Spatiotemporal Evolution of Land Use and Ecosystem Service Value and Its Driving Factors in the Lhasa River Basin: Postprint

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Abstract

Land use change exerts strong impacts on ecological civilization construction, thereby threatening sustainable socio-economic and ecological development. Based on high-precision land use data, this study analyzed the spatiotemporal evolution characteristics of land use and Ecosystem Service Value (ESV) in the Lhasa River Basin from 2000 to 2020, and explored the driving factors of land use change and the spatial differentiation of ESV using the PLUS model and Geodetector, respectively. The results show that: (1) From 2000 to 2020, land use in the Lhasa River Basin was dominated by grassland, accounting for 85.23% of the total basin area. Land use exhibited a trend of grassland shrinkage and expansion of other land types. Specifically, grassland decreased by 2.45%, while construction land, water bodies, and forest land expanded by 199.72%, 44.64%, and 21.97%, respectively. (2) Land use change in the basin was influenced by factors such as elevation, annual average ground temperature, and distance to lakes and reservoirs. Among these, the contribution degree of elevation to the expansion of cultivated land, forest land, water bodies, and construction land reached 0.18, 0.11, 0.28, and 0.13, respectively, while the contribution degrees of slope and annual average ground temperature to grassland and unused land change were 0.14 and 0.15, respectively. (3) From 2000 to 2020, the overall ESV in the basin increased by 1.14% (14.96$×$10^8 yuan). Grassland and climate regulation were the most prominent land use type and ecosystem service type contributing to ESV, with contribution rates of 87.13% and 25.50%, respectively. (4) ESV in the basin exhibited significant spatial heterogeneity, influenced by factors such as NDVI, elevation, annual average wind speed, and annual average temperature. Among these, the explanatory power of NDVI reached 0.46, and the interaction of any two factors enhanced the differentiation of ESV. The research results can provide scientific references for territorial spatial planning and ecological civilization construction in the Lhasa River Basin and similar regions.

Full Text

Spatio-temporal Evolution and Driving Factors of Land Use and Ecosystem Service Value in the Lhasa River Basin, China

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Abstract

Land use change exerts profound impacts on ecological civilization construction, thereby threatening the sustainable development of society, economy, and the ecological environment. Based on high-precision land use data from 2000 to 2020, this study analyzes the spatiotemporal evolution characteristics of land use and ecosystem service value (ESV) in the Lhasa River Basin, and employs the PLUS model and geographic detectors to explore the driving factors of land use change and the spatial differentiation of ESV. The results indicate that: (1) Grassland dominated the land use pattern in the Lhasa River Basin during 2000–2020, accounting for 85.23% of the total basin area. The overall trend showed grassland reduction while other land categories expanded, with grassland decreasing by 2.45% and construction land, water bodies, and forest land increasing by 199.72%, 44.64%, and 21.97%, respectively. (2) Land use change was influenced by factors including elevation, annual mean ground temperature, and distance from lakes and reservoirs. Elevation contributed most significantly to the expansion of cultivated land, forest land, water bodies, and construction land, while slope and annual mean ground temperature were the primary drivers of change in grassland and unused land. (3) The total ESV of the basin increased by 1.14% (1.496 billion yuan) from 2000 to 2020, with grassland and climate regulation representing the most prominent land use type and ecosystem service type, contributing approximately 87.13% and 25.50% of the total value, respectively. (4) ESV exhibited significant spatial heterogeneity, influenced by NDVI, elevation, annual mean wind speed, and annual mean temperature. The explanatory power of NDVI reached 0.46, and the interaction between any two factors enhanced ESV differentiation. These findings provide scientific references for territorial spatial planning and ecological civilization construction in the Lhasa River Basin and similar regions.

Keywords: land use; ecosystem service value; driving factors; Lhasa River Basin

1 Introduction

Ecosystem services refer to the life-supporting products and services that humans obtain directly or indirectly through ecosystem structures, processes, and functions, which are closely related to human well-being. Their sustainable provision forms the cornerstone of socio-economic development. Ecosystem Service Value (ESV) serves as a key method for evaluating the intensity of ecosystem services, and scientific assessment of ESV is crucial for regional ecological protection policy formulation. Land use represents humanity's most fundamental practical activity and constitutes a significant factor affecting ecosystem service function changes. Since the quantitative assessment of global ecosystem service value and the establishment of China's terrestrial ecosystem service value equivalent tables, scholars have conducted extensive research on ESV at various scales, focusing on temporal evolution, spatial heterogeneity, terrain gradient distribution, driving mechanisms, and future scenario simulation. Among these, driving mechanisms have been investigated using principal component analysis, geographic detectors, and models such as CA-Markov and PLUS. The PLUS model, differing from previous cellular automata models, has gained widespread application due to its raster-based foundation, convenient data acquisition, and simple operation. It can analyze the contribution of various driving factors to land use change through random forest classification algorithms, providing important support for ecological protection policy development.

Spatial heterogeneity has primarily been examined using multiple regression analysis, spatial regression models, and geographic detectors. Geographic detectors represent a novel spatial statistical method that can reveal the driving forces behind spatial differentiation through factor detection, interaction detection, risk area detection, and ecological detection. However, current research on land use change and ESV has mostly focused on economically developed regions with rapid urbanization and frequent land use transitions in the second and third topographic steps, often neglecting the ecological value of construction land. Research remains scarce in the Tibetan Plateau, known as the "Third Pole," particularly in its economic hinterland—the Lhasa River Basin. Close attention to the evolution of land use and ESV in this basin is of great significance for the region and even the whole of Tibet.

Since the end of the 20th century, urbanization in the Lhasa River Basin has accelerated rapidly under national policy support, accompanied by population surges and dramatic land use structural changes due to global warming. The contradiction between economic development and ecological civilization construction has become increasingly prominent. Therefore, this study analyzes the spatiotemporal evolution of land use and ESV in the basin from 2000 to

2020, and employs the PLUS model and geographic detectors to investigate the driving factors of land use change and ESV spatial differentiation, aiming to provide decision-making support for optimizing land use layout and ecological environmental protection.

1.1 Study Area

The Lhasa River originates from the Pengcuo Lakongma Gully on the southern slope of the Nyenchen Tanghla Mountains, flows through Maizhokunggar, Dagzê, Doilungdêqên, and other counties, and finally empties into the Yarlung Tsangpo River at Qüxü County. As the largest tributary of the Yarlung Tsangpo River, the Lhasa River stretches approximately 568 km with a basin area of 32,692.86 km^2, accounting for 13.5% of the Yarlung Tsangpo River basin area. The basin has an average elevation exceeding 4,500 m and an average gradient of about 0.29%. Runoff primarily originates from precipitation and snowmelt. The basin belongs to a plateau temperate semi-arid climate, influenced by the southwest monsoon with distinct wet and dry seasons. Precipitation is concentrated from June to September, with annual precipitation ranging from 257–699 mm. The region experiences strong solar radiation, with annual mean temperatures of 6.3–9.1°C and large diurnal temperature variations. By the end of 2020, the basin's permanent population reached 678,160, with a GDP of 86.79 billion yuan. Rapid economic and population growth has caused significant disturbances to the basin's ecological environment, which faces numerous challenges.

1.2 Data Sources

The 30 m spatial resolution land use dataset (2000–2020) was obtained from the Global Fine Surface Cover Dynamic Monitoring Product (GLC_{FCS30}) developed by the Aerospace Information Research Institute, Chinese Academy of Sciences, based on Landsat imagery (Landsat TM/ETM+/OLI), with an overall accuracy of 82.5% and Kappa coefficient of 0.73, meeting research requirements. DEM data (30 m resolution) was sourced from the Geospatial Data Cloud (http://www.gscloud.cn/), from which slope, aspect, and terrain relief were derived. Annual mean wind speed, sunshine hours, relative humidity, ground temperature, evaporation, precipitation, air temperature, $ $10°C accumulated temperature, and population density data were obtained from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/) at 1 km resolution. Railway, highway, residential point, river, lake, and reservoir data were obtained from the National Basic Geographic Information Center (1:1,000,000 basic geographic information data). Grain yield and sown area data were sourced from the *Tibet Statistical Yearbook* during the study period, and grain price data from the Tibet Autonomous Region Grain and Material Reserve Bureau (http://xz.lswz.gov.cn/).

1.3 Methods

1.3.1 Ecosystem Service Value Assessment Based on the evaluation model and referencing the equivalent factor table for Chinese terrestrial ecosystem services per unit area, we corrected the value equivalent coefficients using the average grain yield of Lhasa City (where the Lhasa River Basin is mainly located) during 2000–2020 (5,794.78 $kg \cdot hm^{-2}$) and the average purchase price of grain in Tibet's main production areas (3.0 $yuan \cdot kg^{-1}$). The economic value of one standard ecosystem service equivalent was set as 1/7 of the market value of average grain yield per unit area, yielding a value equivalent of 2,483.48 $yuan \cdot hm^{-2}$ for the Lhasa River Basin. The corrected equivalent table (Table 1) was then used to calculate ESV for the study area using the formula:

$$ESV = \sum_i A_i \times \sum_j S_{ij}$$

where ESV is the ecosystem service value, A_i is the area of land use type i in the evaluation grid, S_{ij} is the equivalent value per unit area for ecosystem service type j of land use type i, i is the number of land use types, and j is the number of ecosystem service types.

1.3.2 PLUS Model The land expansion analysis strategy in the PLUS model employs the Random Forest Classification (RFC) algorithm to analyze land use expansion and its driving factors, obtaining development probabilities for each land type and the contribution of driving factors to expansion during specific periods. The RFC algorithm can handle high-dimensional data and multicollinearity among variables, determining the probability of land use type k occurring in cell i as:

$$P_{k,i} = \frac{1}{M} \sum_{n=1}^{M} I(h_n(x) = k)$$

where $I(\cdot)$ is the indicator function, $h_n(x)$ is the predicted class of vector x by the n-th decision tree, and M is the total number of decision trees.

1.3.3 Geographic Detector Geographic detectors can explore spatial differentiation characteristics of elements. We used factor detection and interaction detection to analyze driving factors and their interactions affecting ESV spatial differentiation in the Lhasa River Basin. The formula is:

$$q = 1 - \frac{1}{N\sigma^2} \sum_{h=1}^{L} N_h \sigma_h^2$$

where q represents the influence of driving factors on ESV spatial differentiation, L is the stratification of variable Y or factor X (i.e., classification or zoning), N_h and N are the number of evaluation units in layer h and the entire region, respectively, and σ_h^2 and σ^2 are the variances of ESV in evaluation grid h and the entire study area, respectively.

2 Results

2.1 Land Use Spatiotemporal Changes

2.1.1 Land Use Pattern and Area Changes Grassland was the dominant land use type in the Lhasa River Basin (Fig. 2), covering 85.23% of the basin area in 2020 and distributed across most of the region. Unused land and forest land ranked second, accounting for 9.79% and 4.35% of the area, respectively. Unused land was concentrated in the northwestern Nyenchen Tanghla Mountains, along both sides of the lower Lhasa River mainstream, and in upstream mountainous areas. Forest land was mainly distributed in southern mountainous areas and mid-upstream mountainous regions. Water bodies, cultivated land, and construction land occupied small proportions, each less than 0.50%. Water bodies were concentrated in lakes such as Pengcuo and Dongdecuo at the river source and in hydropower stations like Pangduo and Zhikong in the mid-lower reaches. Construction land was concentrated in downtown areas of Chengguan, Dagzê, and Doilungdêqên in the lower basin, while cultivated land was mainly in river valleys of Maizhokunggar, Lhünzhub, and Dagzê in the mid-lower reaches.

From 2000 to 2020, all land types except grassland showed expansion trends (Fig. 3). Grassland area decreased by 2.45% (687.13 km^2), while cultivated land, forest land, water bodies, and construction land expanded by 21.97% (308.05 km^2), 44.64% (10.72 km^2), 199.72% (5.76 km^2), and 32.92% (293.78 km^2), respectively. The land use change characteristics were primarily influenced by global warming and national policies such as the "Western Development Strategy," as well as water conservancy projects like the Pangduo Reservoir (impounded in 2011).

2.1.2 Land Use Transfer Patterns Land use transfers were frequent in the Lhasa River Basin from 2000 to 2020 (Fig. 4). The reduced grassland area was mainly converted to unused land (969.38 km^2) and forest land (676.67 km^2), concentrated in the mid-lower river valleys, Nyenchen Tanghla Mountains, and mid-upstream mountainous areas. Notably, large areas of grassland were converted to water bodies (51.19 km^2), cultivated land (43.98 km^2), and construction land (25.18 km^2). Conversion to water bodies occurred mainly around the Pangduo and Zhikong water conservancy facilities, conversion to cultivated land was distributed in river valleys of Dagzê, Lhünzhub, and Maizhokunggar counties, and conversion to construction land was highly concentrated in the Lhasa River valley from Dagzê District through Chengguan District to Doilungdêqên District.

Conversely, unused land (666.03 km^2) and forest land (365.28 km^2) converted to grassland also covered substantial areas, concentrated in mid-upstream mountainous areas, downstream valley slopes, and western mountains. Additionally, notable conversions included unused land to water bodies (40.65 km^2) and forest land (25.87 km^2), and water bodies to unused land (22.09 km^2) and grassland (13.56 km^2), mainly in the Chengguan District section of the Lhasa River, midstream mountainous areas, and the Nyenchen Tanghla Mountains. Meanwhile, 16.84 km^2 of forest land in southeastern and mid-upstream mountainous areas degraded to unused land, further confirming that land use change in the Lhasa River Basin is deeply affected by both economic activities such as urbanization and natural factors like global climate change.

2.2 Ecosystem Service Value Spatiotemporal Changes

2.2.1 ESV Temporal Trends The total ESV of the Lhasa River Basin showed an increasing trend from 2000 to 2020, rising from 131.602 billion yuan to 133.098 billion yuan, an increase of 1.496 billion yuan (1.14%). Grassland was the largest contributor to basin ESV, accounting for approximately 87.13% of the total value, followed by forest land (7.80%), water bodies (4.38%), and unused land (0.64%). Cultivated land and construction land, despite their extremely low proportions (both below 0.04%), still had some impact on ESV.

In terms of ecosystem service types, climate regulation and hydrological regulation were the most prominent contributors, accounting for 25.50% and 21.98% of the total ESV, respectively. Other important services included biodiversity (11.70%), soil conservation (10.72%), and water supply (10.00%). The remaining service types contributed less than 10.00% each.

The changes in ESV aligned with area change trends. Forest land and water body expansion were the main drivers of ESV growth, increasing by 2.012 billion yuan (20.12%) and 1.504 billion yuan (15.04%), respectively. Grassland and climate regulation were the land use type and ecosystem service type with the most significant changes, with contribution rates of approximately 87.13% and 25.50%, respectively. Cultivated land and construction land showed insignificant growth, with rates below 0.05%. Among ecosystem service types, climate regulation, hydrological regulation, water supply, environmental purification, and aesthetic landscape all increased to varying degrees, while soil conservation, gas regulation, and climate regulation decreased significantly by 0.50 billion yuan (0.32%), 0.48 billion yuan (0.38%), and 0.49 billion yuan (0.15%), respectively.

2.2.2 ESV Spatial Distribution Using 1 km × 1 km grids as calculation units, we analyzed the spatial distribution and changes of per-unit-area ESV. The natural breaks method classified ESV into five levels: very low value [0.23, 2.19), low value [2.19, 3.65), medium value [3.65, 4.40), high value [4.40, 6.20), and very high value [6.20, 30.59] (10^4 yuan·km^{-2}). The results showed that ESV exhibited significant spatial heterogeneity. Very low value zones stretched across the northwestern Nyenchen Tanghla Mountains and urban built-up areas of Chengguan and Doilungdêqên, covering approximately 3.77% of the basin area. Low value zones were mainly distributed at the edges of very low value zones and in the northeastern mixed zones of unused land and grassland, accounting for 13.71% of the area. Medium value zones covered most grassland areas in the western and central basin, representing 63.31% of the area. High value zones were distributed in the southern margins and mid-upstream mountainous areas with concentrated forest land, covering 18.21% of the area. Very high value zones were highly concentrated around the Pangduo Hydropower Station, Sijinlacuo Lake, and Pengcuo Lake in the northeast, accounting for 1.00% of the area.

From 2000 to 2020, the spatial pattern of ESV showed a trend of medium value zones shrinking while other levels expanded. Medium value zones decreased by 1.41%, while high and low value zones expanded by 2.26% and 4.94%, respectively. Very low and very high value zones showed minimal expansion. The shrinkage of medium value zones was concentrated in the source lake area, mainly replaced by high value zones. Very low and low value zones expanded mainly toward the Nyenchen Tanghla Mountains and midstream-downstream urban agglomerations, while very high value expansion areas were concentrated in the core zones of the Pangduo and Zhikong water conservancy facilities.

2.2.3 Driving Factors of ESV Spatial Differentiation Using 18 selected driving factors (including natural and economic factors), we analyzed the influencing factors of ESV spatial differentiation with geographic detectors. The results showed that ESV spatial differentiation was influenced by both natural and economic factors (Fig. 8). NDVI was the dominant factor, with a q-value of 0.46. Elevation, annual mean wind speed, and annual mean temperature also showed strong explanatory power, with q-values of 0.17, 0.15, and 0.14, respectively. Other factors had q-values below 0.06 but still exerted certain influences. This indicates that natural factors such as NDVI, elevation, and annual mean wind speed had more significant effects on ESV differentiation than economic factors like population density, distance to highways, and distance to residential points.

Interaction detection revealed that the interaction between NDVI and elevation had the most significant effect, with an explanatory power of 0.58. Interactions between NDVI and annual mean wind speed, and between NDVI and annual mean temperature, also showed strong effects, with q-values of 0.52 and 0.51, respectively. Other factor interactions had explanatory powers ranging from 0.13 to 0.49, all higher than single factors. This demonstrates that the interaction between any two factors significantly enhanced ESV differentiation, particularly interactions among natural factors. Therefore, both natural and economic factors and their interactions must be considered comprehensively in basin economic development and ecological civilization construction.

3 Discussion

Land use change is widely recognized as a primary driver of ecological environmental change. With rapid socio-economic development, intensifying human interference has caused varying degrees of change in land use patterns. Similar to other major cities on the Tibetan Plateau, the Lhasa River Basin has experienced dramatic land use structural changes under frequent human economic activities and climate change, showing a trend of grassland reduction and expansion of other land types. Benefiting from water body and forest land expansion, the basin's ESV has increased. Notably, land use expansion mostly occurred after 2010, characterized by rapid growth of construction land with low ecological value and forest land and water bodies with very high ecological value, consistent with previous research findings and aligning with ecological projects such as the "Grain for Green" program and the "Western Development Strategy," as well as infrastructure development including the Qinghai-Tibet and Lhasa-Shigatse railways and high-grade highways, and economic development activities such as the establishment of the Lhasa Economic and Technological Development Zone and Liuwu New District.

Under global warming, the annual mean temperature in the Lhasa River Basin continues to rise. Combined with strong evaporation, strong winds in winter and spring, and uneven seasonal precipitation distribution, desertification in the basin is intensifying. Previous studies have indicated that the material basis for desertification in the lower Lhasa River valley consists primarily of alluvial deposits from the Lhasa River and its first-order tributaries, with sand sources mainly distributed in alluvial fans, floodplains, river terraces, and valley slopes. Inappropriate use of natural grasslands and large areas of exposed cultivated land in winter and spring significantly affect the formation and distribution of these sand sources, threatening ecosystem stability. Therefore, under the future urban development plan of "extending east-west and crossing south," the Lhasa River Basin urgently needs to adjust its urban development strategy, optimize land use layout, and consolidate achievements from the "Grain for Green" and "Returning Grazing Land to Grassland" programs. The ongoing Lhasa North-South Mountain Greening Project and river channel control and dam engineering should be further promoted to mitigate desertification risks caused by climate warming. Additionally, addressing grassland degradation requires measures such as limiting livestock development, rotational grazing, and irrigation to protect and improve grassland resources. These research results can provide theoretical guidance for coordinating economic development and environmental protection in territorial spatial planning for the Lhasa River Basin, though errors remain due to data precision limitations. Future research should improve data accuracy and focus on predictive simulation of future land use and ESV.

4 Conclusions

Based on high-precision land use data, this study analyzed land use structure and ESV evolution in the Lhasa River Basin from 2000 to 2020, and explored the impacts of natural and economic factors on land use change and ESV using the PLUS model and geographic detectors. The main conclusions are:

(1) Grassland dominated the land use pattern in the Lhasa River Basin from 2000 to 2020, accounting for 85.23% of the total basin area. The overall trend showed grassland reduction while other land types expanded, with grassland decreasing by 2.45% and construction land, water bodies, and forest land increasing by 21.97%, 199.72%, and 44.64%, respectively.

(2) Land use change was influenced by elevation, annual mean ground temperature, and distance from lakes. Elevation contributed most significantly to the expansion of cultivated land, forest land, water bodies, and construction land, while slope and annual mean ground temperature were the primary drivers of change in grassland and unused land.

(3) The total ESV of the basin increased by 1.14% (1.496 billion yuan) from 2000 to 2020. Grassland and climate regulation were the most prominent land use type and ecosystem service type, contributing approximately 87.13% and 25.50% of the total value, respectively.

(4) ESV exhibited significant spatial heterogeneity, influenced by NDVI, elevation, annual mean wind speed, and annual mean temperature. The explanatory power of NDVI reached 0.46, and the interaction between any two factors enhanced ESV differentiation, with interactions among natural factors being particularly prominent.

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