Response of Habitat Quality to Land Use Change and Its Driving Forces in the Tarim River Basin: Postprint

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Abstract

Understanding the response characteristics and driving factors of habitat quality to land use change can provide a scientific basis for ecological conservation in arid regions. Based on land use data, methods such as the InVEST model, habitat contribution rate, and geographical detector were employed to assess the response of habitat quality to land use change and its influencing factors, and to predict habitat quality in 2030. The results indicate: (1) Land use types are dominated by unused land and grassland, with cultivated land and construction land expanding by 10,545 km^2 and 1,170 km^2, respectively, while areas of forest land, grassland, and unused land contracted; (2) The overall habitat quality level is relatively low, showing a continuous declining trend, with a spatial distribution characterized by high values at the edges and low values in the central region; conversion of grassland to unused land leads to a significant decrease in habitat quality, whereas the reverse transition results in a substantial improvement; (3) The spatial distribution of habitat quality is primarily influenced by elevation, temperature, and precipitation, with the interaction between elevation and precipitation exhibiting the strongest explanatory power for watershed habitat quality; (4) In 2030, the ecological protection scenario demonstrates significant advantages over the natural development and economic development scenarios, with habitat quality showing improvement. Future ecological conservation should focus primarily on preventing desert expansion, protecting grasslands, and managing water resources.

Full Text

Abstract

Understanding the response characteristics and driving factors of land use change on habitat quality provides a scientific basis for ecological protection in arid regions. Based on land use data, this study employs the InVEST model, habitat contribution rate, and geographic detector methods to evaluate the response of land use change to habitat quality and its influencing factors, and predicts habitat quality for 2030. The results show that: (1) Land use types are dominated by unused land and grassland, with cultivated land and construction land areas expanding by 10545 km^2 and 1170 km^2, respectively, while forest land, grassland, and unused land areas have contracted; (2) The overall habitat quality level is low and shows a continuous declining trend, with spatial distribution characterized by high values at the edges and low values in the center. When grassland flows into unused land, habitat quality decreases significantly, whereas the opposite transition substantially improves habitat quality; (3) The spatial distribution of habitat quality is primarily influenced by elevation, temperature, and precipitation, with the interaction between elevation and precipitation having the strongest explanatory power for watershed habitat quality; (4) By 2030, the ecological protection scenario demonstrates significant advantages over the natural development and economic development scenarios, with habitat quality showing improvement. Future ecological protection should focus primarily on preventing desert expansion and protecting grasslands and water resources.

Keywords: habitat quality; land use change; habitat contribution rate; geodetector; Tarim River Basin

Introduction

Habitat quality, as a core component of ecological civilization construction, is increasingly important in national economic and social development, directly influencing sustainable socioeconomic development. Land use change represents a crucial factor affecting regional habitat quality, as it influences material and energy exchange between habitat patches and alters regional habitat distribution patterns. Therefore, studying the relationship between habitat quality and land use change, along with the driving factors of habitat quality, is significant for ecological civilization construction and sustainable development.

Assessment methods for habitat quality include InVEST, SolVES, and MaxEnt models. Among these, the InVEST model offers advantages such as simple data acquisition, relatively accurate evaluation results, and visualization capabilities, and has been widely applied to assess habitat quality in Guangdong Province, the central and southern Liaoning urban agglomeration, Southwest China, and the Poyang Lake Basin. However, research on the response of habitat quality to land use change has primarily focused on southern regions, with relatively insufficient studies in ecologically fragile arid zones. Methodologically, previous studies have mainly focused on two aspects: first, separately evaluating land use change and habitat quality and qualitatively analyzing the impacts of land use change on habitat quality; and second, using models to analyze the relationship between changes in various land type areas and habitat quality changes. However, less attention has been paid to the impacts of mutual conversions between land types on habitat quality changes.

The Tarim River Basin is China's largest inland river basin and one of the country's most arid and ecologically fragile regions, playing a key role in safeguarding economic development and ecological restoration in southern Xinjiang. Since the 21st century, human activity intensity in the Tarim River Basin has significantly increased, with expansion of cultivated and construction land and grassland degradation leading to intensified soil erosion, increased landscape ecological risk, and declining ecosystem service value, threatening the basin's ecological security. Based on this context, this study uses the InVEST model to evaluate watershed habitat quality, analyzes the response mechanism of land use change to habitat quality in the Tarim River Basin through habitat contribution rate calculations, employs geographic detector to analyze influencing factors of habitat quality, and predicts the spatiotemporal pattern of future habitat quality to further promote ecological protection and support high-quality development in the Tarim River Basin.

1.1 Study Area Overview

The Tarim River Basin is located between 73°39 –93°45 E and 34°20 –43°39 N, covering an area of 37.04$×10^{4}$ km^2, of which desert area reaches 102.70$×10^{4}$ km^2, forming a typical closed arid desert ecosystem. The region belongs to the arid zone's typical continental warm temperate climate. The basin's landforms are complex and diverse, comprising three major geomorphic units: mountains, plains, and deserts. Soil types are primarily hydromorphic soils and aeolian soils. Vegetation species are relatively simple, and water resources mainly come from glacier and snow melt, with an average annual water resource volume of approximately 429$×10^{8}$ m^3.

1.2 Data Sources

The data used include land use data, socioeconomic data, natural factor data, and location data. Specific data details are provided in Table 1. Land use data were reclassified into cultivated land, grassland, forest land, water bodies, construction land, unused land, and marsh. Monthly average precipitation data were summed to obtain annual average precipitation for the study period. Monthly average temperature data were averaged to obtain annual average temperature. DEM data were clipped to the study area, and slope was calculated using the ArcGIS slope tool. Location data include distances to major roads and rivers, calculated using Euclidean distance.

1.3 Research Methods

The InVEST Habitat Quality module was used to assess habitat quality in the Tarim River Basin. This module calculates habitat quality based on land use types, habitat suitability for flora and fauna, and threat intensity from threat factors. The calculation formula is as follows:

$$Q_{xj} = H_j \times \left(1 - \frac{D_{xj}^z}{D_{xj}^z + K^z}\right)$$

where Q_{xj} is the habitat quality index for grid cell x in land use type j, with a value range of $[0, 1]$; H_j is the habitat suitability of land use type j; D_{xj} is the degree of habitat degradation for grid cell x in land use type j (calculation method 可参考模型手册); K is the half-saturation constant; and z is a scaling parameter.

Based on relevant research findings and the actual conditions of the study area, cultivated land, construction land, and unused land were defined as threat sources, with relevant parameters set as shown in Tables 2 and 3.

1.3.2 Geographic Detector Geographic detector is a method for detecting spatial stratified heterogeneity and its driving factors, including factor detection, interaction detection, risk detection, and ecological detection. Factor detection can analyze the explanatory power of various driving factors on the spatial differentiation of habitat quality, while interaction detection can explore whether the explanatory power of different factors acting together is enhanced or weakened. Therefore, this study analyzes influencing factors of habitat quality in the Tarim River Basin from the perspectives of factor detection and interaction detection. The calculation formula is:

$$q = 1 - \frac{\sum_{k=1}^{L} N_k \sigma_k^2}{N\sigma^2}$$

where q represents the explanatory power of the influencing factor on habitat quality, with a value range of $[0, 1]$; L represents the stratification of influencing factors; N_k and N represent the number of units in layer k and the entire region, respectively; and σ_k^2 and σ^2 represent the variance values for layer k and the entire region, respectively.

Eight driving factors were selected: elevation, slope, precipitation, temperature, GDP, population density, distance to major roads, and distance to major rivers, exploring influencing factors of habitat quality in the Tarim River Basin from four dimensions: topography, climate, socioeconomic factors, and accessibility.

1.3.3 Habitat Contribution Rate Habitat contribution rate refers to the ratio of habitat quality change caused by the conversion of a certain land type, which can measure the impact of land use change on habitat quality. The calculation formula is:

$$R_{ij} = \frac{Q_N \times Q_M - Q_O}{S} \times 100\%$$

where R_{ij} represents the contribution rate of land use type i converting to type j to habitat quality change; Q_M and Q_N represent the habitat quality at the end and beginning of the study period for land type i, respectively; Q_O represents the habitat quality at the beginning of the study period for land type j; and S represents the total study area.

1.3.4 PLUS Model The PLUS model is used to predict future land use patterns, primarily consisting of a Land Expansion Analysis Strategy (LEAS) and a Cellular Automata (CA) model based on multiple random patch seeds. Using land use data from 2000, 2010, and 2020, the expansion portions of each land type from 2000–2010 and 2010–2020 were analyzed to obtain development probabilities for each land type. The 2020 land use structure was used as the initial state, with transition matrices for different scenarios referencing existing research findings. The neighborhood weights for each land type were calculated based on the proportion of expansion area to total expansion area during 2010–2020.

2.1 Land Use Change

From 2000 to 2020, land use types in the Tarim River Basin were dominated by unused land and grassland, covering the majority of the basin's area (Figure 2). The areas of forest land, grassland, and unused land continued to decline, decreasing by 735 km^2, 7507 km^2, and 3741 km^2, respectively. Forest land and grassland were mainly distributed at the basin's edges, while unused land was primarily distributed in the central Tarim Basin. Cultivated land and construction land areas continued to increase, expanding by 10545 km^2 and 1170 km^2, respectively, and were mainly distributed along the main stream of the Tarim River. Water bodies were patchily distributed in the southern part of the study area.

The largest transition area occurred for grassland, with 10529 km^2 and 12949 km^2 of grassland transferred out in 2000–2010 and 2010–2020, respectively, mainly flowing into unused land (5985 km^2 and 9860 km^2) and cultivated land (4072 km^2 and 4893 km^2). Unused land transfer-out areas were 6162 km^2 and 8471 km^2, mainly flowing into grassland (6104 km^2 and 7507 km^2). In 2000–2010, grassland transfer-out area was the largest, mainly flowing into cultivated land and unused land (5985 km^2). In 2010–2020, cultivated land and grassland had larger transfer-in areas, with cultivated land primarily sourced from grassland (8471 km^2) and grassland mainly sourced from unused land (7507 km^2). Grassland transfer-out area was the largest, followed by unused land. Grassland mainly flowed into cultivated land and unused land, while unused land mainly flowed into grassland and cultivated land. Overall, the mutual conversion between grassland and unused land and the unidirectional conversion from grassland to cultivated land represent the main characteristics of land use type transitions in the Tarim River Basin.

2.2 Spatiotemporal Evolution Characteristics of Habitat Quality

Habitat quality in the Tarim River Basin from 2000 to 2020 was 0.2415, 0.2394, and 0.2368, respectively, indicating an overall low level and a continuous declining trend, with habitat quality decreasing by 0.0047 from 2000 to 2020, reflecting deteriorating ecological environmental quality. Based on the data characteristics, the equal interval method was used with 0.2 as the breakpoint to divide habitat quality into five grades: Grade I [0–0.2), Grade II [0.2–0.4), Grade III [0.4–0.6), Grade IV [0.6–0.8), and Grade V [0.8–1] (Figure 3). The results show that habitat quality in the Tarim River Basin exhibits a pattern of high values at the edges and low values in the center. High-grade habitat quality is mainly distributed near the edges of the Tarim Basin, the Tianshan Mountains, and the Kunlun Mountains, while low-grade habitat quality is mainly distributed in the central Tarim Basin.

Changes in the proportion of area for each habitat quality grade from 2000 to 2020 show that the area transitioning from low-grade to high-grade habitat quality (20061 km^2) is smaller than the area transitioning from high-grade to low-grade habitat quality (36382 km^2), further reflecting the decline in habitat quality in the Tarim River Basin. From each study period perspective, Grade I area proportion increased by 0.64%, mainly sourced from Grade II (1665 km^2) and Grade III (3249 km^2). Grade II area proportion decreased by 0.38%, mainly converting to Grade I (1513 km^2). Grade III area proportion decreased by 0.17%, mainly converting to Grade II (1680 km^2). Grade IV area proportion decreased by 0.02%, mainly converting to Grade III (2093 km^2). Grade V area proportion decreased by 0.14%, mainly converting to Grade IV (3470 km^2).

[Figure 3: see original paper]

[Figure 4: see original paper]

2.3 Contribution of Land Use Change to Habitat Quality

The contribution rate of land use type transitions to habitat quality change shows that from 2000 to 2020, land use transitions that improved habitat quality covered an area of 48170 km^2, with a total contribution rate of 0.7938%. The transition from unused land to grassland had the highest habitat contribution rate, reaching 0.3652%, with a transition area of 7495 km^2. The transition from unused land to water bodies had the second highest contribution rate of 0.1811%, with a transition area of 7495 km^2. Land use transitions that decreased habitat quality in the Tarim River Basin covered an area of 982800 km^2, with a total contribution rate of -1.0207%, mainly occurring in transitions from water bodies and grassland to unused land, and from grassland to cultivated land, with transition areas of 1825 km^2, 5927 km^2, and 8471 km^2, and habitat contribution rates of -0.1460%, -0.3557%, and -0.2291%, respectively. Overall, transitions from ecological land to threat sources cause habitat quality decline, while the opposite transitions improve habitat quality. The conversion from unused land to grassland contributes most to habitat quality improvement, while the conversion from grassland to unused land significantly reduces watershed habitat quality.

[Figure 5: see original paper]

2.4 Influencing Factors of Habitat Quality Spatial Distribution

Based on geographic detector analysis of factors influencing habitat quality spatial distribution, the explanatory power (q values) of single factors on habitat quality spatial differentiation are ranked as: elevation (0.7938), temperature (0.3652), precipitation (0.1811), slope (0.1460), GDP (0.3557), population density (0.2291), distance to major roads (0.1460), and distance to major rivers (0.1811). This indicates that topographic and climatic factors have non-negligible effects on habitat quality, with elevation having the largest q value, followed by temperature and precipitation. The q values for GDP and population density are close to 0.1, indicating that socioeconomic factors have relatively small explanatory power for habitat quality spatial distribution in this region.

The explanatory power of two-factor interactions on habitat quality in the Tarim River Basin is shown in Table 6. The explanatory power of all two-factor interactions is greater than that of single factors, indicating that habitat quality spatial distribution in the Tarim River Basin results from multiple factors acting together. The interactions between elevation and precipitation, elevation and temperature, elevation and distance to major roads, and slope and temperature show strong explanatory power, indicating that topographic, climatic, and accessibility factors influence land use type changes to some extent, thereby affecting habitat quality. Specifically, the interaction between elevation and precipitation has the strongest explanatory power (0.8471), indicating that the interaction between elevation and precipitation is the dominant factor influencing habitat quality in the Tarim River Basin.

2.5 Prediction of Habitat Quality in 2030

The PLUS and InVEST models were used to predict habitat quality in the Tarim River Basin under three scenarios for 2030. The results show that under natural development, ecological protection, and economic development scenarios, habitat quality in the Tarim River Basin will be 0.2339, 0.2415, and 0.2335, respectively. Compared with 2020, habitat quality improves under the ecological protection scenario, while it decreases under the other two scenarios. The spatial distribution pattern of habitat quality continues the “high at edges, low in center” pattern from 2000 to 2020. The spatial distribution of habitat quality change areas is consistent across the three scenarios, but the area sizes differ. Areas with increased habitat quality are sporadically distributed near water bodies, with areas from largest to smallest being: ecological protection scenario (8008 km^2), economic development scenario (7624 km^2), and natural development scenario (8431 km^2). Areas with decreased habitat quality are mainly distributed in transition zones from cultivated land to grassland and from unused land to grassland, with areas from largest to smallest being: natural development scenario (56764 km^2), economic development scenario (55843 km^2), and ecological protection scenario (24991 km^2). Among the three scenarios, compared with 2020, the ecological protection scenario shows increased habitat quality, with the largest increase area and smallest decrease area, demonstrating an improving effect on the ecological environment of the Tarim River Basin.

[Figure 6: see original paper]

Discussion

Land use change is an important cause of habitat quality change, while regional land use change results from the combined effects of human activities, climate change, and natural conditions. Factors threatening habitat quality include construction land, unused land, and cultivated land. Changes in the area of these three land use types directly affect habitat quality. From 2000 to 2020, cultivated land and construction land in the Tarim River Basin continued to expand, while ecological land such as forest land and grassland decreased, with dramatic changes in land use structure. The area of land use transitions that improved habitat quality was smaller than the area of transitions that decreased habitat quality, resulting in an overall decline in habitat quality from 2000 to 2020. This is consistent with research results from Kashgar Region and Aksu Region. Existing studies have shown that the interaction between elevation and precipitation is the main reason affecting watershed habitat quality spatial distribution, and that high habitat quality areas are highly correlated with land use types, which is basically consistent with the conclusions of this paper.

Habitat quality is higher at the edges than in the center of the Tarim River Basin. This is because the edge region has higher altitude, relatively higher precipitation due to terrain effects, and more abundant water resources in summer, with land use types dominated by forest land and grassland, which promote biodiversity and environmental regulation. In contrast, the central basin has flat terrain, low precipitation, scarce water resources, and is unfavorable for vegetation growth, being dominated by unused land, which increases threats to habitat quality.

In the future, without ecological protection, habitat quality in the Tarim River Basin will continue its previous evolution pattern and show a decreasing trend. Areas with decreasing habitat quality will mainly be in transition zones from cultivated land to grassland and from unused land to grassland. The transition from unused land to grassland has the highest habitat contribution rate, while the transition from grassland to unused land has the lowest habitat contribution rate. Therefore, to prevent habitat degradation, it is necessary to continue consolidating achievements in desertification prevention, establish shelterbelts at desert edges, vigorously develop grass seed industry, and carry out protection and construction of grasslands and deserts in combination with relevant policies. Additionally, it is recommended to improve land use efficiency, 守住耕地红线和生态保护红线, strictly control blind expansion of cultivated land, and gradually increase the proportion of ecological land such as grassland.

Water resource allocation has a significant impact on land use types in inland river basins in arid regions, making habitat quality closely related to water resource distribution. Areas with increased habitat quality in the Tarim River Basin are mainly distributed near water bodies. Maintaining stable ecological environment in this region requires strengthening unified management of water resources in the basin, building a water system ecological corridor based on the Tarim River, developing water-saving and intensive advantageous industries, promoting economical and intensive water resource utilization, implementing watershed ecological management projects, and continuously consolidating ecological environmental protection achievements.

This study explores the response and driving factors of habitat quality to land use change in the Tarim River Basin from 2000 to 2020 and predicts future habitat quality using the InVEST model. The research results can provide references for ecological protection in arid regions. However, this study also has certain limitations. InVEST model parameter settings rely on research findings from similar regions, which to some extent introduces subjectivity. Additionally, this study only considers single-factor and two-factor interactions when evaluating habitat quality influencing factors, lacking research on the multiple combination effects of regional habitat quality influencing factors. Future research should combine field survey results and relevant monitoring data to optimize parameters, improve the accuracy of habitat quality results, and further analyze the multiple combination effects of habitat quality influencing factors.

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