Ecological Risk Assessment of Ecological Migration Resettlement Areas Based on Landscape Structure: A Case Study of Hongsibu District, Ningxia (Postprint)

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Abstract

Taking Hongsibu District, Ningxia Hui Autonomous Region as a case study, this research utilized remote sensing images from five periods (1995, 2000, 2005, 2010, and 2015) as data sources, and comprehensively applied multiple research methods including landscape pattern indices, ecological risk index, spatial analysis, and geographical detector to investigate the spatiotemporal characteristics of ecological risk in resettlement areas. The results indicate that from 1995 to 2015, the landscape pattern in the study area underwent substantial changes: grassland area decreased by 2.97×10 hm^2, while cropland, forestland, and construction land increased by 1.90×10 hm^2, 0.42×10 hm^2, and 0.43×10 hm^2, respectively. During the study period, the total number of landscape patches continuously increased, leading to greater overall landscape fragmentation. The ecological risk in the study area was dominated by relatively low and medium risk levels, with construction land, sandy land, and unused land exhibiting relatively high ecological risk values. The average ecological risk value decreased from 0.166 to 0.154 during the study period, indicating a declining trend in ecological risk. Diagnosis via geographical detector revealed that factors including number of landscape patches, landscape fragmentation, landscape dominance, landscape loss degree, and patch density constitute the main influencing factors of ecological risk in the resettlement area.

Full Text

Preamble

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Ecological Risk Assessment of an Ecological Migrant Resettlement Region Based on Landscape Structure: A Case Study of Hongsibu in Ningxia

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Abstract

Taking Hongsibu District in Ningxia Autonomous Region as a case study, this research utilized remote sensing images from 1995, 2000, 2005, 2010, and 2015 as data sources. Landscape pattern indices, ecological risk indices, spatial analysis, and geographic detectors were employed to investigate the spatiotemporal characteristics of ecological risk in the resettlement area. The results revealed that the landscape pattern of the study area changed substantially from 1995 to 2015. Grassland area decreased by 2.97×10, while cultivated land, forest land, and construction land increased by 1.90×10, 0.42×10, and 0.43×10, respectively. During the study period, the total number of landscape patches increased continuously, leading to greater overall landscape fragmentation. The ecological risk of the study area was dominated by low and medium risk levels, with construction land, sandy land, and unused land exhibiting high ecological risk. The average ecological risk decreased from 0.166 to 0.154, indicating a declining trend in ecological risk values. Geographic detector analysis identified landscape patch number, landscape fragmentation degree, landscape dominance degree, landscape loss degree, and patch density as the primary influencing factors of ecological risk in the resettlement area.

Keywords: ecological migration resettlement area; landscape pattern index; ecological risk index; geographic detector; Hongsibu District

Introduction

Ecological migration differs from environmental migration, project migration, and climate migration, and its connotation aligns with China' s concept of poverty alleviation through relocation. It refers to the process of relocating impoverished populations from ecologically fragile areas, important ecological function zones, regions with severe environmental degradation, and areas with harsh natural conditions that have lost basic living conditions. This process holds dual significance for ecological protection in source areas and poverty reduction. Theoretically, ecological migration transfers ecological pressure from source areas to resettlement areas, potentially causing varying degrees of disturbance or damage to the ecosystems of receiving areas.

International research on ecological migration primarily focuses on reflections on the legitimacy of ecological migration, land and environmental issues, and cultural changes and conflicts. Domestic research in China, however, concentrates on livelihood assessments of ecological migrants, resettlement model construction, environmental capacity, environmental benefits, driving mechanisms of ecological impacts, farmer satisfaction in resettlement areas, land use changes, and resource optimization allocation. Notably, studies on ecological risk assessment in ecological migration resettlement areas remain scarce.

Ecological risk assessment has emerged and developed as a new research field alongside shifts in environmental management objectives and concepts. Its evolution has progressed from environmental risk assessment to ecological risk assessment and then to regional ecological risk assessment. Risk sources have expanded from single to multiple sources, and risk receptors have developed from single to multiple receptors, with evaluation scales extending from local to regional landscape levels. Research primarily employs methods such as modeling, entropy valuation, and response methods, combined with remote sensing and GIS technologies, to conduct risk source identification, hazard characterization, and exposure-effect measurement in watersheds, mining areas, and nature reserves, thereby formulating corresponding management models. International ecological risk assessment focuses on new research and explorations regarding regional land use, with development trending toward large-scale, multi-level, and computer-aided analysis, particularly through the application of multi-level models and statistical tools. China' s ecological risk assessment research started relatively late, focusing mainly on introducing foreign basic theories, with key research areas concentrated on establishing evaluation indicator systems and standards, regional ecological risk assessment, landscape ecological risk assessment, watershed ecological risk assessment, and GIS technology applications. Although still developing, these increasingly sophisticated theories and methods provide robust scientific support for ecological risk assessment.

The national plan for poverty alleviation through relocation aims to address situations where "local resources cannot support local populations." Using Hongsibu District—the largest concentrated ecological poverty alleviation resettlement area in China—as an example, this study adopts widely recognized ecological risk assessment methods and technologies to evaluate ecological risks in the resettlement area. The objective is to provide theoretical and technical support for regional ecological security and environmental management during the ecological migration process.

1. Study Area

Hongsibu District is located in the central arid zone of Ningxia (105°43 –106°42 E, 37°28 –37°37 N), within an intermontane basin area and the geographical center of Ningxia. The terrain slopes from high in the south to low in the north, with elevations ranging from 1240–1450 m. The region has a typical temperate continental climate with an average annual temperature of 8.4°C, average frost-free period of 155 days, and annual sunshine duration of 3036.4 hours. Precipitation is low, concentrated, and varies significantly between years, with an average of 277 mm.

In 1995, the Hongsibu Development Zone Working Committee of the Chinese Communist Party was established. In 1999, the region became a key area for the national water conservancy project "1236" (Ningxia Poverty Alleviation Yellow River Irrigation Project). In 2009, Wuzhong City Hongsibu District was officially established. The district primarily resettles migrants from Tongxin, Haiyuan, and Xiji counties, with 19 town communities and poverty alleviation relocation households. The total area is 2767 km², and by 2015, the Hui population accounted for 62.3% of the total population.

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2. Data Sources and Processing

Remote sensing images from 1995, 2000, 2005, 2010, and 2015 served as data sources. With support from remote sensing software, images underwent geometric correction, image registration, and comprehensive processing. Based on the national land resource classification system and combined with local land use characteristics, the study area was classified into cultivated land, forest land, grassland, water bodies, construction land, sandy land, and unused land. Human-computer interactive interpretation and field sampling verification were conducted, with sample separability exceeding 0.85 and Kappa coefficients greater than 0.88, meeting interpretation accuracy requirements. Landscape pattern vector maps for the five periods were generated, and ecological risk indices were established based on these landscape types. Using spatial analysis in geostatistics, the study produced spatial distribution maps of ecological risk indices to analyze dynamic changes in ecological risk spatial characteristics.

[Figure 1: see original paper] Geographical location of study area

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3. Analysis Methods

3.1 Division of Ecological Risk Zones

To spatialize ecological risk indices and considering the study area scope and workload, the region was divided into 3 km × 3 km risk zones using systematic sampling with equal intervals, based on the average landscape patch area. The comprehensive ecological risk of various landscape types within each risk zone was calculated to represent the ecological risk level at the zone' s center point.

[Figure 2: see original paper] Division of the ecological risk area

3.2 Construction of Landscape Ecological Risk Index

The magnitude of ecological risk depends on the intensity of external disturbances to regional ecosystems and their internal resistance capacity. Different landscape types vary in their roles in protecting species, maintaining biodiversity, improving overall structure and function, and promoting natural succession. Their resistance to external disturbances also differs. The study converted vector maps to raster format and used landscape pattern analysis software Fragstats 3.4 to calculate landscape characteristic parameters at both landscape and class levels. The landscape loss index was constructed by superimposing landscape pattern indices to reflect the degree of natural attribute loss of ecosystem receptors under human disturbance. This study selected landscape fragmentation index, landscape separation index, landscape dominance index, and landscape vulnerability index to construct a comprehensive ecological risk index.

3.2.1 Landscape Disturbance Index The landscape disturbance index reflects the degree of external disturbance to ecosystems represented by different landscape types. Greater disturbance corresponds to greater ecological risk. Drawing on relevant literature, the landscape disturbance index is obtained through weighted superposition of landscape fragmentation (Ci), separation (Ni), and dominance indices. The calculation methods and significance are shown in Table 1.

Calculation of landscape pattern index

Where:
- ni = number of patches of landscape type i
- Ai = area of landscape type i
- A = total landscape area
- Qi = number of quadrats where patch appears
- Mi = number of patches
- $a,\ b,\ c$ = weights for fragmentation, separation, and dominance, respectively, with $a + b + c = 1$. Based on references and expert opinion, weights of 0.5, 0.3, and 0.2 were assigned.

3.2.2 Landscape Vulnerability Index Different landscape types exhibit varying capacities for maintaining biodiversity, improving overall landscape structure and function, and promoting natural succession. Their resistance to external disturbance also differs. Greater vulnerability corresponds to greater ecological risk. This difference relates to succession stages—ecosystems in early succession with simple food web structures and low biodiversity indices are more vulnerable to external disturbance. Human activity is a major disturbance factor, and land use types represent the combined effects of anthropogenic and natural factors on landscape structure. Based on the study area' s actual conditions and existing research, vulnerability grades were assigned to land use types and normalized to obtain vulnerability indices (*Ei*), ranked from high to low as: unused land > sandy land > construction land > water bodies > grassland > cultivated land > forest land.

3.2.3 Landscape Loss Index The landscape loss index (*Ri*) reflects the degree of natural attribute loss of ecosystems under natural and human disturbances, expressed as:

$$\mathbf{Ri = Si \times Ei}$$

where *Si* is the landscape disturbance index and *Ei* is the landscape vulnerability index.

3.2.4 Landscape Ecological Risk Index The ecological risk index describes the relative magnitude of comprehensive ecological loss within a sample plot, facilitating the transformation of landscape spatial structure through sampling methods:

$$\mathbf{ERIi = \Sigma(Ri \times Aki) \ / \ Ak}$$

where *ERIi* is the landscape ecological risk index of risk zone *i*, *Ri* is the landscape loss index of class *i*, *Aki* is the area of landscape type *k* in risk zone *i*, and *Ak* is the total area of risk zone *i*.

3.3 Spatial Analysis Method

To investigate landscape spatial regularity and hierarchical structure in comprehensive ecological risk analysis, geostatistical variogram methods were employed. Semivariogram functions were fitted to theoretical variogram models for intuitive description and spatial structure analysis of ecological risk distribution. Based on systematic sampling of ecological risk, interpolation methods were used to compile ecological risk level maps, revealing spatiotemporal patterns in Hongsibu resettlement area. The calculation formula is:

$$\mathbf{(h) = (1/2N(h)) \ \Sigma[Z(xi) - Z(xi + h)]^2}$$

where *(h)* is the variogram, *h* is the lag distance (spatial interval), *N(h)* is the number of sample pairs at interval *h*, and *Z(xi)* and *Z(xi + h)* are observed ecological risk index values at spatial positions *xi* and *xi + h*.

3.4 Geographic Detector Mechanism Analysis

Spatial distribution differences of geographic phenomena are profoundly influenced by socioeconomic or natural factors. The geographic detector method, initially applied to detect causes of endemic diseases, was used to analyze driving mechanisms. The model is:

U = 1 - (Σni ²UiD) / (n ²U)

where U is the detection power indicator of ecological risk influencing factors (range [0,1]), n is the total sample number, m is the number of subregions, ni is the sample number in subregion i, ^2U is the variance of ecological risk for the entire region, and ^2UiD is the variance of subregion i. A larger U value indicates stronger influence of partitioning factors on resettlement area ecological risk.

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4. Results

4.1 Land Use Changes in the Resettlement Area

Land use type area proportions revealed that grassland dominated the landscape from 1995-2015, accounting for 68.3%, 58.8%, 58.8%, 58.6%, and 57.8% of total landscape area, showing a 逐年递减 (year-by-year decreasing) trend. Cultivated land proportion increased from 25.5% to 32.5% then decreased to 27.2%, with a clear growth trend during 2005-2015 reaching 32.5% in 2015. Construction land showed a small proportion but significant increase. Land use change rates reflect the magnitude of land resource quantity changes. During 1995-2015, grassland area change rate was negative, while other land use types showed positive rates, with forest land and construction land exhibiting the highest change rates. Sandy land showed positive change rates, indicating area increase, while unused land change rates fluctuated dramatically, and cultivated land change rates increased gradually.

Land use type/cover change in Hongsibu resettlement area from 1995 to 2015

4.2 Landscape Pattern Index Analysis

Using Fragstats 3.4 software and Excel 2007, landscape indices for each type were calculated for 1995, 2000, 2005, 2010, and 2015. Significant land use type changes occurred during 1995-2015. Throughout the study period, patch numbers increased and overall fragmentation intensified. The landscape was dominated by grassland and cultivated land, which were widely distributed despite substantial area changes. Cultivated land patch numbers increased while separation degree decreased and dominance increased. Forest land area rose continuously with increasing dominance and decreasing separation, significantly impacting landscape patterns. Construction land showed substantial area increases. Grassland patch numbers increased markedly, with separation degree showing initial decline followed by increase. Fragmentation indices increased continuously due to area changes, deepening fragmentation. Spatial distribution shifted from large contiguous blocks to small scattered patches.

Landscape pattern indices of Hongsibu from 1995 to 2015

4.3 Landscape Ecological Risk Index by Land Use Type

The overall ecological risk index in Hongsibu resettlement area showed small variation amplitudes. The change rate of ecological risk values decreased during 2000-2005, 2005-2010, and 2010-2015, with period contributions of 19.72%, 14.91%, 1.61%, and 1.58% to total change. Among land use types, grassland contributed most to the ecological risk index (7.7%). Grassland ecological risk values showed a slight decreasing trend, while sandy land and unused land showed initial increase then decrease. Average ecological risk index values ranked as: grassland > cultivated land > forest land > construction land > sandy land > unused land > water bodies, indicating that grassland occupation and fragmentation posed the greatest potential ecological risk to Hongsibu' s ecological environment and socioeconomic development. Construction land risk showed an increasing trend.

Ecological risk index of different land use patterns in Hongsibu resettlement area, 1995-2015

4.4 Spatial Analysis of Ecological Risk

Comprehensive ecological risk indices were calculated for each risk zone and interpolated using Kriging in ArcGIS. Risk levels were classified as: minimum risk (0.0065 ERI 0.0114), lower risk (0.0114 ERI 0.0163), medium risk (0.0163 ERI 0.0213), higher risk (0.0213 ERI 0.0262), and highest risk (0.0262 ERI 0.0311). The spherical model was used for variogram fitting.

[Figure 3: see original paper] Spatial distribution of ecological risk in Hongsibu resettlement area

Ecological risk changed significantly in the resettlement area, dominated by lower, medium, and higher risk zones, transitioning from higher to medium levels with overall improvement. Spatially, highest and higher risk zones gradually shifted southward, shrinking from large northern areas to smaller southern patches with continuously decreasing area. Medium risk zones were mainly distributed in Hongsibu Town, Liuquan Township, and Dahe Township. Lower risk zones were primarily in Xinzhuangji Township, increasing from 22,435 hm² to 52,051 hm² (proportion rising to 27.4%). Minimum risk zones in eastern Xinzhuangji Township increased by 13,475 hm² (47.5%).

Ecological risk level area by Kriging interpolation

Dynamic conversions occurred between risk levels. Lower risk area showed fluctuating increase then decrease, but net increase over the study period. The fluctuation mainly resulted from construction land expansion and transportation networks fragmenting grassland. Higher and highest risk areas showed fluctuating decline, while minimum risk area increased continuously. During 1995-2000, minimum and lower risk proportions increased while medium and higher risk decreased. During 2000-2005, low-medium risk dominated, with decreased medium risk and increased minimum, lower, and higher risk proportions. During 2005-2010, minimum, lower, and medium risk proportions increased while higher risk decreased. During 2010-2015, minimum, lower, and medium risk proportions increased while higher risk decreased, indicating overall ecological risk reduction.

4.5 Dominant Factors of Ecological Risk

Regional landscape ecological risk is influenced by multiple factors. This study selected 12 landscape indices reflecting pattern changes for detection analysis. Using the geographic detector model, landscape indices were classified and partitioned to calculate each index' s influence on land ecological security. Results showed that from 1995-2015, regional landscape ecological risk formation was primarily affected by landscape patch number, total patch area, fragmentation index, landscape separation index, landscape dominance index, landscape interference index, landscape vulnerability index, landscape loss index, degree of conjugation, degree of polymerization, scatter-tied indicators, maximum patch ratio, patch density, and landscape shape indicators.

Determination of ecological risk influencing factors

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5. Discussion and Conclusion

The degree and status of ecological risk in resettlement areas are crucial for sustainable ecological migration development. Quantifying this risk is a core issue. Based on remote sensing data and supported by ARCGIS software, this study used landscape pattern indices to construct a comprehensive ecological risk index, analyzing land use types, landscape structure changes, and spatiotemporal ecological risk variations in Hongsibu resettlement area. The main conclusions are:

1. Grassland and cultivated land were the dominant landscapes. Significant land use changes occurred during 1995-2015, with widespread conversions between types and remarkable landscape pattern changes. Grassland showed the largest area reduction, primarily due to resettlement construction and human activities occupying extensive grassland areas.

2. Cultivated land area increased initially but decreased after 2005 due to the Grain-for-Green policy, then slowly grew after 2010, reaching 32.5% of total area in 2015. Forest land showed gradual growth throughout the study period, mainly for ecological protection and resettlement development needs, with the establishment of Luoshan Nature Reserve contributing to annual increases. Water area increases were mainly due to reservoir construction for production and living needs (29,744 hm^2). Construction land increases resulted from housing, roads, and public service expansion.

Sandy land and unused land areas remained similar at the study' s beginning and end but fluctuated significantly during the period.

3. Land use changes altered landscape patterns. Overall patch numbers increased annually, intensifying fragmentation. Grassland area decreased while construction land increased. Cultivated land fragmentation and disturbance indices increased, enlarging the loss index and indicating enhanced disturbance and loss. The Grain-for-Green policy effectively protected forest land, increasing its area, patch number, and dominance index. Construction land showed substantial area increases, continuously increasing patch numbers and dominance while decreasing separation, significantly impacting landscape patterns.

4. Comparing the five-period comprehensive ecological risk area proportion changes and spatial distribution maps revealed large spatial variations, generally diffusing outward from Luoshan as the center. All risk level areas changed: minimum risk area proportions increased while other levels decreased during 1995–2000; low-medium risk dominated during 2000–2005 with decreased medium risk; minimum, lower, and medium risk proportions increased during 2005–2010; minimum, lower, and medium risk proportions increased during 2010–2015 while higher risk decreased, demonstrating overall ecological risk reduction.

5. Geographic detector analysis identified landscape patch number, fragmentation degree, dominance degree, loss degree, and patch density as main influencing factors. The constructed ecological risk values, based on landscape pattern indices, evaluate relative rather than absolute ecological risk. However, landscape pattern changes inevitably alter ecological risk, and multi-temporal landscape structure information combined with spatial statistics can quantitatively describe relative landscape ecological risk degrees, revealing spatial distribution characteristics and dynamic changes.

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