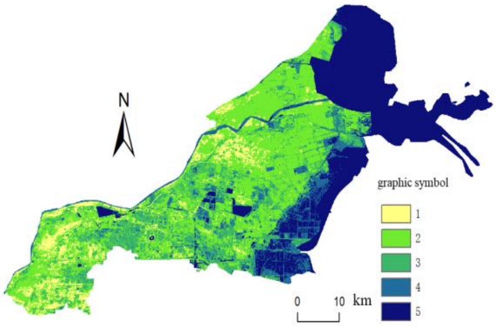
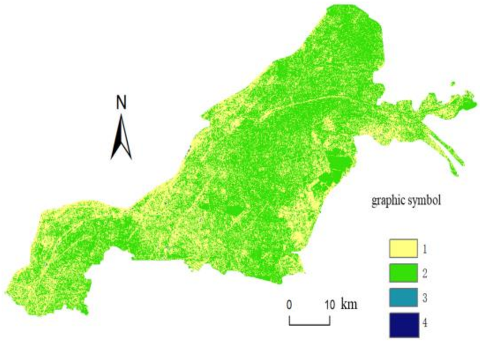
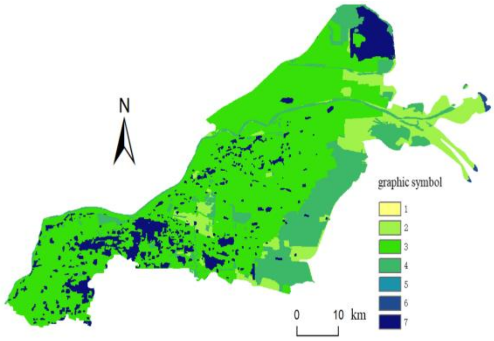


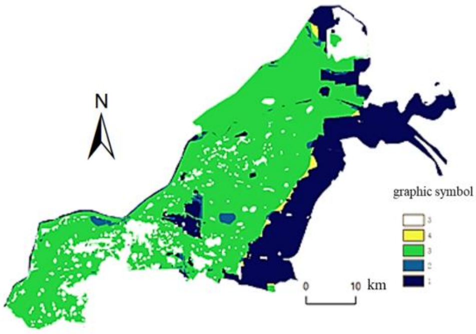
(a) Vegetation cover resistance



(b) Elevation resistance



(c) Land use type resistance



(d) Habitat quality resistance

***Figure 3.*** *Single factor ecological resistance surface*

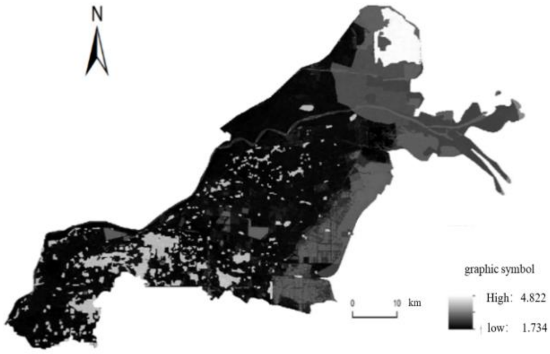



***Figure 4.*** *Comprehensive resistance surface in Kenli*

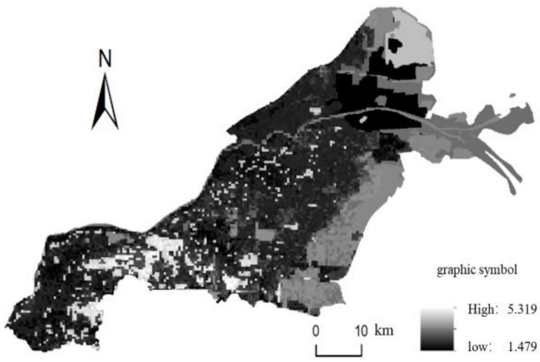



***Figure 5.*** *Ecological correction resistance surface in Kenli*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## *Ecological corridor construction*

The ecological corridor serves as the foundational “skeleton” of the ecological security pattern, serving as a vital conduit for material and energy circulation between source areas. Its crucial role in bridging isolated ecosystems within the region facilitates essential ecological processes. Typically, the ecological corridor exhibits linear or ribbon-like structures, facilitating the communication of one or more ecosystems (Wang et al., 2019). Its profound significance lies in the maintenance of overall ecological system stability, with the effectiveness and stability of the entire ecological security pattern hinging on the scientifically informed establishment of these corridors.

Leveraging the minimum cost distance model and the ArcGIS 10.2 platform, this study seamlessly integrated the ecological sources and resistance surface to establish a network of ecological corridors, resulting in a total of 91 corridors in 2020. In terms of spatial distribution, the corridors primarily cluster within Kenli District, predominantly in the central and eastern regions, with the southeast exhibiting the highest concentration. However, no ecological corridors were identified in the southwest and northeast regions. From the perspective of corridor length, the cumulative extent of ecological corridors within Kenli District, Dongying, China measures approximately 1,532.44 km. The longest corridor spans approximately 33.04 km, while the shortest measures about 30.8 m (*Fig. 6*).

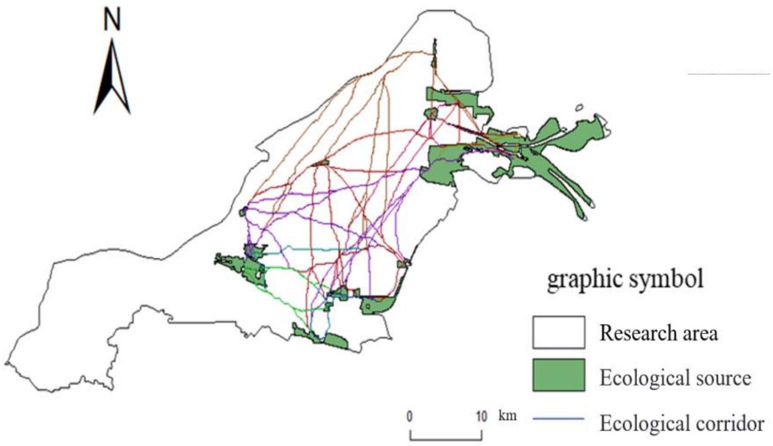


***Figure 6.*** *Ecological corridor of Kenli*

## *Ecological node extraction*

### *Ecological pinch extraction*

Identification and Significance of Ecological Pinch Points ecological pinch points serve as pivotal components facilitating the exchange of matter and energy between ecological patches, thus playing a crucial role in regional ecological processes. These points hold immense significance in preserving regional connectivity and stability (Meng et al., 2012). Employing the sophisticated ArcGIS platform’s editing tools, this study meticulously examined the intersection of ecological corridors within Kenli District, Dongying, China in 2020. The investigation yielded a total of 521 ecological pinch points, comprising one primary node, 115 secondary nodes, and 405 tertiary nodes. The distribution of these ecological pinch points across the study area is non-


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uniform, with a pronounced concentration in the eastern regions of Yong'an Town and Huanghekou Town. This specific area stands proximate to wetlands, boasts high habitat quality, a relatively sparse road network, and exhibits low values in night light data—signifying minimal human impact within this territory (*Fig. 7*).

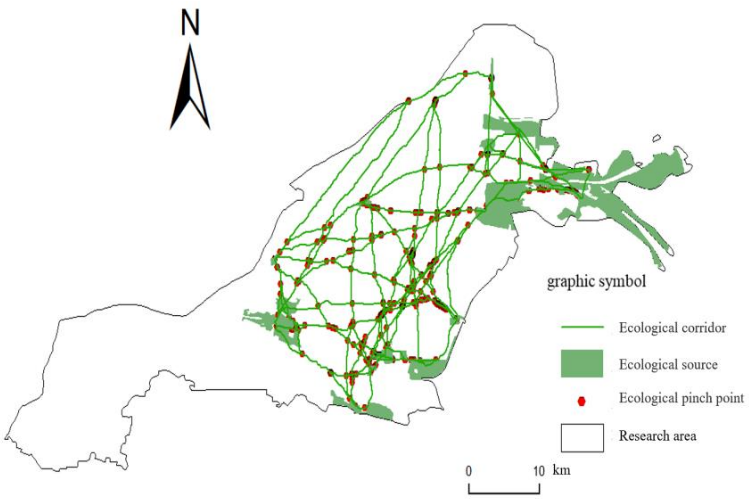


***Figure 7.*** *Ecological pinch point of Kenli*

*Extraction of ecological obstacle points*

Ecological obstacle points denote areas situated between high-resistance ecological source regions, representing pivotal zones for ecological restoration and environmental enhancement. The removal of these obstacle points yields significant reductions in ecological resistance between regions, thereby enhancing landscape connectivity among ecological source areas. This endeavor holds substantial importance in bolstering the overall connectivity of regional ecosystems and ensuring the stable development of ecological systems. The study successfully identified a total of 424 ecological obstacle points in 2020. In terms of spatial distribution, these points were notably concentrated in Kenli Street, Xinglong Street, and the western part of Yong'an Town, situated at the heart of the region. This concentration aligns with the densely populated nature of the area, where a dense road network poses a challenge to ecological connectivity (*Fig. 8*).

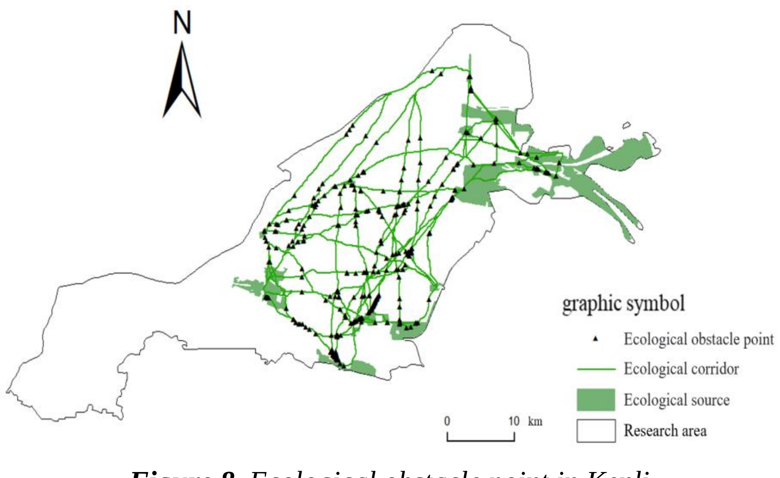


***Figure 8.*** *Ecological obstacle point in Kenli*


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### *Establishing the ecological security pattern in Kenli District, Dongying, China in 2020*

The development of the ecological security pattern in Kenli District of Dongying, China involved a multifaceted approach, integrating land use analysis and ecosystem service evaluation. Fourteen crucial ecological source patches were pinpointed, complemented by the identification of 91 connecting ecological corridors, 521 strategic ecological pinch points, and 424 challenging ecological obstacle points in 2020. This comprehensive framework shaped the ecological security pattern for Kenli District. Notably, the ecological source areas displayed a wide distribution throughout the county, with focal points in Huanghekou Town and Yong'an Town, along with scattered regions in the west exhibiting strong ecosystem service capabilities.

The ecological corridors were predominantly concentrated in the eastern and central sectors of Kenli District, while the western part featured a more sparse distribution. Of particular significance, the ecological pinch points clustered in the eastern areas of Yong'an Town and Huanghekou Town, facilitating the flow of critical ecosystem services. Meanwhile, ecological barrier points were prevalent in the central region, posing a challenge to seamless ecological connectivity.

Kenli District boasts an abundance of wetlands, often designated as ecological sources, rendering them pivotal for ecosystem services. Being situated in the densely populated eastern coastal region of China, Dongying experiences the intricate interplay of river, sea, land, and human activities, leading to elevated demand for ecosystem services. Population growth and urban expansion have exacerbated conflicts between human activities and land use.

The core focus of the ecological security pattern in Kenli District of Dongying, China lies in preserving the existing ecological source areas despite the pronounced conflicts between human activities and land use. This necessitates not only enhancing the ecosystem service function of the original ecological source areas but also elevating the function of non-ecological source areas. Additionally, bolstering the connectivity among ecological source areas is essential to fortify regional ecological security.

It is imperative to acknowledge the regional variations in ecosystem services within Kenli District of Dongying, China. Consequently, the implementation of ecosystem optimization, ecological protection, and construction strategies should align closely with local conditions, considering the specific circumstances of the region, in order to enhance overall ecological security.

## Discussion

### *Identification of ecological source areas based on ecosystem services*

Kenli District of Dongying, China has the youngest delta and the youngest wetland ecosystem in the world, with short landfall time, low vegetation coverage and high population density. It is also the location of Shengli Oilfield, a typical area where rivers, sea, land and people interact together, and the ecological environment is fragile. At the same time, the Kenli District of Dongying is located in the Bohai coast of China, in the economic circle delimited by the state and the province, how to balance its economic development and ecological protection is a problem to be solved.

In this study, land use, ecosystem services and ecological security pattern were combined to judge the ecological source area of Kenli District in Dongying according to


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the land use pattern and ecosystem services, and ecological security pattern at the county scale was constructed based on the minimum cost distance model. Firstly, the land use/cover change in the region was studied, and then four ecosystem service values, namely habitat quality, carbon storage, water conservation and soil conservation, which were closely related to the ecosystem in 2000, 2010 and 2020, were evaluated. The total ecosystem service value in 2000, 2010 and 2020 was calculated and its change rule was explored. On this basis, considering that most of the areas with higher habitat quality and ecosystem service value in Kenli District of Dongying are concentrated in the wetland area, and the wetland area is widely distributed in the region, wetland patches with an area larger than 10 $km^2$ are selected as the ecological source area of the research area.

There have been many studies (Tong et al., 2020; Wu et al., 2020, 2016; Zheng et al., 2021) which have incorporated the value of various ecosystem services derived from InVEST model into the identification and determination of ecological source, and determined the selection of ecological source from the regional differences of ecosystem service value. Many studies on ecosystem services and ecological security pattern focus on the Yellow River Delta wetland (Sun et al., 2023; Wang et al., 2022b; Li et al., 2011; Zhang et al., 2009), which also reflects the importance of the Yellow River Delta wetland in ecosystem services. Based on the source identification of landscape, this study realizes the combination of landscape pattern and ecological function to a certain extent, which is reasonable. In future studies, the trade-offs and synergies between different ecosystem services can be further considered, and more scientific methods of ecological source identification can be explored.

***Construction of the resistance surface using multi-data inputs: land use and ecosystem services***

Resistance surface is the degree to which species are affected by resistance when moving landscape units. In this study, considering that Kenli is located at the mouth of the Yellow River, the surface fluctuation is small but there are highlands and depression prone to water accumulation, the vegetation coverage rate is low in some areas due to high salinization degree, and the land use is affected by natural and human factors, etc., the natural factors are firstly discussed. Based on the comprehensive consideration of habitat quality research results, land use type, elevation and vegetation cover, the basic resistance surface was established, and the light data reflecting human activities was used to modify the resistance surface, and the ecological corridor was constructed with the minimum cost distance model to further determine the ecological sandwiches and ecological obstacle points.

The construction of resistance surface system with multiple data superposition is not uncommon in studies on ecological security pattern. Existing studies (Li et al., 2021) have established a resistance evaluation system based on ecosystem service value by taking habitat quality assessment as one of the resistance factors, or in ecosystem service value rating, taking areas with high comprehensive ecosystem service level as ecological source (Liu et al., 2021). The ecological security pattern based on multi-data resistance surface construction and corridor construction, taking into account natural and human factors, is relatively reasonable for research, but there is no unified standard and quantitative method for the construction of ecological resistance index system. In addition, this paper considers the land use type and light data factors, which can partially represent the intensity of human activities, so the influence of factors such as


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distance from roads and water bodies is not included. In future studies, factors should be further reasonably added to make the research results more suitable for the actual study area and reduce errors at the same time. In future studies, we can further consider how to construct resistance surfaces more accurately, how to correct resistance surfaces, and explore more scientific methods of resistance surface construction and identification.

## Conclusion

In the face of rapid urbanization, the delicate balance between ecological security and economic development has immense implications for regional growth. Taking Kenli District of Dongying, China—a pivotal town within the Yellow River estuary—as a case study, this paper develops an ecological security pattern through the integration of ArcGIS, landscape ecology theory, and the minimum cost distance model, leading to the following conclusions:

This study has identified a total of 263 ecological source areas in 2020, covering approximately 220.6 $km^2$, constituting 11.72% of the overall area. These source areas are predominantly situated in the Yellow River estuary and the eastern wetland and grassland regions. To meet research objectives, 14 substantial wetland patches, each exceeding 10 $km^2$ and contributing significantly to habitat quality, were selected as ecological source areas. The construction of 91 ecological corridors, encompassing a total length of approximately 1,532.44 km, with the longest corridor spanning 33.04 km and the shortest measuring 30.8 m, was primarily concentrated within the central and western regions. Moreover, 521 ecological pinch points were pinpointed, comprising 1 first-level node, 115 second-level nodes, and 405 third-level nodes, mainly clustered in Yong’an Town and the eastern part of Huanghekou Town. Concurrently, 424 ecological obstacle points were identified, primarily localized within Kenli Street, Xinglong Street, and the western region of Yong’an Town.

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