

Ecological Land Use Change and Security Pattern Construction in Haikou City: Postprint

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Abstract

During the urbanization process, changes in urban ecological land use and the construction of security patterns are of great significance to the health of urban ecosystems, the quality of life of urban residents, and sustainable urban development. Changes in ecological land use directly affect the evolution of ecological security patterns, while ecological land use security patterns, in turn, guide the planning of ecological land use. Based on GIS technology, this study investigates the spatiotemporal change process of ecological land use in Haikou City from 1991 to 2016, and further analyzes the evolution of ecological land use. Elevation, slope, and water resource security are selected as single factors influencing ecological security, and graded values are assigned to construct a comprehensive ecological land use distribution pattern. Using baseline ecological land use as the source, based on the Minimum Cumulative Resistance (MCR) model and using resistance thresholds as classification boundaries, ecological land use areas at different security levels are delineated, thereby determining inter-source ecological corridors, radiation paths, and strategic points to construct an ecological land use security pattern. The analysis results indicate that from 1991 to 2016, three types of ecological land use in Haikou City changed most significantly: forest land decreased by 13.33%, orchard land increased by 9.136%, and pond water surface increased by 3.71%. Ecological land use west of the Nandu River shifted from being dominated by forest land to being dominated by orchard land and construction land, while changes in other areas were relatively minor. Areas of ecological land use security change are concentrated in the western and eastern parts of Haikou City, where high-security level zones in the west have decreased, leading to a sharp deterioration in overall security levels, while high-security level zones in the east have slightly improved. Therefore, it is necessary to formulate and implement reasonable ecological land use protection policies, optimize and adjust the ecological land use pattern, in order to construct a feasible scheme for the coordinated development of the regional ecological environment.

Full Text

Ecological Land Use Change and Construction of Ecological Land Security Pattern in Haikou City

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Abstract

Urban ecological land use change and security pattern construction are of great significance for urban ecosystem health, residents' quality of life, and sustainable urban development. Ecological land use directly affects ecological security patterns, which in turn guide ecological land planning. Based on GIS technology, this study examines the spatiotemporal changes of ecological land in Haikou from 1991 to 2016 and analyzes its evolution. Height, slope, and water resource security were selected as single-factor indicators of ecological safety impact, graded and assigned values to construct a comprehensive ecological land distribution pattern. Using the minimum cumulative resistance (MCR) model with resistance thresholds as hierarchical boundaries, we delineated ecological land areas at different security levels, identified inter-source ecological corridors, radiation paths, and strategic points to construct an ecological land security pattern.

The results show that from 1991 to 2016, three types of ecological land in Haikou experienced the most significant changes: forest land decreased by 13.33%, garden land increased by 9.136%, and pond water surface increased by 3.71%. The ecological land west of the Nandu River transformed from predominantly forest to garden and construction land, while other areas changed less. The high-security level area in 1991 was much larger than in 2016, while the low-security area was smaller than in 2016, indicating a gradually deteriorating overall trend. Over the two years, the western and southern areas formed a circular arrangement of high, medium, and low security zones centered on two "sources," while along the Nandu River, high, medium, and low security areas were localized along the river corridor. In 2016, corridors were arranged in three rings distributed evenly throughout the city, but the relationship between sources weakened. Radiation paths remained irregularly distributed, while the number of strategic points decreased significantly compared to 1991, indicating increasingly serious ecological impacts and imbalances among components, with regional ecological safety stability being destroyed.

Areas of ecological land use change are concentrated in the western and eastern parts of Haikou City. The high-security area in western Haikou decreased, and the overall security level deteriorated rapidly, while the high-security area in the east improved slightly. Therefore, it is necessary to formulate and imple-

ment reasonable ecological protection policies and optimize land use patterns to provide a feasible scheme for coordinated development of the regional ecological environment.

Keywords: ecological land; minimum cumulative resistance model; security pattern; Haikou

Introduction

The “National Ecological Environmental Protection Outline” issued by the state does not specifically define ecological land but clearly points out its importance [1]. Numerous scholars have developed concepts and connotations of ecological land based on this foundation. Some perspectives advocate distinguishing ecological land from land types, considering all land providing natural ecosystem service values as ecological land, while others distinguish based on land’s primary functions, excluding agricultural production land with economic output as the core purpose [2]. Various methods exist for constructing ecological land security patterns. Rong Bingling et al. identified and extracted important ecological sources and key nodes, integrating water bodies and transportation buffer zones to construct an urban ecological land network space [3]. Zeng Zhaobing evaluated and optimized regional ecological land landscape patterns, establishing a comprehensive evaluation system for ecological land construction [4]. Li Xiaoli et al. conducted a comprehensive evaluation of ecological land construction status in Changsha and constructed ecological corridors using the minimum cost distance model [5]. Yu Kongjian et al. applied landscape security pattern theory and simulated Beijing’s future urban spatial expansion pattern [6], which can better reflect the intrinsic organic connections of ecological security patterns. Previous researchers have conducted detailed studies on Haikou’s land use type changes and analyzed ecological sources, corridors, and nodes, but no systematic scientific analysis has been conducted specifically on Haikou’s ecological land security patterns and corresponding spatiotemporal changes, nor have comprehensive factors been considered. Using landscape security pattern theory to delineate high, medium, and low security level areas, this paper further analyzes the changes in ecological land types and their driving forces between the two years, and finally examines the spatiotemporal changes in ecological land security patterns. This study represents an initial exploration of Haikou’s ecological land security pattern based on the minimum cumulative resistance model, providing a scientific basis for Haikou’s ecological security construction that can be applied to urban planning to maximize ecological benefits.

1. Study Area Overview

Haikou City is located in northern Hainan Island, bordering the Qiongzhou Strait to the north, Wenchang City to the east, and Ding’an County to the south. It has a tropical maritime monsoon climate. Geomorphologically, it is divided into northern coastal plain areas, central river terrace areas, and western lava plateau areas [7], covering 2,304.84 km². Vegetation is dominated by

shrubs and grasslands, with natural vegetation being common wild shrub and grass populations in tropical regions; urban areas are dominated by artificial vegetation [8]. As Hainan's political, cultural center and largest transportation hub, Haikou faces both opportunities and pressures from Hainan's International Tourism Island construction. The city's overall ecological environment is good, but rapid economic development and urban expansion have caused varying degrees of damage to local areas, making ecological security pattern construction crucial for Hainan's eco-tourism island development.

2. Data Sources and Processing

Based on Haikou's land use data from 1991 and 2016, this study selected forest land, garden land, grassland, and pond water surface as ecological land types. Unused land mainly includes wasteland and grassland with difficult transformation and small ecological functions [10]. Cultivated land requires continuous fertilization during production, causing serious negative ecological impacts, so this paper selected forest land, garden land, grassland, and pond water surface as Haikou's ecological land. Using land use data and Haikou's 1:10,000 core element map water systems, a single-factor index system was established based on literature review. A digital elevation model was generated from contour elements for single-factor analysis, and a comprehensive ecological land layout map was created through weighted overlay. The baseline ecological land from the comprehensive layout was selected as the "source." Literature review provided relative resistance coefficient tables for land cover types, and the MCR model was used to generate ecological land distribution maps for both years. Overlay analysis of the two maps quantitatively analyzed ecological land changes, and land use transfer matrices were exported using ArcGIS.

3. Analysis of Ecological Land Use Changes

3.1 Statistical Analysis of Ecological Land Distribution Statistical analysis of ecological land area for both years shows that forest land had the largest decrease (303.85 km², 13.33%), while garden land had the largest increase (207.44 km², 9.136%). Pond water surface increased in proportion among land use types (increase of 3.71%). Grassland decreased by 14.46 km² (0.13% decrease). The area proportion of pond water surface increased from 0.63% to 4.35%, mainly converted from cultivated land and unused land in northeastern Haikou.

Figure 1 [Figure 1: see original paper] Distribution of ecological land use in Haikou

3.2 Land Use Transfer Matrix and Change Area Analysis The land use transfer matrix reveals conversion areas between 1991 and 2016. In 1991, forest land was mainly distributed in northwestern Haikou, converting to other types primarily due to economic development. Garden land in 2016 was distributed in western, eastern, and southern Haikou, with the highest proportion among

ecological land types, dominated by orchards. This conversion is driven by both high orchard yields and the rise of orchard tourism. Forest land mainly converted to garden land and construction land due to market demand for fruit trees and rubber plantations, as well as urban expansion. The most significant changes occurred west of the Nandu River, where large areas of forest were converted to garden land.

Figure 2 [Figure 2: see original paper] Land use change in Haikou from 1991 to 2016

4. Construction of Ecological Land Security Pattern Based on MCR

Using ArcGIS spatial analysis functions, this study used baseline ecological land as the “source,” established buffer zones, and used the relationship curve between minimum cumulative resistance values and area to determine resistance thresholds for classification. Key strategic points were identified to complete the landscape security pattern construction, establishing ecological corridors between sources and radiation paths connecting sources to external areas, obtaining land use patterns at different security levels.

4.1 Determination of Impact Factors The “source” is the starting point and base for outward diffusion. Baseline ecological land serves as the ecosystem source, playing a critical role in maintaining life-land security and providing basic guarantees for sustainable development. Ecological land security pattern analysis should examine comprehensive water security patterns, geological disaster security patterns, and biological conservation security patterns [12]. Single-factor indicators were selected based on data stability and availability: height, slope, and water safety. Among these factors, slope has the greatest weight, while height has minimal impact in the model. A $30\text{m} \times 30\text{m}$ resolution grid was created from elevation points and contour data. Each factor’s ecological sensitivity was assigned values (extremely important, moderately important, generally important, and unimportant) based on literature [15-16], and weighted overlay analysis was conducted [17] to obtain four levels of ecological land importance.

4.2 Establishment of Resistance Surface The minimum cumulative resistance (MCR) model was used to establish the resistance surface [19-20]. The basic formula is:

$$MCR = f_{min} \sum_{j=1}^n (D_{ij} \times R_i)$$

where f_{min} is an unknown positive function, D_{ij} is the spatial distance from source j to a point through landscape i , and R_i is the resistance of landscape i to species movement. The minimum cumulative resistance from all sources

to a point measures its accessibility. Model calculations used the ArcGIS cost-distance module. Resistance coefficients from literature were added to the land cover vector layer' s value attribute and converted to raster format.

Figure 5 [Figure 5: see original paper] Resistance coefficient of land use type in Haikou

4.3 Identification of Radiation Paths Based on the resistance surface, low-resistance valley lines radiating outward from sources can be identified, typically dendritic in shape. The process borrows from hydrological analysis tools for extracting river networks, applying them to the ecological resistance surface to extract low-resistance channels for ecological flow diffusion.

4.4 Determination of Strategic Points On the resistance surface map, strategic points appear as tangent points of resistance contour lines centered on adjacent sources, representing resistance valleys between sources that are critical for ecological flow control and inter-source connectivity [22-23].

4.5 Establishment and Comparison of Security Patterns Baseline ecological land was used as the ecological protection source. Using ArcGIS cost-distance methods [24] and the natural breaks classification method [25], which groups pixels based on clustering characteristics, we processed the two years' ecological security pattern raster data through raster calculator intersection to obtain change area maps. The natural breaks method follows natural clustering patterns. By calculating area changes and comparing the two years' security pattern maps, we identified change characteristics and proposed targeted planning measures.

5. Results and Analysis

5.1 Ecological Land Security Pattern Construction Calculating the area of each level after integrating three indicators reveals that baseline ecological land is the bottom line that cannot be crossed and requires key protection. Buffer ecological land is distributed in transition zones around baseline land, also requiring protection [26-27]. Ideal ecological land is farthest from baseline land and most vulnerable to urban construction encroachment.

Figure 3 [Figure 3: see original paper] Survey of comprehensive ecological land use in Haikou in 2016

Figure 4 [Figure 4: see original paper] "Source" areas

Using 1991 and 2016 resistance coefficient data, buffer zones and radiation paths were constructed. The security patterns show circular distributions around sources at different security levels. In 1991, low-security ecological land accounted for 12.4% of Haikou' s area, concentrated in the west and south, while medium and high-security land accounted for 76.2%. In 2016, low-security land

increased to 13.5%, mainly in western and central areas in closed or semi-closed rings, while medium and high-security land accounted for 77.7%, primarily east of the Nandu River. High-security areas served as buffers for core protected areas.

Figure 6 [Figure 6: see original paper] The ecological map of ecological land in Haikou

5.2 Security Pattern Change Analysis Overlay analysis of the two years' security patterns shows that changed areas account for 52.33% of the total region, while unchanged areas account for only 47.67%. Low-security land increased by 173.96 km² and 25.47 km² respectively. The overall trend shows high-security land decreasing and low-security land increasing, with rapid deterioration. Change areas are concentrated in central and eastern regions, while western areas show conversion from high-security to other levels. Eastern high-security areas slightly improved, while central areas changed minimally. These trends are primarily human-driven, with topography also influencing outcomes. The western lava plateau has fragile ecology where large forest areas are difficult to restore. The eastern plateau benefits from windward slopes, abundant precipitation, and policy support, maintaining relatively stable security levels.

Figure 7 [Figure 7: see original paper] Area map of ecological security pattern change in Haikou from 1991 to 2016

6. Discussion

Previous research focused on ecological suitability evaluation of agricultural and construction land or overall urban landscape pattern optimization in Haikou. This study centers on ecological land, analyzing its change drivers and directions to construct patterns ensuring functional performance. While some researchers used MCR models for landscape security patterns, they replaced radiation paths with ecological corridors, generating multiple corridors and nodes beneficial for global urban landscape research but without focusing on the highest ecological value land. This paper emphasizes ecological land security patterns, establishing key protected corridors and strategic points for precise urban ecological security protection. However, limitations exist in single-factor selection, and future research should incorporate socio-economic levels and environmental pollution factors for more comprehensive multi-factor security pattern construction. Specific optimization networks and protection schemes require further design.

7. Conclusion

Using the minimum cumulative resistance model and single-factor resistance coefficients, this study scientifically analyzed and constructed Haikou's ecological land security pattern, considering landscape connectivity and multiple overlay effects. The main conclusions are:

1. Forest land showed the largest decrease (13.33%), garden land the largest increase (9.136%), and pond water surface increased in proportion (3.71%). The most significant changes occurred in western Haikou, where large areas were converted to garden land for economic benefits.
2. In 1991, the high-security area was much larger than in 2016, while the low-security area was smaller, showing a gradually deteriorating trend. Both years featured two main “sources” in the west and south, with security zones arranged circularly around them. In 2016, corridors formed three rings distributed evenly, but inter-source connections weakened. Radiation paths remained irregularly distributed, and strategic points decreased significantly, indicating increasingly serious ecological impacts and destroyed ecological safety stability.
3. The areas requiring urgent protection are mainly in western Haikou. Planning measures should counteract the growth of low-security zones. Based on the identified corridors and strategic points, additional corridors (mainly greenways) should be reasonably added to strengthen connections between urban ecological components. Construction should be prohibited near strategic points while strengthening ecological construction. Low-security ecological land should be strictly controlled, while medium and high-security land should be designated as restricted construction zones. Other land can be optimized through diversified ecological space construction, allowing the same area to provide greater ecological benefits and enabling coordinated environmental and economic development.

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Note: Figure translations are in progress. See original paper for figures.

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