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Research on Ecological Land Expansion: A Case Study of Haixing County of China

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ABSTRACT

As China's natural resource governance has turned to high-quality management, establishing reasonable and ecological land-use patterns is an effective means of promoting natural resource utilization and improving the quality of the ecological environment. Therefore, this study used ecological land as the expansion source to construct an ecological land-use pattern with the minimum cumulative resistance model in Haixing County, China, based on regional food security, ecological security, and construction land expansion patterns. This work also involved designing ecological corridors, radiation channels, strategic nodes, and other ecological components. The results demonstrate that (1) the ecological land source is 7976.93 hm^2, accounting for 9.19% of the total area. It is mainly distributed in the southeast of the county, mainly in the river system and woodland; (2) the food security situation of Haixing County can be divided into four zones, most of which are agricultural adjustment areas, indicating that the ecological security of cultivated land in this area needs to be improved; (3) the ecological security level of Haixing County is divided into four areas, and the ideal safety zone accounts for the smallest area, indicating that the regional ecological situation is very unstable; (4) construction land expansion zone is divided into four parts. A suitable construction zone occupies the largest area and is mainly distributed around the current construction land; (5) the expansion of the ecological land-use pattern of Haixing County includes four zones, 15 ecological corridors, 12 radiation channels, and 35 strategic nodes, which is conducive to optimal land allocation from an ecological security perspective. This paper puts forward some suggestions for ecological protection and intensive urban development.

INTRODUCTION

Since the 21st century, China's land-use patterns have undergone complex and drastic changes, including the gradual expansion of construction land and the reduction of natural land. Such changes significantly affect the natural and social development systems and cause serious ecological and environmental problems (Zheng et al. 2019). The land is the basic carrier of natural ecosystems and human activities, and its structure and pattern reflect the influence of external factors such as nature, society, and the economy (Lambin & Meyfroidt 2011). As a land-use type with important ecological value, ecological land plays an important role in maintaining regional land ecological security and guaranteeing natural ecosystem services and functions, which can effectively promote the sustainable development of a society (Fu 2019).

Changes in ecological land have been seen as one of the most significant driving factors for changes in ecological processes and ecosystem services (Liang et al. 2021). Scholars recognize that ecological land is the basic carrier for maintaining regional land ecological security and ensuring ecological material flow and energy exchange (Wang et al. 2019). The study of ecological land started with greenway design. The emergence of urban parks and nature reserves in the United States is based on the initial concept of greenway design, which has been gradually popularized and applied after extensive research (Jongman & Pungetti 2005). The Greenway movement in Singapore has developed gradually, and its experience and model have been constantly promoted (Tan 2006). After extensive research, ecological land use has gradually been promoted and applied by international scholars (Fath et al. 2017, Green et al. 2016). Ecological land use has been planned based on qualitative and quantitative analyses, gradually into data calculation, static structure optimization, dynamic simulation state, and trend analysis of rapid development. The research methods are mainly related to ecological suitability/sensitivity, landscape pattern index, scenario analysis, and index systems (Huck et al. 2011, Chaudhary et al. 2019, Macmillan et al. 2007, Ojea et al. 2016). The research topics mainly include biodiversity assessment, ecological conservation and restoration, coupling analysis of human-natural systems (Gergely & Leah 2019, Schröter et al. 2020), and ecological security pattern (Tang et al. 2020).

Chinese scholars have discussed the connotation and classification of ecological land from many fields and perspectives; however, no consensus has yet been reached. Scholars have studied ecological issues from different perspectives, and further clarified the conceptual scope of ecological land, and the role of ecological land in maintaining biodiversity, improving ecological environment quality, adjusting climate, and improving human-land relationships (Yu et al. 2009, Zhang et al. 2017, Liu et al. 2021). Methods of ecological value (Cao et al. 2020), reverse recursion (Long et al. 2015), and construction of the land-use pattern and ecological security pattern (Zhou et al. 2020) are used to identify the spatial extent of ecological land and provide a basis for its further. The matter element analysis method, entropy weight method (Yu et al. 2012), and ecological footprint method (Xiu et al. 2020) are used to construct a land ecological security evaluation index system. The theory of "patch-corridor-matrix" and the model of cumulative minimum resistance is used to identify ecological strategic nodes and ecological corridors, and the ecological security pattern has been widely constructed in China in recent years to optimize land-use pattern (Liu et al. 2020, Yu et al. 2021).

To meet the need for ecological land use and sustainable human development at the county scale, this study researched the expansion of ecological land in Haixing County, which is a coastal county. It is relatively backward in economic development. Its economic development is bound to expand on construction land, and this could pose risks to food security and ecological security. How to realize ecological security construction at the county level while protecting cultivated land and developing the economy is a problem that Haixing County must face and solve. This study took the quality of cultivated land, the level of ecological security, and the expansion trend of construction land as the premises for realizing the optimal allocation of ecological land, then researched the ecological land expansion. The results provide accurate planning and layout scheme for food security, economic development, and ecological protection in Haixing County and the similar areas.

DATA AND METHODS

Study Area

Haixing County is located in Hebei province, at the junction of Hebei and Shandong; to the east is in the proximity of the Bohai Sea (Fig. 1), and experiences a warm temperate sub-humid continental monsoon climate.

The county covers a total area of 86825.84 hm^2, including 197 administrative villages, among which ecological land covers a total area of 26776.83 hm^2, mainly woodland, grassland, garden land, water area, wetland, and unused land (Table 1).

Data Sources

There are two types of data sources: File data and remote sensing data. The file data were mainly obtained from the

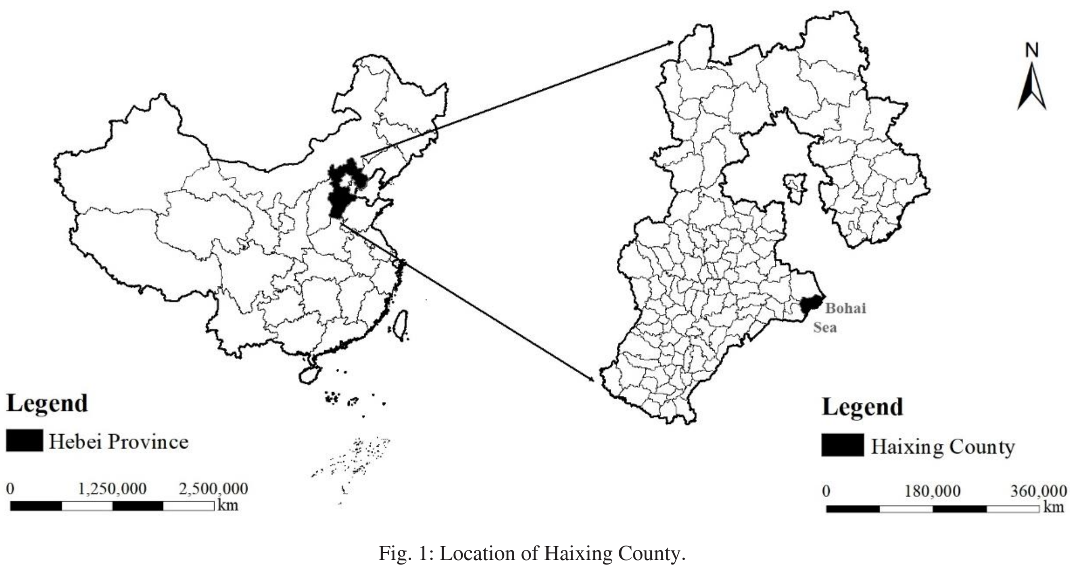

Fig. 1: Location of Haixing County.

Table 1: Classification of ecological land in Haixing County.

Ecological land type	Area (hm^2)	Proportion (%)
Water area	4609.48	17.21
Wetland	2453.91	9.16
Woodland	1412.04	5.27
Garden land	900.64	3.36
Grassland	1609.73	6.01
Unused land	15791.02	58.97

Note: Although there are no wetlands (which are not at the same level as other ecological land) in the 73 secondary categories of land-use classification in 2017, wetlands play a primary role in maintaining regional ecological environment stability, and they are treated as separate categories here and regarded as ecological land.

Haixing County Natural Resources and Planning Bureau, including the land-use database of Haixing County in 2017, grading results of cultivated land quality in 2018, the overall land-use plan of Haixing County (2013-2030), and the land survey update data of Haixing County (2017). By downloading Landsat OLI imagery and DEM data with 30 m spatial resolution from the USGS and using ArcGIS10.2's spatial analysis and processing function, the index status of Haixing County was obtained. The impact distances of roads, residential locations, and geological disasters were obtained by distance analysis of the current situation of roads, residential areas, and ponds extracted from the geographical map. Vegetation coverage was extracted from remote sensing images and the slope was extracted from digital elevation model data. Other data, such as habitat quality and landscape diversity, were obtained through relevant mathematical models. The research unit was a 30 × 30 m grid unit.

Evaluation Method of Ecological Land Expansion Constraint Factor

The expansion of ecological land will inevitably occupy other types of land. Whether to allow the expansion of ecological land to occupy cultivated land and construction land, and whether to ensure ecological security in the expansion process, need to be demonstrated from food security, ecological security, and the expansion of construction land.

Food Security Zoning Method

Global spatial autocorrelation analysis: Using ArcGIS10.2 and GeoDa software, the Global Moran's I index was run to verify the spatial similarity of the quality grading index of all cultivated land polygons. The Global Moran's I value was between [-1, 1]. A value > 0, indicates that the space is positively correlated, and the research objects are spatially aggregated. A value < 0 indicates that the space is negatively correlated and that the studied objects tend to be spatially discrete, and 0 means that Moran's I significance test cannot be passed, and that the studied objects are randomly distributed. Moran's I was calculated as follows:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} \quad \ldots(1)$$

where I represents the adjacent relation between the spatial positions i and j. X_i and X_j have cultivated land quality indices for units I and J, respectively. $\bar{x}$ is the average value of cultivated land quality index in the study area. When i and j meet the adjacent spatial relation, w_{ij} is assigned as 1. When i and j don't meet the adjacent spatial relation, w_{ij} is assigned a value of 0. w_{ij} w_{ij}

Local spatial autocorrelation analysis: Local spatial autocorrelation is mainly used to analyze the spatial position of agglomeration or dispersion of cultivated land quality in this article. Local Moran's I (LISA) is taken as the statistic to measure the degree of spatial difference between the spatial unit i and its adjacent units (Anselin 2010). $LISA_i$ was calculated using Eq (2).

$$LISA_i = \frac{(x_i - \bar{x})}{\sum_i (x_i - \bar{x})^2 / n} \sum_j w_{ij}\,(x_i - \bar{x}) \quad \ldots(2)$$

Here, $LISA_i$ is the local Moran's I of the ith cultivated land polygon. A positive $LISA_i$ indicates that the spatial unit is similar to the attribute value of a neighboring unit, and a negative $LISA_i$ value indicates that the attribute value of the spatial unit is different from that of a neighboring unit.

Ecological Security Zoning Method

Index system construction: Based on the principles of data accessibility, operability, and comprehensiveness, this study combined the actual situation of the study area to construct an ecological security index system (Table 2).

Relevant software and models were used to obtain all indicators. For example, the Biodiversity module in the InVEST model was used to obtain the habitat quality; ArcGIS10.2 and ENVI 5.3 were used to calculate the Normalized Difference Vegetation Index (NDVI) for vegetation coverage; landscape diversity, distance from roads, and landscape fragmentation were supplied by ArcGIS10.2.

Human interference is used to describe the overall intensity of human disturbance to the land ecological environment, it was calculated as follows:

$$HAI = \sum_{i=1}^{N} A_i P_i / TA \quad \ldots(3)$$

Table 2: Ecological security zoning construction index system in Haixing County.

Target layer	Constraint layer	Indicator layer
Comprehensive indicators of ecological security	Ecological stability index	Habitat quality
		Vegetation coverage
		Landscape diversity
	Ecological interference index	Human interference
		Distance from road
		Landscape fragmentation

Where *HAI* represents the synthetic index of human interference; N is the number of land types. A_i is the area of ecosystem type i; P_i is the intensity coefficient of anthropogenic influence reflected by the i^{th} ecosystem type. *TA* is the total area. This article uses Lohani list method, Leopold matrix method and Delphi method to determine the artificial influence intensity factor Pi.

Cumulative Correction Summation Method

When the ecosystem service functions of an ecological unit are diversified, the accumulation of multiple functions can promote the maximum comprehensive effect. Therefore, this study uses the cumulative correction summation method to calculate the comprehensive ecological security index and analyze the regional ecological security level. The calculation method is as follows:

$$EL = \max(Q,V,S,H,D,C) + (Q+V+S+H+D+C-\max(Q,V,S,H,D,C))/3 \quad \ldots(4)$$

where *EL* is the ecological security composite index; *Q* is the habitat quality index; *V* is the vegetation coverage index; *S* is the landscape diversity index; *H* is the man-made influence composite index; *D* is the distance from the road index; and *C* is the landscape fragmentation index.

Zoning Method for Construction Land Expansion

Construction land expansion "source": The "source" of construction land expansion, referred to as the construction source, reflects the core driving force of construction land expansion. The expansion of construction land was refined into the urbanization process of land. The administrative towns and village settlements were selected as the sources of construction land expansion.

Expansion of resistance surfaces: The resistance surface was constructed to analyze the limiting factors and driving factors in construction land expansion. This study selected slope, geological disaster, distance from the road, distance from the settlement, and land development cost as the main factors affecting construction land expansion, divided the classification standards, and provided different resistance values (Table 3).

Minimum cumulative resistance model: The minimum cumulative resistance (MCR) model was used to calculate the MCR value of construction land expansion, and the cumulative resistance value was classified according to the natural breakpoint classification to obtain the construction land expansion pattern. The MCR was calculated as follows:

$$MCR = f_{\min} \sum (D_{ij} \times R_i) \ (i=1, 2, 3...n, j=1, 2, 3...m) \quad \ldots(5)$$

where MCR is the minimum cumulative resistance of matter, energy, and phenomenon diffusing from the source point to a certain point in space, which is related to distance and cost; *f* is a monotonically increasing unknown function that maps the relationship between MCR and the variable ($D_{ij} \times R_i$) in direct proportion; D_{ij} represents the distance of a matter, energy, and phenomenon passing through unit *i* when moving from unit *i* to unit *j* in the path of motion after leaving the source; R_i represents the resistance coefficient of the *i*th element to a motion.

Table 3: Resistance value and weight of factors affecting construction land expansion.

Influencing factor	Resistance value				Weight
	10	20	50	100	
Slope	0^o–2^o	2^o–6^o	6^o–15^o	> 15^o	0.0691
Distance from geological disaster (m)	> 300	200~300	100~200	0~100	0.1265
Distance from road (m)	0~500	500~1000	1000~1500	> 1500	0.2474
Distance from settlement (m)	0~500	500~1000	1000~1500	> 1500	0.3176
Land development cost	Construction land	Cultivated land, Ditches, Grassland	Woodland, Garden land	Water area, Wetland, Unused land	0.2394

Note: Haixing County is a key area for flood control due to its special geographical location and climatic characteristics. The geological disaster was analyzed taking ponds facing the sea as the origin of the geological disaster buffer.

Research on Ecological Land Expansion

Ecological land source: The ecological land source is the most suitable land for ecological protection, with a strong ecological function and the least expansion resistance (Yu et al. 2009). Based on the land-use database, the overall land-use plan, and relevant research theories (Costanza et al. 1997, Xie et al. 2015), the extraction of ecological land sources was mainly selected by high-value areas of ecosystem services, such as nature reserves, water areas, wetlands, and centralized contiguous woodland with an area of > 3 hm^2.

Ecological land expansion model construction: (1) First, ArcGIS10.2, spatial analyst function, and options module were used to set the scope of the work content and the size of the unit, and then the convert tool was used to convert the map into a raster data format. Second, the raster calculator tool was used to calculate the cost surface. Third, the minimum resistance surface was obtained using a cost-weighted tool to generate the expansion partition of ecological land. Finally, the zoning of food security patterns, ecological security patterns, and construction land expansion patterns were taken as the resistance factors (Table 4).

(2) The ridge lines and valley lines were extracted using the hydrologic analysis method. The low-resistance valley lines that diverged from the ecological source to all directions were radiation channels. The ecological strategy point plays a key role in the flow of ecological materials and energy. It was a significant "springboard" between two adjacent ecological land sources.

RESULTS

Expansion of Ecological Land Source

The ecological land source area of Haixing County was 7976.93 hm^2, accounting for 9.19% of the total study area. As shown in Fig. 2, the ecological land sources were mainly distributed in the southeast of the county, mainly in the river system and woodland, while other ecological sources are scattered in each town and township.

Table 4: Ecological land expansion resistance value of each factor.

Resistance factor	Resistance value			
	10	20	50	100
Food security zone	Non-agricultural construction zone	Agricultural structure adjustment zone	Key promotion zone	Permanent protected zone
Ecological security zone	Low-security zone	Basic security zone	Medium security zone	Ideal security zone
Construction land expansion zone	Prohibited construction zone	Restricted construction zone	Construction buffer zone	Suitable construction zone

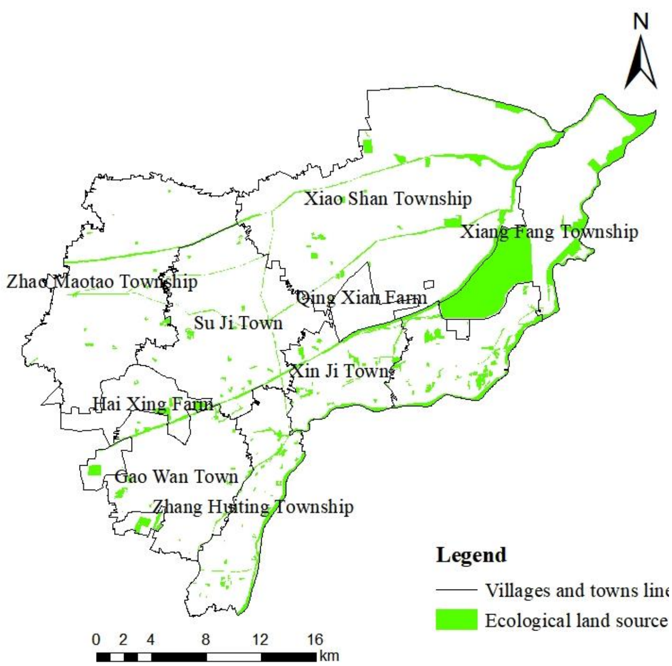

Fig. 2: Expansion of ecological land sources in Haixing County.

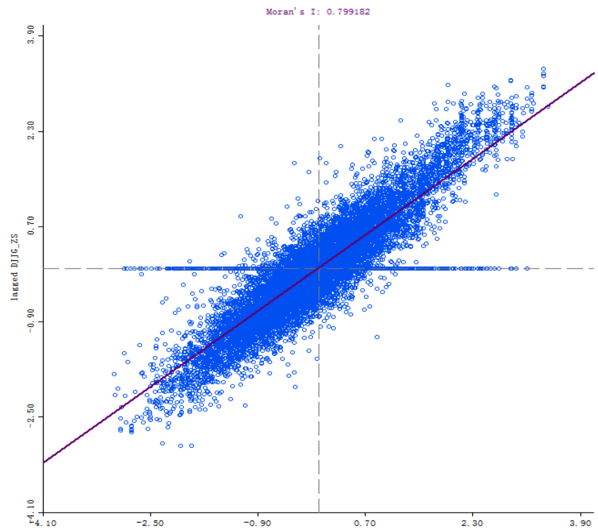

Fig. 3: Result of Moran's I.

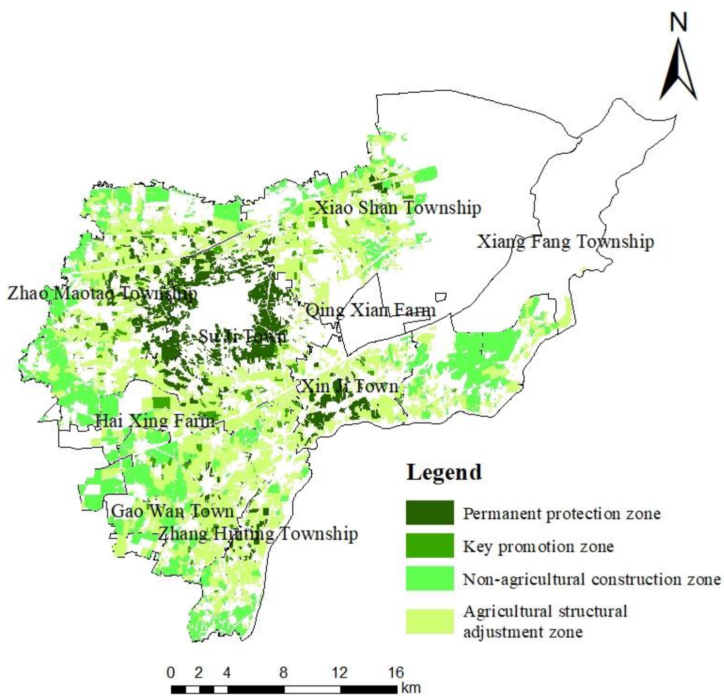

Fig. 4: Food security zone in Haixing County.

Table 5: Statistics of spatial autocorrelation types in Haixing County. HH – high value aggregation, LL – low value aggregation, HL – high low discrete distribution, LH – low high discrete distribution.

Autocorrelation type	HH type	LL type	HL type	LH type	Non-obvious type
Number	1889	2266	249	278	7734
Proportion (%)	15.21	18.25	2.01	2.24	62.29

Food Security Assessment

With the aid of the cultivated land quality classification index, based on global spatial autocorrelation analysis and the local spatial autocorrelation type and proportion (Fig. 3, Table 5), the autocorrelation type of cultivated land quality index was analyzed.

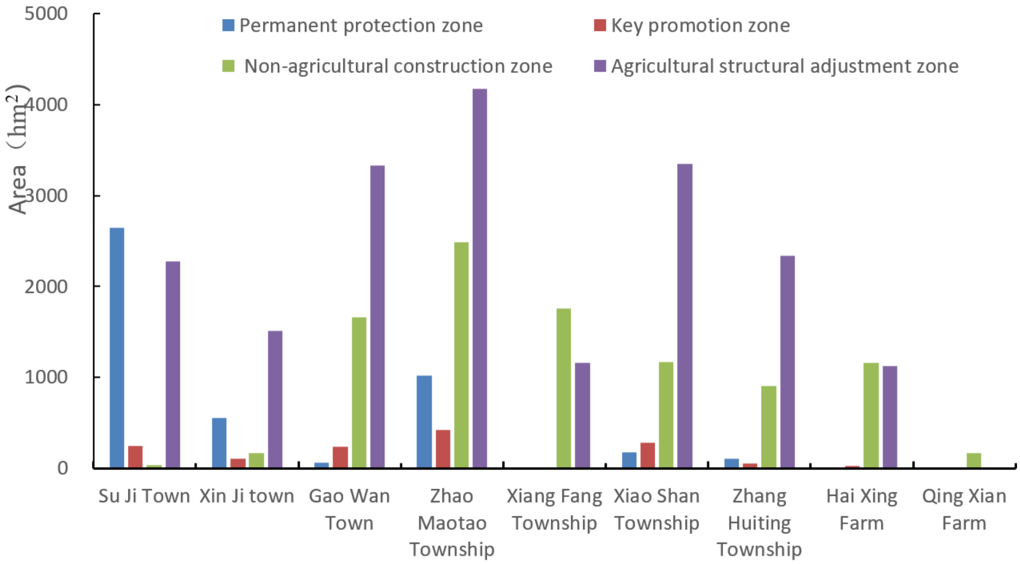

Fig. 5: Statistics on food security zone in each township in Haixing County.

Through the combination of all spatial autocorrelation types, Haixing County has developed a cultivated land protection zone to ensure food security. The HH type was classified as a permanent protection zone, the HL and LH types were classified as key promotion zone, the LL type was classified as a non-agricultural construction zone, and the non-sobvious was classified as an agricultural structural adjustment zone (Fig. 4 and Fig. 5).

(1) **Permanent protection zone:** This zone was mainly distributed in Su Ji Town. This region has better natural conditions, utilization level, and output benefits of cultivated land than the other three. Cultivated land with high quality accumulates and is distributed, and is an ideal area for the construction of high-standard basic farmland.

(2) **Key promotion zone:** This zone was mainly distributed in Zhao Maotao Township. The natural conditions and output benefits of this region were relatively good; however, the utilization and management levels of cultivated land were deficient. The utilization of cultivated land and the status of input and output can be improved through land consolidation projects.

(3) **Non-agricultural construction zone:** This zone was mainly distributed in Zhao Maotao Township and Xiang Fang Township. The natural conditions of cultivated land in this region were poor, the accessibility of roads was low, and the input-output of cultivated land was relatively poor. We can comprehensively adjust the distribution of cultivated land, garden land, woodland, and grassland based on food security and ecological land use patterns.

(4) Agricultural structural adjustment zone:

This zone was mainly distributed in Zhao Maotao Township and Gao Wan Town. The cultivated land quality had no obvious aggregation rules and a spatially random distribution. In order to improve the comprehensive quality of cultivated land, it is necessary to carry out the rotation and fallow experiments.

Ecological Security Assessment

The ecological security pattern of Haixing County can be divided into ideal security zones ($7 < EL$), medium security zones ($5 < EL \leq 7$), basic security zones ($3 < EL \leq 5$), and low-security zones ($1 \leq EL \leq 3$). The higher the level, the better the ecological safety (Table 6, Fig. 6 and Fig. 7).

(1) **Ideal security zone:** This zone was mainly distributed in the south of Xiang Fang Township and east of Zhang Huiting Township, as well as in a large area of woodland in the southwest of the study area. This area must be strictly protected, which is the basic guarantee for maintaining regional ecological security and ecosystem stability.

(2) Medium security zone: This zone was distributed across all regions except the Qing Xian farm. The ecological conditions in this area were good, and the

Table 6: Ecological security zone in Haixing County.

Ecological security zone	Ideal security zone	Medium security zone	Basic security zone	Low security zone
Area (hm^2)	6494.57	28965.10	29885.45	21480.71
Proportion (%)	7.48	33.36	34.42	24.74

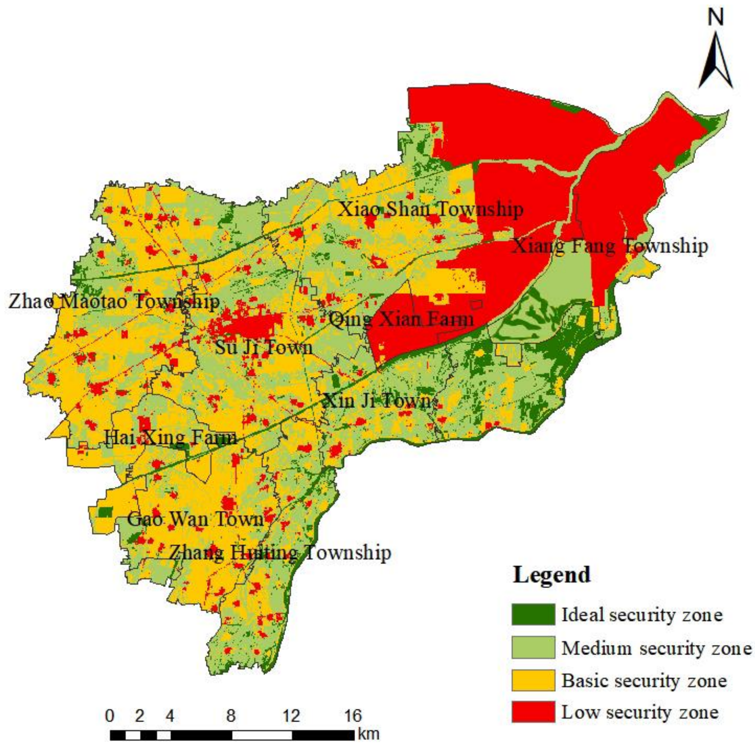

Fig. 6: Ecological security zone in Haixing County.

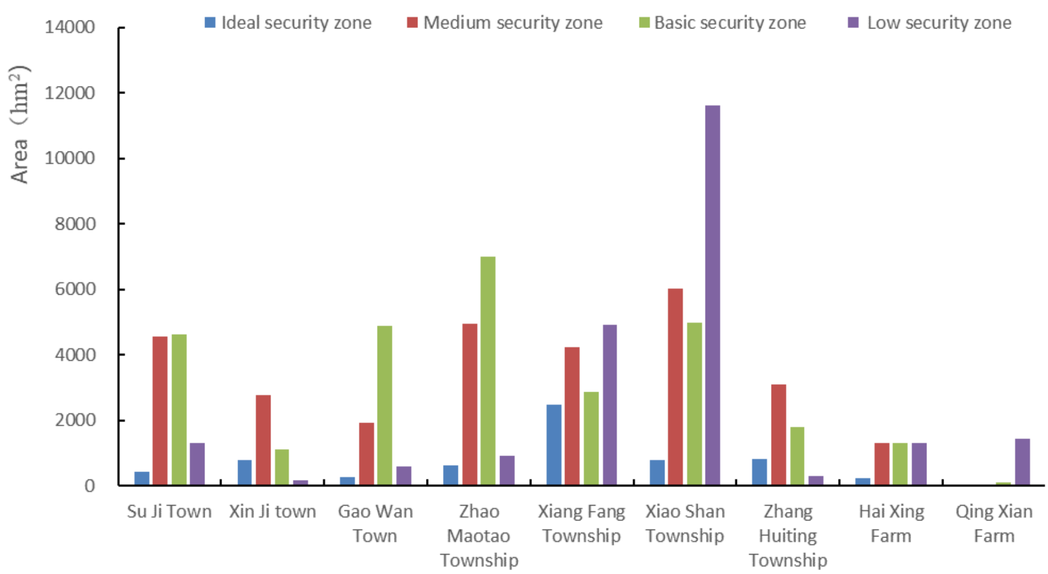

Fig. 7: Statistics on ecological security zone of each township in Haixing County.

balance of the ecosystem was maintained. The key point is to protect the ecological environment, and the development and construction activities that are harmful to the function of the ecosystem should be strictly prohibited.

(3) **Basic security zone:** This zone was a transition between medium and low security zones. This region was of great significance to the maintenance of basic ecological processes and played a buffer role in the

conflict between urban expansion and the ecological environment.

(4) **Low security zone:** This zone was mainly distributed in the northeast of the study area, with some scattered in other areas. This region is close to a human active area and is subject to a high degree of spatial stress from Haixing County's economic construction activities and urbanization process.

Construction Land Expansion Assessment

According to the natural breakpoint method, the cumulative resistance value was graded to obtain the pattern of construction land expansion, i.e., suitable construction, construction buffer, restricted construction, and prohibited construction zones (Table 7, Fig. 8 and Fig. 9).

(1) Suitable construction zone: The proportion of this zone was relatively high, and this zone was mainly distributed around the current construction land, with a trend of outward expansion from the center of the county. This area can carry out construction activities and is ideal for the expansion of construction land.

(2) Construction buffer zone: Based on the spatial proximity effect, the construction buffer zone was mainly distributed in the peripheral areas of the suitable construction zone, which was a buffer pattern to maintain and provide the demand for urban expansion. Industrial land and ecological land can be increased appropriately through a reasonable industrial layout to realize regional economic development and improve the level of ecological security.

(3) Restricted construction zone: Restricted construction zone occupied the smallest area and was close to the construction buffer zone. This area had great resistance and a high cost of construction land expansion; therefore, it was generally not selected as the development area of construction land.

(4) Construction zone: This zone was mainly distributed in the northeastern region of the county and the surrounding areas. The resistance to construction land expansion was high, and the spatial distribution was

Table 7: Construction land expansion in Haixing County.

Construction land expansion partition	Suitable construction zone	Construction buffer zone	Restricted construction zone	Prohibited construction zone
Area (hm^2)	32783.62	17972.56	16952.67	19116.98
Proportion (%)	37.76	20.70	19.52	22.02

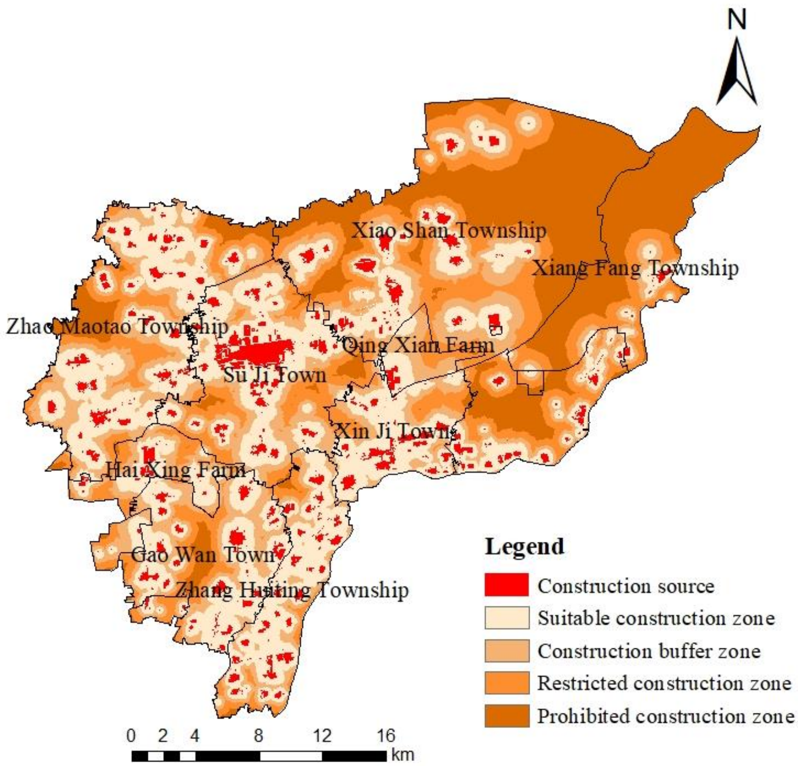

Fig. 8: Construction land expansion zone in Haixing County.

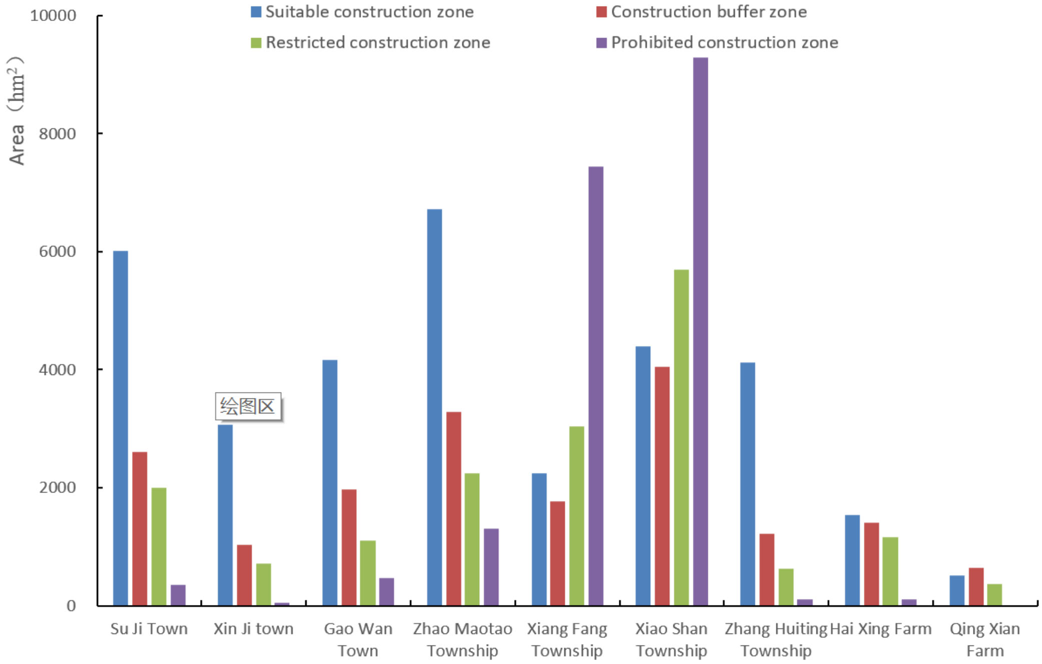

Fig. 9: Statistics on construction land expansion zone of each township in Haixing County.

a long distance from the source of urban expansion. Therefore, the development boundary of construction land should be delineated.

Comprehensive Evaluation

The natural breakpoint method was used to divide the calculation results into four levels. Using the hydrological analysis method in ArcGIS, the minimum cumulative resistance cost path was extracted, and the spatial locations of 15 major ecological corridors, 12 radiation channels, and 35 strategic nodes were then identified (Table 8, Fig. 10, Fig. 11 and Fig. 12).

(1) **Optimal expansion zone:** This zone was mainly distributed around the ecological source, mostly concentrated in Xiao Shan and Xiang Fang townships. The ecological conflicts caused by land degradation can be effectively alleviated by increasing the amount of ecological land and the intensity of ecological governance.

Table 8: Areas and proportions of ecological land expansion zones.

Extended type	Area (hm^2)	Proportion (%)
Optimal expansion zone	42087.30	48.47
Suitable expansion zone	26305.77	30.30
Extended adjustable zone	13591.20	15.65
Extended restricted zone	4841.57	5.58

(2) **Suitable expansion zone:** This zone was adjacent to the optimal expansion zone, in the southwest and south of the county. The ecological land that should be increased was mainly distributed in a banded or scattered manner around the existing ecological land, such as by appropriately increasing the number of banded ecological land areas around the cultivated land, building shelterbelts, etc.

(3) **Extended-adjustable zone:** Extended-adjustable zone was mainly distributed in the vicinity of a residential area and had a scattered distribution. By increasing the greening of relevant areas and carrying out ecological restoration and renovation, the sustainable development of regional ecological security can be achieved in a friendly direction to drive the ecological civilization construction of the entire region.

(4) **Extended restricted zone:** Extended restricted zone was mainly distributed in areas of basic cultivated land. To ensure food security, basic cultivated land was prohibited from being used for other purposes. However, green passageways can be added around the high-quality cultivated land, so that an ecological corridor maintaining ecological mobility was maintained, which can achieve the optimal result of cultivated land protection and an increase in ecological land.

(5) **Ecological corridors, radiation channels, and strategic nodes:** The ecological expansion corridor

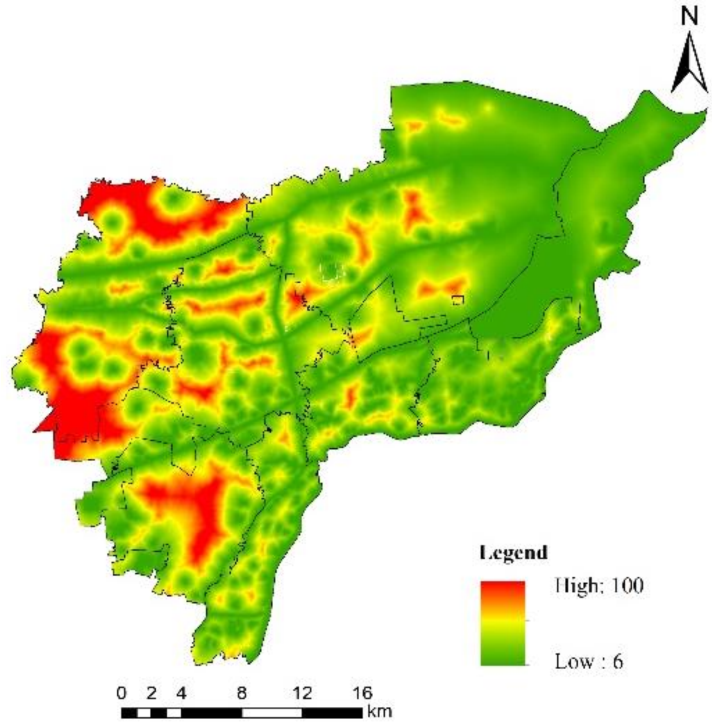

Fig. 10: The minimum comprehensive resistance surface.

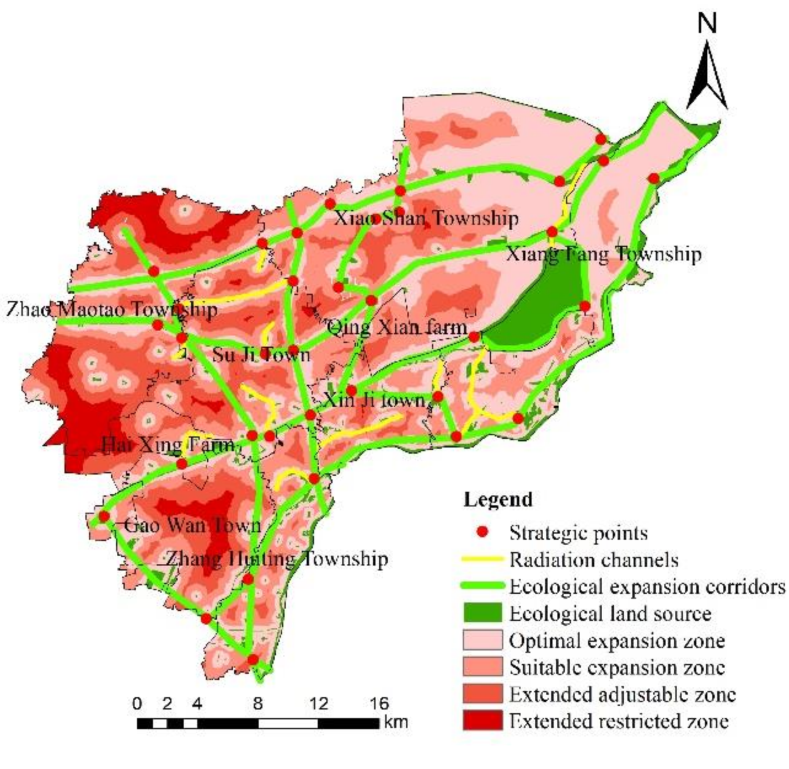

Fig. 11: Ecological land expansion pattern in Haixing County.

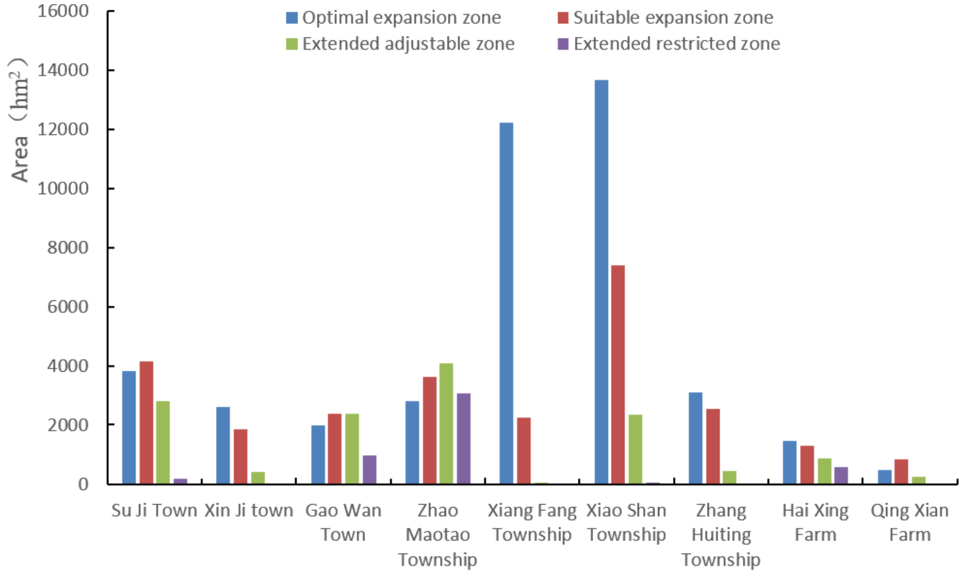

Fig. 12: Statistics on the ecological land expansion of each township in Haixing County.

was the most easily connected low-resistance channel between adjacent ecological sources (Wu et al. 2000). The radiation channel was the low-resistance valley line of radiation from an ecological source, and was a possible path for species diffusion. The strategic node was a significant "springboard" between two adjacent ecological sources. In short, ecological corridors, radiation channels, and strategic nodes cooperate to jointly promote the flow of material and energy in the ecosystem and maintain its healthy and sustainable development (Fig. 11 and Fig. 12).

DISCUSSION

Ecological Land Expansion

(1) The food security zone can be divided into four districts, among which the agricultural structural adjustment zone occupied the largest area, and the permanent protection zone occupied the same area as the non-agricultural construction zone. The key promotion zone occupied the smallest area and was mainly distributed in the buffer area in the central part of the county.

(2) The ecological security zone was divided into four districts, among which the ideal security zone occupied the smallest area and was mainly distributed in the northern part of the county. The medium security, basic security, and low security zones occupied the same area. The medium and basic security zones were cross-distributed in the county space, and the low security zone was mainly distributed in the northeast of the county.

(3) The expansion zone of construction land was divided into four districts, among which the proportion of suitable construction zones was relatively high. Each of the construction buffer zones restricted construction zones, and prohibited construction zones occupied approximately 20% of the study area, which can be regarded as multiple buffer zones suitable for the outward direction of the construction area.

(4) The expansion zone of ecological land consisted of four expansion areas, 15 ecological corridors, 12 radiation channels, and 35 strategic nodes. The area surrounding the ecological land source was mainly the optimal expansion zone. The suitable expansion zone was close to the optimal expansion zone, and the area that was suitable for an increase in ecological land was mainly distributed around the existing ecological land in a banded or scattered manner. In addition, the 15 ecological corridors were distributed in four horizontal and three vertical directions, promoting the flow of materials and energy in the natural ecosystem. The 12 radiation channels were the supplement of ecological corridors and the low-resistance routes of potential ecological land expansion. The 35 strategic nodes played a key role in the ecological land expansion.

Limitations and Implications

This study had several limitations. First, we only analyzed the current land-use situation in one year, and statically analyzed the ecological land development pattern at the county scale and failed to reveal the internal mechanism between different activities. Future research should involve identifying change processes at different scales and analyzing the internal relationships. By comprehensively considering climate, public security, and other factors, a more perfect evaluation system for land ecological-use pattern expansion will be established. The ecological land-use pattern is affected by many human factors such as land conversion cost, local ecological network, and different interest groups' demands (Liang et al. 2021). In future studies, optimization algorithms such as tradeoffs and synergies should be introduced into the expansion of land ecological use patterns, which will greatly improve the rationality of the research results.

Second, the limitations of the evaluation indices may affect the accuracy of the quantification results. For example, only six primary indices reflect ecological security pattern construction. Further studies are needed to integrate multiple evaluation indexes to obtain more accurate results.

Third, the limitations of the evaluation models may affect the accuracy of the quantification results. For example, using Analytic Hierarchy Process (AHP) to determine resistance factor weights is more objective, and the consistency of the judgment matrix is discussed. In the future, it is necessary to introduce other weight confirmation methods, such as Delphi and the fuzzy comprehensive evaluation method, and to use the highest-accuracy method.

CONCLUSIONS

Based on the perspective of ecological land security, this study used the MCR model, etc. to research Haixing County. First, woodland, grassland, garden land, water area, wetland, and unused land were determined as ecological land. Second, the cultivated land quality, ecological security level, and expansion direction of construction land were determined, and a three-in-one pattern of food security, ecological security, and expansion of construction land was established. Finally, the MCR model was used to determine the expansion of ecological land, which is mainly composed of four extension areas, 15 ecological corridors, 12 radiation channels, and 35 strategic nodes.

Although this study had some limitations, it provides an extended framework of ecological land expansion for decision-makers to clarify the concept of constructing ecological security patterns. This research will contribute towards solving the contradiction between the expansion of construction land and the protection of cultivated land and realizing the multiple protection of food security, ecological security, and economic development. This study provides not only guidance for local governments to improve ecological environment quality and achieve the goal of promoting sustainable development, but also the essential basis for rural revitalization strategy.

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