Land Use Transition Based on "Three-Life" Functions and Its Eco-environmental Effects: A Case Study of Yuli County (Postprint)

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Abstract

To explore the land use function transformation and its ecological environmental effects in Yuli County, this study utilized TM imagery data from four periods (1993, 2001, 2009, and 2017) to interpret and obtain land use change data. Following the "production-living-ecological" function classification, quantitative analyses were conducted on the quantitative changes in land use functions, land use function transformation, and its induced ecological environmental effects in Yuli County through methods including the area-weighted method, land use transition matrix, and ecological environmental quality index. The results show that: (1) From 1993 to 2017, production land and living land continuously increased, while ecological land decreased overall; in land use function transformation, pasture ecological land had the largest transferred area, followed by other ecological land, and urban living land had the smallest transferred area. (2) The ecological environmental quality index of Yuli County decreased from 0.07629 in 1993 to 0.06378 in 2001, then continuously increased to 0.07339 in 2017; the overall ecological environmental quality deteriorated, but was in a state of gradual recovery and improvement. (3) The transformation from other ecological land to wetland ecological land and pasture ecological land was the main cause of ecological environmental quality improvement; conversely, the occupation of pasture ecological land by other ecological land and agricultural production land was the main cause of ecological environmental quality deterioration. Overall, over the past 25 a, trends of both ecological environmental deterioration and improvement coexisted in Yuli County, but the improvement trend was greater than the deterioration trend.

Full Text

Land Use Transformation Based on Production-Living-Ecological Functions and Associated Eco-Environmental Effects: A Case Study in Yuli County

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Abstract: To explore land use function transformation and its eco-environmental effects in Yuli County, this study utilized remote sensing imagery data to obtain land use change information. Following the production-living-ecological ("three functions") classification system, we quantitatively analyzed the quantitative changes in land use functions, land use function transformation, and the resulting eco-environmental effects in Yuli County through methods including area-weighted calculation, land use transfer matrix, and eco-environmental quality index. The results indicate: (1) From 1993 to 2017, production land and living land continued to increase, while ecological land decreased overall. Among land use function transformations, grassland ecological land showed the largest transferred area, followed by other ecological lands, with urban living land showing the smallest transferred area. (2) The eco-environmental quality index of Yuli County decreased from 0.07629 in 1993 to 0.06378 in 2001, then continuously increased to 0.07339 in 2017. Overall, the ecological environment quality deteriorated but has entered a state of gradual recovery and improvement. (3) The transfer of other ecological lands to wetland ecological land and grassland ecological land was the primary reason for ecological environment quality improvement. Conversely, the occupation of grassland ecological land by other ecological lands and agricultural production land was the main cause of ecological environment quality deterioration. Overall, during the past 25 years, Yuli County has experienced coexisting trends of ecological environment deterioration and improvement, but the improvement trend has been stronger than the deterioration trend.

Keywords: production-living-ecological function; land use transformation; eco-environmental effect; Yuli County

Introduction

The report of the 18th National Congress of the Communist Party of China formally proposed the development goal of "intensive and efficient production space, livable and moderate living space, and beautiful ecological space," establishing the important position of the three functional spaces (production, living, and ecological, collectively termed "three functions") in achieving rational allocation of land resources, ecological civilization construction, and sustainable development. This has made the coordinated development of "three functions" an important measure for promoting the construction of a beautiful China in the new era. The transformation of land functions is both a driving factor and manifestation of land use transformation, and land use function transformation has profound impacts on regional ecosystem function and structure transformation processes. Studying the eco-environmental effects of land use function transformation is an important approach to understanding regional eco-environmental quality status and predicting its change trends. Current research on land use transformation mainly involves theoretical foundations and frameworks, characteristic analysis, spatiotemporal evolution processes, driving mechanisms, and regional differences. The three functional spaces of production, living, and ecological encompass direct and indirect production, satisfaction of spiritual, cultural, recreational, and aesthetic needs, as well as biophysical processes. These are products of the synergistic coupling of natural and socio-economic systems, and they often transform mutually through land use transition.

The concept of land use transition was first proposed by Grainger of the University of Leeds in his study of forest transition. After Long Hualou introduced this concept to China, it became a new research hotspot and frontier in land use/cover change (LUCC) studies. President Xi Jinping pointed out in the report of the 19th National Congress that "building a beautiful China requires firmly establishing a socialist ecological civilization perspective, focusing on solving prominent environmental problems, and implementing comprehensive management of basin environments and coastal waters." In arid regions, land resource utilization and the ecological environment interact and change synergistically, forming an intertwined support system. The ecological environment issues in the Tarim River Basin are a major ecological hotspot in Xinjiang. Uncontrolled expansion of artificial oases, desert erosion, and frequent land use function transformations still exist, causing local ecological imbalance, deterioration of the fragile ecological environment, and threatening human survival. Analyzing land use function transformation and its eco-environmental effects in Yuli County has important practical significance for spatial planning of land resources and sustainable eco-environmental development.

Therefore, this study, based on the "three functions" framework, quantitatively analyzes land use function transformation and eco-environmental quality changes in Yuli County over four periods, revealing the impacts of land use function transformation on the ecological environment. We hope to provide references for promoting rational allocation of regional land resources and for sustainable development and ecological civilization construction in ecologically vulnerable areas.

1 Study Area Overview

Yuli County, also known as "Lop Nur" (meaning "lake with abundant water and grass"), is located in the northeastern margin of the Taklimakan Desert (the world' s second-largest mobile desert) in the arid desert region. It belongs to the middle and lower reaches of the Tarim River and is a typical ecologically vulnerable area in the core area of the Silk Road Economic Belt in southern Xinjiang. The county has a total area of 59,700 km^2, with desert area accounting for approximately half of the total county area. Yuli County has a warm temperate continental desert climate, with hot summers, dry and cold winters, scarce precipitation, strong evaporation, and dry air. The annual temperature range is 36.8°C, with average annual precipitation of 43 mm and average annual evaporation 50 times that amount. The county is rich in cotton, wheat, and fragrant pears, and contains the country' s largest poplar forest protection area (66,666.67 hm^2). In recent years, Yuli County has made new progress in ecological environmental protection, but the ecological environment remains extremely fragile, and the contradiction between land resource protection and utilization has become increasingly prominent. Achieving regional ecological security goals remains an arduous task [Figure 1: see original paper].

2 Data and Methods

2.1 Data Sources and Processing

This study obtained Landsat 5/Landsat 8 remote sensing imagery data with 30 m spatial resolution from the China Geographic Spatial Data Cloud for April 1993, 2001, 2009, and 2017. Using ENVI 5.1, we performed preprocessing and supervised classification, dividing the land into nine types according to local conditions: cultivated land, forest land, grassland, construction land, water area, wetland, salinized land, desert, and unused land. Considering that land is a multifunctional complex with corresponding dominant functions, we established a new land use function classification system with three primary categories and eight secondary categories based on the "three functions" method. Cultivated land was classified as agricultural production land, forest and grassland as ecological land, etc. Using ArcGIS 10.4, we reclassified the basic data and performed transfer matrix analysis. Based on the dominant functions and eco-environmental quality indices established by Gao, Yang, Lü, and others [5-6,32], we modified and assigned eco-environmental quality values for each land use function transformation in Yuli County using the area-weighted method (Table 1). Since industrial/mining production land and rural living land account for very small proportions, they were not included in the secondary classification or eco-environmental quality index corrections.

The remote sensing imagery data were geographically corrected based on the 2017 land use classification. The classification results were validated through field surveys, with overall accuracy ranging from 85.24% to 90.33% and Kappa coefficients reaching 0.80-0.85.

2.2 Methods

2.2.1 Land Use Transfer Matrix The land use transfer matrix quantitatively describes the mutual transfers among land use types in a land use system. By arranging the area transfer matrix of land use changes between any two periods, we can analyze the magnitude and direction of land use area transfers. Using the spatial overlay function of ArcGIS 10.4, we performed cross-analysis on land use type data from different periods to obtain the transfer matrix for four periods. The transfer matrix is expressed as:

$$S_{ij} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{bmatrix}$$

where S is land use area; i and j represent land use function types at the beginning and end of the study period, respectively; and n is the number of land use function types.

2.2.2 Eco-Environmental Effects **(1) Eco-environmental quality index.** Based on the "three functions" classification method, we quantitatively analyzed the overall status of eco-environmental quality in Yuli County during four periods using the eco-environmental quality index. The expression is:

$$EV_t = \sum_{i=1}^{n} \frac{S_{ki}}{S_k} \times R_i$$

where EV_t is the eco-environmental quality index in period t; n is the number of land use function types; S_{ki} is the area of land use function type i in period t; S_k is the total area of the region; and R_i is the eco-environmental quality index of land use function type i.

(2) Ecological contribution rate of land use function transformation. This method can further identify transformation processes that improve or deteriorate the ecological environment, helping to explore the dominant factors causing eco-environmental changes in the study area. The expression is:

$$LEI = (LE_{t1} - LE_{t0}) \times \frac{LA}{TA}$$

where LEI is the ecological contribution rate of land use function transformation; LE_{t1} and LE_{t0} are the eco-environmental quality indices at the end and beginning of the transformation period, respectively; LA is the area of this transformation type; and TA is the total area of the study region.

3 Results

3.1 Analysis of Land Use Function Area Changes

From 1993 to 2017, the area of ecological land was the largest among the "three functions" in Yuli County, showing a patchy distribution. Production land (agricultural production land) and living land (urban living land) showed continuous area increases, while ecological land decreased overall. Specifically, agricultural production land and urban living land increased by 143,399.97 hm^2 and 2,062.89 hm^2, respectively. Forest ecological land and grassland ecological land decreased by 44,726.67 hm^2 and 27,644.58 hm^2, respectively, accounting for 82.41% of the total ecological land change, indicating that changes in forest and grassland areas had the greatest impact on ecological land. Water ecological land and wetland ecological land areas increased, with wetland ecological land increasing by 2,828.07 hm^2. Other ecological land showed a relatively stable trend, first increasing then decreasing, with a total reduction of 76,115.25 hm^2 (mainly due to increased desert and salinized land areas) [FIGURE:2, TABLE:2].

Although living land accounts for the smallest proportion in Yuli County, the demand for production and living land has continuously increased with urbanization, leading to sustained increases in their areas and consequent decreases in ecological land area. Therefore, while protecting the ecological environment, it is necessary to rationally plan and layout production and living land to lay a foundation for sustainable regional economic and ecological development.

3.2 Analysis of Land Use Function Transformation

To explore the mutual conversion patterns among land use function types in Yuli County, we obtained land use transfer matrices for four periods using ArcGIS 10.4 spatial analysis functions, clarifying the transformation directions and magnitudes of different land use functions. The analysis shows that during the four periods, agricultural production land, forest ecological land, grassland ecological land, and other ecological land showed obvious transformation processes, while other land use function types showed varying degrees of transformation.

From 1993 to 2017, the net transferred-in areas of agricultural production land and urban living land were 118,526.85 hm^2 and 2,099.61 hm^2, respectively. The increase in agricultural production land mainly resulted from transfers from grassland, other ecological land, and forest ecological land, indicating that its area increase exceeded the area used for the "returning farmland to forest and grassland" policy. Some agricultural production land was transferred out to urban living land, reflecting urbanization processes. Forest ecological land and grassland ecological land were the main objects of mutual conversion. From 1993 to 2017, grassland ecological land transferred out 211,601.34 hm^2, with transfers to other ecological land exceeding transfers from other ecological land, indicating grassland degradation due to overgrazing, reclamation, desert erosion, and water scarcity. The decrease in forest ecological land mainly resulted from large transfers to grassland ecological land, agricultural production land, and other ecological land. For example, from 2009 to 2017, transfers to these three types were 30,468.60 hm^2, 7,145.28 hm^2, and 9,727.92 hm^2, with corresponding transfer rates of 53.76%, 12.61%, and 17.17%, respectively .

With increasing government attention to water and wetland ecological land resources, their areas have recovered, particularly during 2009-2017 when they increased substantially, mainly due to large transfers from grassland ecological land, other ecological land, and forest ecological land, totaling 19,548.81 hm^2 and 67,060.35 hm^2, respectively.

3.3 Eco-Environmental Effects Analysis

3.3.1 Eco-Environmental Quality Index Analysis Based on formula (1), the comprehensive eco-environmental quality indices of Yuli County for the four periods were 0.07629, 0.06378, 0.06934, and 0.07339, respectively. This shows that the overall eco-environmental quality index first decreased then increased. From 1993 to 2001, the index decreased by 0.01251, indicating overall ecological environment deterioration. However, from 2001 to 2017, the index increased continuously, showing that the ecological environment quality is moving toward a healthy direction.

Using the area-weighted method, we recalculated that forest ecological land had the highest eco-environmental quality index, followed by wetland ecological land, while urban living land and other ecological land had the lowest indices. However, due to differences in area proportions, the final contribution to overall eco-environmental quality index varied. For example, in 2017, other ecological land contributed the highest eco-environmental quality index, while forest ecological land contributed the lowest. From the perspective of overall index fluctuations, the ecological environment quality was relatively stable, with mutual transformations among land use function types having either positive or negative impacts on the ecological environment.

The analysis shows that from 1993 to 2017, the eco-environmental quality indices of agricultural production land and urban living land showed increasing trends, but their proportions in the total eco-environmental quality index were small (combined less than 6.57%). As important ecological systems in the study area, forest ecological land and grassland ecological land play roles in soil and water conservation and windbreak and sand fixation, effectively preventing land degradation. However, as their areas decreased, their eco-environmental quality indices also gradually declined. Forest ecological land decreased from 10.59% to 3.31%, and grassland ecological land from 58.25% to 44.79%. Wetland ecological land has multiple ecological functions, particularly in arid regions where its water storage, desert erosion control, climate regulation, and biodiversity maintenance functions are irreplaceable. From 1993 to 2017, the eco-environmental quality index of wetland ecological land increased from 3.49% to 6.57%, contributing significantly to overall ecological environment quality improvement .

3.3.2 Ecological Contribution Rate Analysis To explore internal changes in the ecological environment, we calculated the ecological contribution rates of land use function transformations in Yuli County using formula (2). The analysis shows that during the four periods, the transformation from other ecological land (with the lowest eco-environmental quality index) to grassland ecological land (with higher index) greatly improved the ecological environment quality, with contribution rates of 55.98%, 44.79%, 36.46%, and 61.36%, respectively. The transfer from other ecological land to wetland ecological land also benefited ecological environment quality, with the highest contribution rate of 70.98% in 2009-2017 .

Conversely, during the four periods, the occupation of grassland ecological land by other ecological land accounted for high proportions of negative ecological effects: 76.04%, 59.23%, 42.18%, and 54.28%, respectively. From 1993 to 2001, the transformation from grassland ecological land to agricultural production land had negative impacts, with ecological contribution rates of -18.61% and -17.38%. The degradation of wetland ecological land to other ecological land also caused significant ecological quality decline. Although overall trends of improvement and deterioration coexisted, local deterioration should not be ignored, especially in this ecologically vulnerable area where such deterioration could cause irreversible ecosystem degradation.

4 Discussion

(1) Based on the analysis of eco-environmental quality indices and transformation contribution rates of each land use function type, Yuli County should prioritize the protection of forest ecological land, wetland ecological land, water ecological land, and grassland ecological land. The main measures should prevent the occupation of grassland and forest ecological land by other ecological land (desert and salinized land) and agricultural production land. The county should focus on rational water resource allocation, strictly implement grazing bans and rotational grazing systems, actively adopt drip irrigation cultivation techniques, strengthen post-management of forest and grassland areas, and prevent the spread of desert and salinized land to eliminate human destruction of forest, grassland, water, and wetland resources.

(2) According to the territorial spatial planning system requirements, the county should clearly define the specific scope of the "three zones and three lines," particularly the control of ecological space and urban space. Scientific delineation of urban development boundaries and ecological protection red lines is crucial for coordinating scientific protection and rational utilization of natural resources. Meanwhile, the county should actively explore the creation of new multi-level circular agricultural ecosystems, forming a virtuous ecological chain cycle among planting, animal husbandry, and fishery modules.

(3) Throughout the study period, the transfer from other ecological land (with the lowest eco-environmental quality index) to other ecological land types (with higher indices) had large ecological contribution rates and positive effects on ecological environment quality. Conversely, the transfer from urban living land and other ecological land to forest and grassland ecological land had negative effects on ecological environment quality.

(4) Eco-environmental effects are related not only to the eco-environmental quality indices of land use function types but also to their areas. Although the research team validated the land use data through field surveys, the data source from remote sensing interpretation may contain accuracy errors. More precise remote sensing imagery data can ensure reliable land use data and thus more accurate and credible research results. Eco-environmental effects are important research content in land ecology, determining the direction and intensity of ecological protection. In addition to the area and eco-environmental quality indices discussed in this paper, influencing factors also include regional economic development level, land resource carrying capacity, water resource "budget," and land use behavior. Comprehensive consideration of these factors is the direction for future research.

5 Conclusions

(1) From 1993 to 2017, land use area changes based on the "three functions" in Yuli County were characterized by rapid increases in production and living land accompanied by slow decreases in ecological land. At the secondary classification level, agricultural production land, urban living land, water ecological land, and wetland ecological land increased in area, while forest ecological land, grassland ecological land, and other ecological land decreased.

(2) During the four land use transformation periods, the transformation processes of production land, forest ecological land, grassland ecological land, and other ecological land were relatively obvious, while other land use function types showed varying degrees of transformation. From 1993 to 2017, the largest transferred-out area was grassland ecological land (211,601.34 hm^2), while the largest net transferred-in area was agricultural production land (118,526.85 hm^2).

(3) From 1993 to 2017, the overall eco-environmental quality index of Yuli County showed a decreasing-then-increasing trend, remaining relatively stable overall. Grassland ecological land and other ecological land contributed significantly to the eco-environmental quality index. Increases in forest ecological land, wetland ecological land, and water ecological land areas greatly contributed to improving Yuli County' s eco-environmental quality.

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