Eco-environmental Effects and Differentiation Mechanism of Land Use Transition in the Manas River Basin: A Postprint Based on the Perspective of Dominant Function Discrimination in "Production-Living-Ecological" Space

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Abstract

The Manas River Basin, an important oasis agricultural region in Xinjiang with a fragile ecological environment, serves as a critical area where investigating land use transition and its eco-environmental effects holds significant importance for territorial spatial optimization and sustainable township development. Based on the dominant functions of "production-living-ecological" space, this study analyzes the functional transition of land use and evolution of eco-environmental effects in the Manas River Basin, and explores the differentiation mechanism of eco-environmental effects in this region. The results indicate that: (1) From 2010 to 2020, the basin primarily witnessed the conversion of ecological space into production and living spaces. (2) The overall eco-environmental quality index decreased from 0.29 to 0.27, with negative eco-environmental impacts from agricultural production space encroaching on ecological space gradually intensifying. (3) Terrain and climate factors are the dominant drivers of eco-environmental effect changes in the Manas River Basin; interactions among these factors collectively drive land use transition in the basin, resulting in a complex spatial pattern of eco-environmental quality.

Full Text

Eco-environmental Effects and Differentiation Mechanism of Land Use Transition in Manas River Basin: A Perspective Based on the Dominant Function of "Production-Living-Ecological" Spaces

Abstract: As a significant oasis agricultural region in Xinjiang, the Manas River Basin possesses a fragile ecological environment. Investigating land use transition and its eco-environmental effects holds great significance for optimizing territorial space and promoting sustainable development at the township level in this region. Based on the dominant function classification of "production-living-ecological" spaces, this study analyzes the functional transformation of land use and the evolution of eco-environmental effects in the Manas River Basin, while exploring the differentiation mechanisms of regional eco-environmental impacts. The results indicate that: (1) From 2010 to 2020, the primary land use change in the Manas River Basin involved the conversion of ecological space into production and living spaces. (2) The overall eco-environmental quality index of the Manas River Basin decreased from 0.29 to 0.27, with the negative environmental impacts of agricultural production space encroaching upon ecological space gradually intensifying. (3) Topographic and climatic factors constitute the dominant drivers of eco-environmental effect variation in the basin, and the interactions among these factors jointly drive land use transformation, resulting in a complex pattern of eco-environmental quality across the Manas River Basin.

Keywords: "production-living-ecological" spaces; land use transformation; eco-environmental effects; spatial differentiation; Manas River Basin

Introduction

With China's rapid socio-economic development and urbanization, conflicts among production, living, and ecological spaces have intensified, triggering profound land use transitions and spatial restructuring across regions. Land use transition represents a dynamic process that evolves with economic and social demands, involving the quantitative and spatial reallocation and redistribution of land resources across production, living, and ecological functions at different stages. As a new entry point for territorial space research, land use transition has become a hot topic, focusing primarily on theoretical frameworks, driving mechanisms, and optimization of urban-rural territorial spaces. Studies have shown that land use transition is closely associated with regional environmental factors such as climate, precipitation, and vegetation cover, directly affecting regional ecosystem balance. Effectively measuring the characteristics of regional land use transition and quantifying its impacts on eco-environmental quality is crucial for regional sustainable development.

The eco-environmental effects of land use transition serve not only as key indicators for measuring regional land use levels but also as important factors for exploring how to maximize economic value with minimal resource input and environmental costs. Research focus has gradually expanded from single-element environmental effects to comprehensive regional studies. As China's territorial space development shifts toward coordinated development among production, living, and ecological functions, research perspectives have also transitioned from land use conflicts to "production-living-ecological" coordination. Examining regional land use transition and ecological effects through the lens of "production-living-ecological" spaces enables more accurate understanding of how land use transformation impacts the ecological environment. The mechanism by which land use transition drives spatial differentiation of eco-environmental effects has become a recent research hotspot. The optimal parameter geographic detector can objectively reveal the driving effects of external influencing factors on eco-environmental effects, providing a new research method for exploring differentiation mechanisms. Existing studies have covered provincial, urban agglomeration, and district-county scales, but research on township-level eco-environmental effects at micro scales remains limited.

The Manas River Basin, located in the arid region of Central Asia, represents Xinjiang's largest oasis farming area and a high-yield crop production region nationwide. In recent years, rapid economic development and urbanization have driven continuous expansion of artificial oases toward desert margins, with living and production spaces gradually encroaching upon ecological space and altering regional land use structure. The basin faces ecological challenges including farmland salinization, forest and grassland degradation, and land desertification, with severe degradation in some ecological function zones. Therefore, this study analyzes land use transition in the Manas River Basin based on the dominant function of "production-living-ecological" spaces, explores the evolution of basin eco-environmental effects, and investigates the differentiation mechanisms of eco-environmental impacts, aiming to provide recommendations for territorial space optimization and regional eco-environmental construction in the Manas River Basin.

1.2 Data Sources

This study covers the Manas River Basin in Xinjiang. Land use data for 2010 and 2020, annual precipitation data for 2020, population density data for 2020, and vegetation coverage data were obtained from the Resources and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn) at a resolution of 30 m. DEM data were sourced from Geospatial Data Cloud (https://www.gscloud.cn/) at a resolution of 30 m. Topographic relief data were obtained from the Global Change Data Repository (https://www.geodoi.ac.cn) at a resolution of 1 km. River network density data for 2020 were sourced from the Science Data Bank (https://www.scidb.cn/) at a resolution of 1 km. All indicators were converted to the same spatial resolution and projection using ArcGIS.

1.3 Research Methods

1.3.1 Construction of "Production-Living-Ecological" Space Evaluation System

At different stages of regional development, land use functions vary according to different development purposes and intensities. Based on existing research and considering primary and secondary functional differences, this study constructs a "production-living-ecological" space evaluation system to classify land use types in the Manas River Basin (Table 1). The system enables analysis of functional transitions among "production-living-ecological" space types and their increases or decreases. The land use transition matrix is constructed as follows:

$$S_{ij} = \begin{pmatrix} s_{11} & \cdots & s_{1n} \\ \vdots & \ddots & \vdots \\ s_{n1} & \cdots & s_{nn} \end{pmatrix}$$

where S_{ij} represents the area converted from space type i to space type j (km^2), and n is the number of space types.

1.3.3 Eco-environmental Quality Index

Based on the relationship between "production-living-ecological" space types and eco-environmental quality, the regional eco-environmental effect is calculated as:

$$E_t = \sum_{i=1}^{n} \left(\frac{V_i \times A_{it}}{TA} \right) \times 100\%$$

where E_t and E_{t+1} represent the eco-environmental quality in periods t and $t+1$, respectively; V_i is the eco-environmental quality value corresponding to space type i; A_{it} is the area of space type i in period t (km^2); and R is the rate of eco-environmental quality change. According to the study area scope and related research, 11 space scales were selected to generate 11 eco-environmental quality indices.

1.3.4 Ecological Contribution Rate

The ecological contribution rate of land use transition is calculated to analyze changes in regional ecological effects caused by land use transformation:

$$C = \frac{(V_i - V_j) \times LA_{ij}}{TA} \times 100\%$$

where C is the ecological contribution rate; LA_{ij} is the area transformed from "production-living-ecological" space type i to type j (km^2); and TA is the total area of the study region (km^2).

1.3.5 Optimal Parameter Geographic Detector Model

In conventional geographic detector models, the discretization method and spatial scale for continuous data are typically set subjectively, often leading to suboptimal discretization. In contrast, the optimal parameter geographic detector model enhances result accuracy by exploring optimal solutions for spatial scale, discretization method, and classification number. The q value is commonly used to measure the influence of driving factors on the spatial distribution of dependent variables, with a range of [0, 1]. Natural and social factors jointly influence the eco-environmental quality of oasis areas in arid regions. Drawing on relevant research and considering study area characteristics, this study selects 11 influencing factors for optimal parameter geographic detector analysis: average elevation (X_1) and topographic relief (X_2) representing topographic factors; GDP per unit area (X_3) and population density (X_4) representing social factors; average temperature (X_5), annual precipitation (X_6), vegetation coverage (X_7), and river network density (X_8) representing natural environmental factors; and land development intensity (X_9), forestland area change (X_{10}), and cropland area change (X_{11}) representing land use factors. The larger the q value, the greater the influence of natural and social factors on eco-environmental quality.

2.1 Land Use Transition in Manas River Basin

2.1.1 Spatiotemporal Evolution of "Production-Living-Ecological" Spaces

From 2010 to 2020, land use changes in the Manas River Basin were active, with the proportion of production and living spaces continuously increasing while ecological space proportion gradually decreased (Figure 2). Specifically: (1) Agricultural production space showed the largest area change, expanding significantly by 2114.35 km^2, mainly concentrated in central townships with flat terrain and abundant water resources suitable for cultivation. (2) Urban living space increased most rapidly, expanding by 56.56 km^2, with living space area increasing annually and radiating outward near cropland areas. Rural living space increased slightly, scattered in a point-like pattern within agricultural production spaces. (3) Ecological space occupies the dominant position in the Manas River Basin, with the largest area change. However, significant differences exist among townships: edge-area townships are dominated by ecological space that varies with altitude; industrial and mining production space increased from 0.02% to 0.30%, mainly distributed at the junctions of Shihezi City, Manas County, and Shawan City, such as Lanzhouwan Town and Beiquan Town.

2.1.2 Characteristics of "Production-Living-Ecological" Space Transition

Analysis of "production-living-ecological" space transition reveals that from 2010 to 2020, ecological function conversion to production function dominated, becoming more pronounced after 2015 (Figure 3). Specifically, from 2010 to

2015, ecological function converted to production function over an area of 51.47 km^2, while from 2015 to 2020, this conversion covered 2200.23 km^2, primarily occurring in the central plain region. The second major transition involved ecological function converting to living function, covering 518.74 km^2 and scattered at the edges of township residential land. Production function converting to living function mainly occurred at urban peripheries. Except for townships surrounding urban areas such as Shihezi Township, Sandaohezi Town, Hankazitan Kazakh Ethnic Township, and Corps 152nd Regiment, where production space converted to living space, other townships predominantly experienced ecological function converting to production function.

2.2 Eco-environmental Effects of "Production-Living-Ecological" Space Transition

2.2.1 Eco-environmental Quality of "Production-Living-Ecological" Space Transition

From 2010 to 2020, the overall eco-environmental quality index of the Manas River Basin decreased from 0.29 to 0.27, showing a gradual deterioration trend (Figure 4). Spatially, northern townships exhibited lower eco-environmental quality due to larger proportions of Gobi desert and sandy land, while southern townships with higher altitudes and forest and ice-covered areas showed higher eco-environmental quality indices. As urbanization progressed and demand for living and production spaces increased, urban living space expanded outward. Townships surrounding urban areas such as Shihezi Township and Beiquan Town experienced eco-environmental deterioration. In contrast, townships like Corps 121st Regiment and 133rd Regiment saw improved eco-environmental quality due to increasing cropland area. Southern townships experienced minimal change. Analysis of eco-environmental quality change rates (Figure 5) reveals complex changes across townships: central townships deteriorated due to increased infrastructure and agricultural facility land; northern desert-edge townships improved with expanding cropland area, such as Corps 121st Regiment and 150th Regiment; Boertonggu Ranch and Qingshuihezi Kazakh Ethnic Township experienced some eco-environmental impacts from tourism and animal husbandry development; Sandaohezi Town's forest park enhanced local eco-environmental quality; and Corps 143rd Regiment's agricultural eco-tourism zone construction improved its eco-environmental quality.

2.2.2 Ecological Contribution Rate of "Production-Living-Ecological" Space Transition

Table 2 shows that conversion from other ecological spaces to agricultural production space represents the primary land use transition type contributing to eco-environmental improvement in the Manas River Basin, accounting for 41.609% of the total contribution. Conversion from water and green ecological spaces to other ecological spaces is the main type causing eco-environmental deterioration. Overall, the ecological contribution rate of "production-living-ecological" space transition in the Manas River Basin is negative, indicating gradual eco-environmental deterioration.

2.3 Differentiation Mechanism of Eco-environmental Effects

2.3.1 Optimal Parameter Identification

The driving degree of various factors shows strong dependence on spatial scale. By analyzing the q values of driving factors at different spatial scales, the optimal spatial scale is identified when the q value reaches its maximum. As shown in Figure 6, the q value is maximized at spatial scales of 1-5 km, indicating that this range can effectively reflect the influence of factors on eco-environmental quality. Different discretization methods and classification numbers also significantly affect the driving mechanism. For land use intensity, the q value reaches its maximum when using quantile classification with 5 intervals, making this the optimal discretization choice. Other influencing factors are similarly discretized optimally based on the principle of maximizing q values.

2.3.2 Analysis of Driving Factors

Single-factor detection results (Table 3) show that all factors have P values less than 0.01, indicating significant influence. The q values of average elevation (X_1), topographic relief (X_2), annual precipitation (X_6), and average temperature (X_5) are greater than 0.3, demonstrating that topographic and climatic factors are the dominant drivers of eco-environmental effect differentiation in the Manas River Basin. Interaction detection results (Figure 8) reveal synergistic enhancement effects among factors. The interaction contribution between average elevation and other factors exceeds 0.5, indicating that average elevation is the core factor influencing eco-environmental effect differentiation in the basin.

2.3.3 Spatial Differentiation Mechanism

Analysis indicates that topographic and climatic factors dominate the differentiation of eco-environmental effects in the Manas River Basin. GDP per unit area, population density, and land development intensity serve as core factors that, together with vegetation coverage, river network density, cropland area change, and forestland area change, jointly drive "production-living-ecological" space transformation, thereby altering eco-environmental quality. The northern basin region features gentle terrain and low elevation, dominated by Gobi desert with scarce precipitation and low eco-environmental quality indices. The southern region has steep terrain with forestland and ice-covered areas as the main land types, resulting in high eco-environmental quality indices. With the implementation of rural revitalization strategies, increasing land development intensity and expanding living space demands drive land use transitions, forming a differentiated eco-environmental quality pattern. Population density and GDP per unit area directly influence township development needs, while benefits from agricultural modernization drive industrial structure diversification, affecting the direction of "production-living-ecological" space transformation across townships and creating a complex eco-environmental quality pattern in the Manas River Basin.

Discussion and Conclusion

This study reveals that from 2010 to 2020, "production-living-ecological" spaces in the Manas River Basin changed significantly, primarily through conversion from ecological space to production and living spaces. Agricultural production space expanded most substantially by 2114.35 km^2. The overall eco-environmental quality index decreased from 0.29 to 0.27. While increased agricultural production space in the northern region and large-scale crop cultivation in the central region improved eco-environmental quality, the negative environmental impacts of agricultural production space encroaching on ecological space gradually intensified.

Topographic and climatic factors are the dominant drivers of eco-environmental effect differentiation in the Manas River Basin. GDP per unit area, population density, and land development intensity are core factors that interact with vegetation coverage, river network density, cropland area change, and forestland area change to drive "production-living-ecological" space transformation and alter eco-environmental quality.

The 20th National Congress of the Communist Party of China proposes new requirements for territorial space development, advocating for the formation of three spatial patterns—urbanization areas, major agricultural product zones, and ecological function zones—to achieve complementary and coordinated development across different functional spaces. As the Manas River Basin embraces new opportunities from the Belt and Road Initiative, it should adhere to the concept that "mountains, rivers, forests, farmlands, lakes, and grasslands form a community of life" and prioritize ecological security. Specifically, planning should focus on: (1) protecting ecological land in the northern ecological barrier zone and constructing protective forest belts in the south to improve land degradation; (2) using water resources as a constraint to rationally plan cropland scale and coordinate agricultural economic development with eco-environmental protection; and (3) vigorously improving urban-rural living space and infrastructure to promote a sustainable development path featuring sound ecology, productive development, and prosperous living in the Manas River Basin.

Township systems in the study area have relatively weak adaptive cycle capacity, and their eco-environmental development exhibits greater complexity and uncertainty. Some townships have long been trapped in pathological conditions, but due to space limitations, this study does not specifically analyze the reasons.

Future research will combine field investigations to provide deeper analysis and references for sustainable development of desert oases at micro scales.

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