Analysis of Spatiotemporal Evolution of Ecosystem Service Value under Land Use Change in Xinjiang, 1980–2020: Postprint

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Abstract

Along with socioeconomic development, investigating the spatio-temporal evolution of ecosystem service value (ESV) under land use change is of great significance for optimizing land use structure and regional sustainable development. Based on Xinjiang land use data from 1980 to 2020, and with the support of ArcGIS and GeoDa, this study employs methods such as the unit area equivalent factor method and spatial autocorrelation to analyze the spatio-temporal evolution characteristics of ESV under land use change in Xinjiang. The results show that: (1) From 1980 to 2020, the main land use types in Xinjiang were grassland and unused land, together accounting for 91.00% of Xinjiang' s total area. The areas of cultivated land and construction land showed increasing trends, with increases of 58.89% and 166.79%, respectively; water area and forest land experienced the largest decreases, with reductions of 29.95% and 26.62%, respectively. (2) From 1980 to 2020, the overall ESV in Xinjiang exhibited a "first increase then decrease" trend, with a net decrease of 1114.51$×$10^8 yuan (6.68%). From a spatial distribution perspective, high-value and relatively high-value areas of ESV in Xinjiang were mainly distributed in the Altai Mountains, Kunlun Mountains, Tianshan Mountains (referred to as the "Three Mountains") and the Ili River Valley region; medium-value and relatively low-value areas were distributed in oasis regions; and low-value areas were mainly distributed in basin and desert regions. (3) From 1980 to 2015, ESV changes in Xinjiang were minimal, but from 2015 to 2020, ESV changes in the northern and central Tianshan regions were significant. From 2015 to 2020, high-value areas in the northern and central Tianshan regions decreased by 75.29%, being replaced by medium-value and relatively low-value areas; medium-value and relatively low-value areas increased by 13.64% and 10.78%, respectively; and low-value areas showed a trend of diffusion toward medium-value areas. (4) From the perspective of spatial autocorrelation of ESV, local correlation and hotspot analysis presented a spatial distribution characteristic of "high in the west and low in the east". High-high cluster areas and hotspot areas were distributed in the "Three Mountains" region, while low-low cluster areas and coldspot areas were distributed in basin and desert regions. The decline in water area and forest land area was one of the main reasons for the decrease in total ecosystem service value in Xinjiang from 2015 to 2020.

Full Text

Preamble

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Temporal and Spatial Evolution of Ecosystem Service Value Under Land Use Change in Xinjiang from 1980 to 2020

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Abstract: With socioeconomic development, investigating the spatiotemporal evolution of ecosystem service value (ESV) under land use change is crucial for optimizing land use structure and promoting regional sustainable development. Based on Xinjiang land use data from 1980 to 2020 and supported by ArcGIS and GeoDa, this study employs the unit area equivalent factor method and spatial autocorrelation analysis to examine the spatiotemporal evolution characteristics of ESV under land use change in Xinjiang. The results demonstrate that: (1) The dominant land use types in Xinjiang from 1980 to 2020 were grassland and unused land, collectively accounting for 91.00% of Xinjiang's total area. Cultivated land and construction land exhibited increasing trends, rising by 58.89% and 166.79%, respectively. Water bodies and forest land experienced the most substantial reductions, decreasing by 29.95% and 26.62%, respectively. (2) Overall, Xinjiang's total ESV followed a "first increase then decrease" trajectory from 1980 to 2020, with a net reduction of 1114.51$\times10^{8}$ yuan (6.68%). (3) Spatially, high-value and higher-value ESV zones were primarily concentrated in the Altai Mountains, Kunlun Mountains, and Tianshan Mountains (collectively termed the "Three Mountains") and the Ili River Valley. Medium-value and lower-value zones were distributed across oasis regions, while low-value zones were mainly located in basins and desert areas. (4) Between 2015 and 2020, the ESV in the northern and central Tianshan region changed dramatically. The high-value zone decreased by 75.29% and was replaced by medium-value and lower-value zones, which increased by 13.64% and

10.78%, respectively. (5) Spatial autocorrelation analysis revealed a consistent “west-high, east-low” distribution pattern. High-high concentration zones and hotspot areas were predominantly located in the “Three Mountains” and Ili Valley regions, whereas low-low concentration zones and cold spot areas were concentrated in basins and deserts. The decline in water body and forest land area represents a primary driver of the overall ESV reduction in Xinjiang.

Keywords: ecosystem service value; spatiotemporal evolution; land use change; Xinjiang

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Since the 18th National Congress of the Communist Party of China, ecological civilization construction has been positioned as a prominent priority in national governance, recognizing that a sound ecological environment is the most inclusive public welfare. Land use change directly impacts ecosystems, altering their structure and function, and consequently transforming ecosystem service value (ESV). Ecosystem services refer to the products and services that humans obtain from ecosystem structures, functions, and processes, encompassing provisioning, regulating, supporting, and cultural services. Recent years have witnessed abundant research achievements on ecosystem services both domestically and internationally.

Methodologically, research primarily employs the unit area equivalent factor method and the unit function value method. The former offers computational simplicity, strong operability, and rapid assessment capability for large-scale regions, making it widely applicable. The latter is complex, cumbersome to implement, and lacks unified standards for estimating each service value, limiting its widespread adoption. Research scales range from macro (national, provincial, municipal, watershed, urban agglomeration) to meso (grid-based units). Costanza et al. pioneered the monetary valuation of global ecosystem services, establishing evaluation principles and methods. Xie Gaodi and colleagues subsequently developed an equivalent factor table based on China’ s natural habitats and socioeconomic conditions, which has been widely applied.

Existing research on ESV under land use change in Xinjiang has primarily focused on specific watersheds such as Bosten Lake, Hotan River, and the Tarim River, as well as prefecture-level regions like Hotan. As China’ s largest provincial-level administrative region, Xinjiang covers 7.83% of the country’ s total area with abundant yet complex land resources, necessitating comprehensive ESV research. While some studies have analyzed temporal changes in Xinjiang’ s ESV, few have investigated its spatial distribution. This study addresses this gap by analyzing the spatiotemporal evolution of ESV under land use change in Xinjiang, providing a scientific basis for ecological conservation.

Based on four periods of land use data (1980, 1995, 2015, 2020) and supported by ArcGIS and GeoDa, this research employs the equivalent factor method and spatial autocorrelation analysis using 10 km$\times$10 km grids as calculation units to examine the spatiotemporal evolution characteristics of ESV under land use change in Xinjiang, offering reference insights for promoting regional sustainable development.

1.1 Study Area

Xinjiang Uygur Autonomous Region is located in northwestern China, deep within the Eurasian continent, bordering eight countries including Pakistan. Geographically positioned between 34°25 -48°10 N and 73°40 -96°18 E, Xinjiang covers approximately 2585.23$×10^{4}$ km^2. The region' s topography is characterized by alternating mountains and basins, with mountains surrounding basins in an embrace configuration, colloquially described as "three mountains sandwiching two basins." The Altai Mountains in the north, Kunlun Mountains in the south, and Tianshan Mountains in the center divide Xinjiang into northern and southern regions. Xinjiang has a typical temperate continental climate, with an average annual temperature of 8.7°C and average annual precipitation of 199.6 mm. By the end of 2020, Xinjiang' s permanent population reached 25.84 million.

1.2 Data Sources

Land use remote sensing data for Xinjiang in 1980, 1995, 2015, and 2020 were obtained from the Resources and Environmental Science and Data Center of the Chinese Academy of Sciences (www.resdc.cn). The data were generated through manual visual interpretation using Landsat TM/ETM imagery as the primary data source. Based on land resources and their attributes, land use types were classified into grassland, cultivated land, water bodies, forest land, construction land, and unused land. Grain yield, price, and planting area data were sourced from the *Xinjiang Statistical Yearbook* and *National Agricultural Product Cost-Benefit Data Compilation*.

1.3 Research Methods

1.3.1 Ecosystem Service Value Calculation This study adopts the unit area equivalent factor method based on Costanza's evaluation methodology and Xie Gaodi' s revised Chinese ecosystem service equivalent value table, adjusted according to Xinjiang' s socioeconomic development conditions. Construction land has minimal ESV with limited impact scope, and no reliable quantification method currently exists for its valuation. Following Xie Gaodi' s revised equivalent factor table, which excludes construction land ESV calculation, this study similarly omits construction land from ESV calculations.

The economic value of grain production per unit area in Xinjiang was calculated based on statistical data. According to the *Xinjiang Statistical Yearbook*, the average grain yield in Xinjiang from 2015 to 2020 was 5428.70 kg · hm^{-2}, with an average grain price of 2.45 yuan · kg^{-1}. Following the principle that "one standard ecosystem service economic value equivalent coefficient equals one-seventh of the economic value of food production per unit area of farmland," the

Xinjiang equivalent factor was calculated as 1902.45 yuan $\cdot$ hm^{-2}. Multiplying this with the revised equivalent table yielded the Xinjiang ecosystem service value coefficient table per unit area (Table 1).

The calculation formulas are as follows:

$$VC_0 = \frac{\sum_{i=1}^{n} m_i p_i q_i}{\sum_{i=1}^{n} m_i} \times \frac{1}{7}$$

where VC_0 is the equivalent value per unit area (yuan $\cdot$ hm^{-2}); i represents major grain types; m_i is the planting area of grain crop i (hm^2); p_i is the price of grain crop i (yuan $\cdot$ kg^{-1}); q_i is the yield per unit area of grain crop i (kg $\cdot$ hm^{-2}); and M is the total area of major grain crops in the study area.

$$ESV = \sum_{k=1}^{m} A_k \times VC_k$$

$$ESV_f = \sum_{k=1}^{m} A_k \times VC_{fk}$$

where A_k is the area of land use type k; VC_k is the ESV coefficient for land use type k; VC_{fk} is the coefficient of the fth service for land use type k; and ESV_f is the value of the fth ecosystem service.

1.3.2 Global Spatial Autocorrelation Analysis This study employs Moran' s I index to measure and test the global spatial autocorrelation of Xinjiang' s ESV at the 10 km$\times$10 km grid scale. Moran' s I characterizes the overall spatial change trend of ESV, with values ranging from -1 to 1. Values greater than 0 indicate positive spatial correlation, with larger values indicating more significant positive correlation and stronger spatial clustering. Values less than 0 indicate negative spatial correlation, and values approaching 0 indicate spatial randomness. The calculation formula is:

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \sum_{i=1}^{n} (x_i - \bar{x})^2}$$

where x_i and x_j are attribute values of grids i and j; $\bar{x}$ is the mean attribute value; w_{ij} is the spatial weight matrix; and n is the number of grids.

1.3.3 Local Spatial Autocorrelation Analysis Local spatial autocorrelation examines spatial heterogeneity and association in local regions. The local Moran' s I index characterizes local features of spatial correlation, identifying high-high or low-low clusters when local I values are significant. The formula is:

$$I_i = \frac{(x_i - \bar{x})}{S^2} \sum_{j=1}^{n} w_{ij}(x_j - \bar{x})$$

where S^2 is the variance of the attribute values.

1.3.4 Hotspot Analysis This study uses Getis-Ord G_i^* hotspot analysis to detect spatial distribution patterns of ESV hotspots and cold spots in Xinjiang. When the ESV change value of a region exceeds that of its neighbors, a hotspot forms, indicating high-value clustering. The opposite indicates cold spots. The formula is:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}x_j - \bar{x}\sum_{j=1}^{n} w_{ij}}{\sqrt{\frac{\sum_{j=1}^{n} w_{ij}^2 - (\sum_{j=1}^{n} w_{ij})^2}{n-1}}}$$

where w_{ij} is the spatial weight coefficient between spatial units i and j; $E(G_i^*)$ is the mathematical expectation of G_i^*; and $Var(G_i^*)$ is the variance of G_i^*.

2 Results and Analysis

2.1 Spatiotemporal Evolution of Land Use Types in Xinjiang

Analysis of Xinjiang' s land use area from 1980 to 2020 reveals that grassland and unused land were the dominant types, accounting for approximately 91.00% of the total area. Water bodies experienced the most significant reduction, decreasing by 1.51$\times10^{4}$ km^2 (29.95%). Forest land and unused land followed, decreasing by 1.00$\times10^{4}$ km^2 (26.62%) and 0.95$\times10^{4}$ km^2 (0.94%), respectively. Notably, grassland and unused land exhibited frequent mutual conversion, with the largest transfer area: 11.43$\times10^{4}$ km^2 of unused land converted to grassland, while 12.75$\times10^{4}$ km^2 of grassland converted to unused land. This dynamic reflects the transitional nature of desert grassland in Xinjiang, which facilitates frequent conversion between these two categories.

Cultivated land and construction land showed increasing trends, expanding by 3.33$\times10^{4}$ km^2 (58.89%) and 0.56$\times10^{4}$ km^2 (166.79%), respectively. This growth aligns with national land policies and sustainable development principles. Water body changes were particularly pronounced, with a dramatic decrease of 5.05$\times10^{4}$ km^2 (32.49%) from 2015 to 2020, likely attributable to climate change-induced reductions in snow storage, glacier melting, and rising equilibrium lines. Forest land decreased by 2.75$\times10^{4}$ km^2 (26.62%) from 1980 to 2020, with the most significant reduction (1.00$\times10^{4}$ km^2, 25.64%) occurring between 2015 and 2020.

The spatial distribution of land use transfer matrices (Figure 3) indicates that the most frequent changes occurred in the “Three Mountains” and oasis regions. Grassland and unused land conversion was particularly active, with unused land converting to grassland primarily in mountainous areas, while grassland converted to unused land mainly in oases. Under global climate change, glaciers across Xinjiang’ s three major mountain systems have retreated to varying degrees, improving microclimatic conditions in mountainous areas and facilitating the conversion of previously glacier-covered unused land to grassland. Conversely, intensified human activities and the shift from “warm-humid” to “warm-dry” climate conditions have destabilized oasis grasslands, making them more susceptible to conversion to unused land. Construction land expansion primarily resulted from cultivated land conversion, driven by socioeconomic development and urban sprawl.

2.2 Temporal Changes in Ecosystem Service Value

2.2.1 Total ESV Temporal Changes Based on Xinjiang land use data and ESV coefficients, the temporal changes in total ESV were calculated (Figure 4). Xinjiang’ s total ESV exhibited a “first increase then decrease” pattern, rising from 166.95$×10^{8}$ yuan in 1980 to 167.51$×10^{8}$ yuan in 1995 (a 0.34% increase), then gradually declining to a minimum of 155.80$×10^{8}$ yuan in 2020. The most rapid decline occurred between 2015 and 2020, with a reduction of 11.324$×10^{8}$ yuan (6.78%). Analysis reveals that the large-scale reduction of forest land and water bodies, which have high ESV coefficients, was a primary cause of this decline.

2.2.2 Temporal Changes in Individual ESV Components Among individual ecosystem service values, only food production value showed a slight increase, while all other services decreased to varying degrees (Table 2). Water regulation, waste treatment, aesthetic landscape, and raw material production values experienced the largest declines, decreasing by 15.39%, 11.07%, 8.72%, and 6.19%, respectively, directly contributing to the overall ESV reduction. The increase in food production value benefited from expanded cultivated land and grassland areas. Water regulation, waste treatment, aesthetic landscape, and raw material production values changed minimally before 2015 but declined sharply thereafter, primarily due to substantial reductions in water body and forest land areas—both critical ecosystems for water conservation, soil conservation, carbon sequestration, and global material and water cycling.

In terms of ESV composition, the proportional contributions of individual services to the total ESV remained relatively stable: water regulation (20.45%), biodiversity (18.23%), waste treatment (15.36%), and soil conservation (11.07%). Collectively, these four services accounted for approximately 65.11% of the annual total ESV.

2.3 Spatial Analysis of Ecosystem Service Value

2.3.1 Spatial Distribution of ESV To further investigate the spatiotemporal evolution characteristics of ESV, this study applied a grid-based approach to partition the study area. After comprehensively considering the area of the study region and the scale effects of minimum mappable units on calculation results, 10 km $\times$ 10 km grids were selected as the optimal unit size through iterative testing. ESV was spatially visuali low (0–0.6×10^{8} yuan), lower (0.6×10^{8}–1.3×10^{8} yuan), medium (1.3×10^{8}–2.2×10^{8} yuan), higher (2.2×10^{8}–3.8×10^{8} yuan), and high (3.8×10^{8}–6.9×10^{8} yuan).

The spatial distribution of ESV in Xinjiang was distinct, showing an overall "west-high, east-low" pattern aligned with the "three mountains sandwiching two basins" topography (Figure 5). High and higher-value zones were concentrated in the "Three Mountains" and Ili River Valley, where vegetation was lush and water resources and biodiversity were abundant. Medium and lower-value zones were distributed in oases with sparser vegetation and greater human impact. Low-value zones were primarily located in basins and deserts with low vegetation cover and fragile ecological environments.

From 1980 to 2015, the spatial distribution of ESV 等级 changed minimally. However, between 2015 and 2020, dramatic changes occurred, particularly in the northern and central Tianshan region. To analyze this area in detail, a finer 5 km $\times$ 5 km grid resolution was applied. In this region, total ESV decreased from 6255.92×10^{8} yuan in 2015 to 5391.20×10^{8} yuan in 2020, a reduction of 864.72×10^{8} yuan (13.82%). This decline was primarily driven by conversions of water bodies and forest land to grassland and cultivated land. Water body conversion to grassland and unused land occurred mainly in the Tianshan Mountains, while forest land conversion to cultivated land occurred primarily in oases. The reduction of forest land in the Tianshan region may be associated with forestry activities such as logging.

2.3.2 Spatial Distribution of ESV in the Northern and Central Tianshan Region (2015–2020) The Tianshan Mountain system comprises the North, Central, and South Tianshan. This study focuses specifically on the North and Central Tianshan, where changes were most significant. High and higher-quality zones showed decreasing trends, with high-quality zones declining most dramatically by 75.29%. The spatial distribution pattern shifted from concentrated to dispersed. Medium and lower-quality zones increased by 13.64% and 10.78%, respectively, and were mainly distributed in oases with intensive human activity, showing a tendency to expand into high and higher-quality zones. Low-quality zones increased by 2.36% and expanded toward medium-quality zones.

Spatially, the northern Tianshan slope saw increases in medium and lower-quality zones, primarily converted from high and higher-quality zones. This reduction may be related to the development of the Tianshan North Slope Economic Belt, where over half of the cultivated and construction land is located in baseline and crisis ecological spaces, creating significant ecological security conflicts that exacerbate salinization and desertification processes. On the southern Tianshan slope, the reduction of high and higher-quality zones was closely related to the conversion of water body areas.

2.3.3 Spatial Autocorrelation Analysis of ESV Global spatial autocorrelation analysis using Moran' s I index revealed that all four periods showed Moran' s I values above 0.75 with P-values less than 0.01, indicating significant spatial positive correlation and clustering of ESV across Xinjiang at the 0.01 significance level. However, Moran' s I values gradually decreased from 1980 to 2020, suggesting a weakening trend in spatial positive correlation.

Local spatial autocorrelation and hotspot analysis (Figure 7) showed consistent patterns, revealing a "west-high, east-low" distribution. High-high concentration zones and hotspots were concentrated in the "Three Mountains" and Ili Valley regions. Low-low concentration zones and cold spots were concentrated in basins and desert areas. Non-significant areas were uniformly distributed across the region. From 2015 to 2020, both high-value and low-value clustering intensified, though low-value clustering remained dominant. The enhancement of high-value clustering resulted from the transformation of low-value zones to medium-value zones, while low-value clustering shifted from dispersed to concentrated distribution.

3 Discussion

Water resources from the Tianshan Mountains sustain production and livelihood activities across both slopes of the range. Climate warming has caused glacier retreat and melting, reducing water supply and exacerbating drought and desertification. The most significant reductions in Xinjiang' s water body and forest land areas occurred after 2015, with dramatic declines in 2020. Given their high ESV coefficients and ecological importance, these reductions substantially impacted Xinjiang' s total ESV. Agricultural irrigation and socioeconomic development have also consumed substantial water resources in the Tianshan region.

From 2015 to 2020, Xinjiang implemented the policy of inter-provincial adjustment of surplus indicators for urban-rural construction land, contributing to construction land expansion. Construction land area increased from 0.34×10^{4} km^2 in 1980 to 0.90×10^{4} km^2 in 2020, including large-scale water conservancy facilities. These facilities, requiring specific topographical conditions, are primarily distributed in river and mountain areas, converting forest and grassland in mountainous regions. Xinjiang' s population grew rapidly from 12.83 million in 1980 to 25.84 million in 2020, with both population growth and economic development closely linked to land use changes.

These findings align with previous research on the Hotan region and Tarim River

Basin, which reported declining ESV due to reduced forest and water body areas and deteriorating ecological quality. However, they differ somewhat from Liu Chuan et al.' s study, which calculated an ESV increase from 309.70$×10^{8}$ yuan in 1996 to 13797.58$×10^{8}$ yuan in 2015 (0.75% annual growth) using detailed land survey data from the Xinjiang Department of Land and Resources. The discrepancy may stem from differences in data sources (survey data vs. remote sensing data) and time periods.

4 Conclusions

(1) From 1980 to 2020, grassland and unused land accounted for approximately 91.00% of Xinjiang' s total land area. Cultivated land and construction land increased by 58.89% and 166.79%, respectively, while water bodies and forest land decreased by 29.95% and 26.62%, respectively. The conversion area between unused land and grassland was the largest.

(2) Xinjiang's total ESV exhibited a "first increase then decrease"trend, with a net reduction of 6.68% (1114.51$×10^{8}$ yuan). The reduction in water body and forest land area was a primary cause of ESV decline. Spatially, high and higher-value ESV zones were concentrated in the "Three Mountains"and Ili Valley, medium and lower-value zones in oases, and low-value zones in basins and deserts.

(3) Between 2015 and 2020, the ESV in the northern and central Tianshan region changed significantly, shifting from concentrated to dispersed distribution. High-value and higher-value zones decreased by 75.29% and 4.83%, respectively, being replaced by medium-value and lower-value zones. Low-value zones showed a tendency to shift toward medium-value zones.

(4) Spatial autocorrelation analysis revealed a "west-high, east-low" distribution pattern. High-high concentration zones and hotspots were concentrated in the "Three Mountains"and Ili Valley, while low-low concentration zones and cold spots were concentrated in basins and deserts.

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