Spatiotemporal Differentiation of Ecological Risk in the Process of Ecological Migration in the Central Arid Zone of Ningxia: A Case Study of Hongsibu District (Postprint)

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Date: 2018-10-23T00:00:00+00:00

Abstract

The ecological migration process is characterized by large-scale and concentrated features, which produce the most direct changes to land use in resettlement areas and theoretically pose explicit or potential ecological risks. Taking Hongsibu District, Ningxia—the largest concentrated ecological poverty alleviation resettlement area in China—as an example, and based on three-phase remote sensing data from 1995, 2005, and 2015, this study comprehensively employs landscape pattern indices, ecological risk indices, and spatial analysis methods to construct an ecological risk index, and utilizes ArcGIS spatial analysis functions to analyze the spatiotemporal variation characteristics of ecological risks in the study area. The results indicate that: between 1995 and 2015, the landscape pattern in the resettlement area underwent substantial changes, with grassland area decreasing by 29,744.04 hm^2, while cultivated land, forest land, water area, and construction land increased by 18,979.73 hm^2, 4,167.3436 hm^2, 672.1933 hm^2, and 4,314.2806 hm^2, respectively; sandy land and unused land experienced considerable changes in magnitude, yet their initial and final areas showed little variation. The spatial distribution of landscape ecological risk in the study area changed significantly, exhibiting a shift from concentrated contiguous distribution to a scattered multi-core regional pattern. High-risk areas were primarily distributed in the northeastern corner of Liuquan Township, the western foothills of Xiaoluoshan, and the central and southwestern parts of Dahe Township; relatively high-risk areas were widely distributed in the northern part of the resettlement area and the central-western regions of Dahe Township; relatively low-risk and low-risk areas were mainly distributed in the vicinity of Luoshan, southeastern Liuquan Township, southwestern Taiyangshan Town, and southern Hongsibu Town. During the study period, the area of high ecological risk zones in the resettlement area decreased substantially, while the areas of relatively high-risk

and low ecological risk zones continued to increase, indicating an overall weakening trend in ecological risk. The ecological risk values in the resettlement area demonstrated significant positive spatial autocorrelation, with spatial clustering effects present, suggesting a close relationship between the spatiotemporal distribution of ecological risk and human activities as well as land use intensity.

Full Text

Abstract

The ecological migration process is characterized by its scale and concentration, producing the most direct changes to land use in resettlement areas and theoretically posing explicit or potential ecological risks. Taking Hongsibu District in central Ningxia Province—the largest ecological poverty alleviation and migration area in China—as an example, this study analyzes the temporal and spatial characteristics of ecological risk in the study area based on remotely sensed data from 1995, 2005, and 2015. Using landscape pattern indices, ecological risk indices, and spatial analysis methods, we constructed an ecological risk index. The results showed that the landscape pattern of the resettlement area changed significantly from 1995 to 2015: grassland area decreased by 29744.04 hm^2, while cultivated land, forest land, water area, and construction land increased by 18979.73 hm^2, 4167.3436 hm^2, 672.1933 hm^2, and 4314.2806 hm^2, respectively. Although the change range of sandy land and unused land during the research period was quite large, the total area of the study region changed little. The spatial distribution pattern of landscape ecological risk in the study area changed obviously, showing a shift from concentrated contiguous distribution to scattered multi-nuclear distribution. High-risk areas are mainly distributed in the northeastern corner of Liuquan Township, the western foothills of Xiaoluoshan Mountain, and the central-western parts of Dahe Township. Higher-risk areas are distributed in the northern part of the resettlement area and the central and western regions of Dahe Township. Low and lower-risk areas are mainly distributed in the surrounding areas of Luoshan Mountain, southeast of Liuquan Township, southwest of Sunjia Beach, and the southern part of Hongsibu Town. During the study period, the conversion rate between different risk area types in Hongsibu Ecological Resettlement Area was rapid, with the area of high ecological risk decreasing significantly while the areas of higher-risk, low-risk, and lower-risk areas continued to increase, indicating an overall weakening of risk. The ecological risk values in the resettlement area show significant spatial positive correlation, with significant spatial agglomeration effects, indicating that the spatio-temporal distribution of ecological risk in the resettlement area is closely related to human activities and land use intensity.

Keywords: ecological migration process; ecological risk; landscape pattern index; spatio-temporal differentiation; Hongsibu District

1 Introduction

Ecological migration, as an important strategy for coordinating regional development and ecological environmental protection, has been widely implemented in ecologically fragile areas of China. The process is characterized by large-scale population relocation and concentrated settlement, which directly alters land use patterns in destination areas and potentially generates ecological risks. Understanding the spatio-temporal evolution of these risks is crucial for sustainable land management and policy optimization.

2 Materials and Methods

2.1 Study Area

Hongsibu District, located in central Ningxia, represents China' s largest ecological poverty alleviation resettlement area. The region' s unique geographical setting and intensive land use changes following migration make it an ideal case for examining ecological risk dynamics.

2.2 Data Sources

Remote sensing data from three time points (1995, 2005, and 2015) were used to analyze land use/cover changes. The data were processed using ArcGIS and related spatial analysis tools to extract landscape pattern information.

2.3 Methods

2.3.1 Landscape Pattern Index Calculation Landscape pattern indices were calculated to quantify structural changes in land use. The formula for LISA (Local Indicators of Spatial Association) is:

$$LISA = \frac{\sum (x_i - \bar{x})^2}{n} + \frac{\sum w_{ij}(x_j - \bar{x})^2}{n} \quad (i \neq j)$$

where x_i and x_j represent the ecological risk values of spatial units i and j, $\bar{x}$ is the mean ecological risk value, and w_{ij} is the spatial weight matrix. A positive LISA value indicates spatial clustering of similar high or low values (high-high or low-low), while a negative value indicates spatial outliers (high-low or low-high).

2.3.2 Ecological Risk Index Construction The ecological risk index was constructed based on landscape pattern metrics and land use intensity. The risk levels were classified into five categories: low, lower, medium, higher, and high risk.

2.3.3 Spatial Autocorrelation Analysis Moran' s I was used to assess spatial autocorrelation of ecological risk values. The analysis revealed significant positive spatial correlation, indicating clustering of similar risk levels.

3 Results

3.1 Landscape Pattern Changes

From 1995 to 2015, the landscape pattern of Hongsibu Resettlement Area underwent substantial transformation. Grassland area decreased by 29744.04 hm^2, while cultivated land, forest land, water bodies, and construction land increased by 18979.73 hm^2, 4167.3436 hm^2, 672.1933 hm^2, and 4314.2806 hm^2, respectively. These changes reflect the intensification of agricultural development and urban construction associated with resettlement activities.

3.2 Spatial Distribution of Ecological Risk

The spatial distribution of ecological risk shifted dramatically from a concentrated contiguous pattern to a dispersed multi-nuclear pattern. High-risk areas were predominantly located in the northeastern corner of Liuquan Township, the western foothills of Xiaoluoshan, and the central-western regions of Dahe Township. Higher-risk areas were found in the northern resettlement zone and central-western Dahe Township. Low and lower-risk areas were concentrated around Luoshan Mountain, southeastern Liuquan Township, southwestern Sunjia Beach, and southern Hongsibu Town.

3.3 Risk Level Transitions

During the study period, conversion rates between different risk levels were rapid. The area of high ecological risk decreased significantly, while the areas of higher-risk, low-risk, and lower-risk zones increased continuously. This trend suggests an overall reduction in ecological risk severity across the region.

3.4 Spatial Clustering Characteristics

The LISA analysis identified distinct spatial clusters: high-high (H-H) clusters in areas with intense land use change, low-low (L-L) clusters in stable natural landscapes, and high-low (H-L) and low-high (L-H) outliers at transition zones. The Moran' s I scatter plot confirmed significant spatial autocorrelation, with risk values showing clear agglomeration effects.

[Figure 3: see original paper]

[Figure 4: see original paper]

[Figure 5: see original paper]

4 Discussion

The ecological risk dynamics in Hongsibu District demonstrate clear linkages between human resettlement activities and landscape changes. The reduction in high-risk areas coupled with the expansion of lower-risk zones indicates improved ecological management and land use optimization over time. However,

the persistent spatial clustering of risk suggests that targeted interventions are needed in specific high-risk nuclei.

The significant positive spatial correlation of ecological risk values confirms that risk distribution is not random but closely associated with the intensity and pattern of human land use. This finding underscores the importance of spatially explicit planning in ecological resettlement programs.

5 Conclusions

1. From 1995 to 2015, Hongsibu District experienced significant landscape pattern changes, with grassland decreasing by 29744.04 hm^2 and cultivated land, forest land, water area, and construction land increasing accordingly.
2. The spatial distribution of ecological risk transformed from concentrated contiguous to scattered multi-nuclear patterns, with high-risk areas concentrated in specific townships and low-risk areas in surrounding natural landscapes.
3. Rapid conversion occurred between different risk levels, with high-risk areas decreasing significantly while higher-risk, low-risk, and lower-risk areas increased, indicating overall risk reduction.
4. Significant spatial positive correlation and agglomeration effects in ecological risk distribution highlight the close relationship between risk patterns and human activity intensity.

These findings provide scientific basis for optimizing land use planning and implementing targeted ecological restoration in resettlement areas.

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