Postprint: Impact of Land Use Change on Carbon Storage Dynamics in Gansu Province

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Abstract

The amount of carbon storage in terrestrial ecosystems is closely related to the global climate crisis. Using the InVEST model and ArcGIS software, along with three-phase land use data (2000, 2010, and 2020) for Gansu Province, a dynamic assessment and analysis of land use type changes and carbon storage was conducted. The results show that: (1) From 2000 to 2020, the area of unused land and cultivated land decreased significantly, while the area of construction land, grassland, forest land, and water bodies showed an increasing trend. Land type conversions were primarily between grassland and cultivated land. (2) The cumulative carbon storage in Gansu Province increased by 331.24$×$104 t from 2000 to 2020, exhibiting an initial increase followed by a decrease. (3) The conversion of unused land to cultivated land and grassland to forest land promoted the increase in regional carbon storage, while the primary factors limiting regional carbon storage increase were the conversion of cultivated land to construction land and grassland to unused land. The research results can serve as a reference for future land use planning and ecological construction in Gansu Province.

Full Text

Impact of Land Use Change on Carbon Storage in Gansu Province

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Abstract

There is a close relationship between carbon stock in terrestrial ecosystems and the global climate crisis. Based on land use data for three periods (2000, 2010, and 2020) in Gansu Province, this study employs the InVEST model and ArcGIS software to dynamically assess and analyze changes in land use types and carbon storage. The results indicate that: (1) Between 2000 and 2020, unused land and arable land areas decreased significantly, while construction land, grassland, forest land, and water bodies showed increasing trends. Land type transitions were primarily dominated by conversions between grassland and arable land. (2) The cumulative increase in carbon stock in Gansu Province from 2000 to 2020 amounted to 331.24$×10^{4}$ t, following a trend of initial increase followed by subsequent decline. (3) The conversion of unused land to arable land and grassland to forest land promoted regional carbon stock enhancement, while the conversion of arable land to construction land and grassland to unused land represented the primary constraints on regional carbon stock increase. These findings provide valuable references for future land use planning and ecological construction in Gansu Province.

Keywords: carbon stock; land use type; InVEST model; Gansu Province

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Introduction

Under the background of global climate change, land use/cover change exerts significant impacts on ecosystem service functions. Since China' s reform and opening-up, accelerated urbanization has made the country the world' s largest carbon emitter. Consequently, reducing atmospheric CO_2 concentration, regulating regional climate, mitigating climate change, and maintaining ecological balance have become critical tasks. Terrestrial ecosystem carbon stock plays a pivotal role in addressing the global climate crisis; however, land use type transitions alter carbon sources and sinks, thereby affecting ecosystem carbon cycling. The InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) model has been widely applied due to its operational convenience, simple data requirements, and accurate simulation capabilities. For instance, researchers such as Xu Aokang et al. and Du Huaiyu et al. have used the InVEST model to analyze carbon storage changes caused by land use in the Shiyang River Basin, demonstrating that grassland, unused land, and arable land contribute most significantly to carbon stock and that carbon storage would increase substantially under ecological protection scenarios. Lei Xin et al. calculated carbon storage in the Qilian Mountains region using the InVEST model, while Cui Xie et al. analyzed and predicted carbon storage changes on the Loess Plateau under climate change scenarios. Additionally, land use type changes directly affect ecosystem energy exchange and material cycling, altering the spatiotemporal distribution patterns of regional habitats, which represents a primary cause of global habitat loss and species diversity reduction. Therefore, exploring regional carbon storage changes based on land use data holds significant importance for ecological environment protection and biodiversity maintenance.

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1 Study Area Overview

Gansu Province (Figure 1) is located at the intersection of the Qinghai-Tibet Plateau, Loess Plateau, and Mongolian-Xinjiang Plateau, with elevations ranging from 559 to 5,856 meters. The terrain slopes from high in the south to low in the northeast, forming a narrow and elongated shape. It borders Shaanxi to the east, Qinghai to the south, Xinjiang to the west, and Inner Mongolia and Ningxia to the north. The province experiences uneven spatial distribution of annual precipitation (40–750 mm) and mean annual temperatures of 0–15°C, forming humid, semi-humid, semi-arid, and arid zones from southeast to northwest. The total area of Gansu Province is 425,800 km^2, with unused land, grassland, and arable land being the dominant land use types. By 2020, construction land area reached 5,564.31 km^2 (1.31% of total area), while unused land covered 170,030.48 km^2 (39.96%). Natural forests such as mixed broadleaf forests, fir forests, and spruce forests constitute the primary carbon stock sources in Gansu Province.

[Figure 1: see original paper]

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2 Data and Methods

2.1 Data Sources

This study selected three periods (2000, 2010, and 2020) of land cover data for Gansu Province, obtained from the Resource and Environmental Science and Data Center (https://www.resdc.cn/) with a spatial resolution of 30 m × 30 m. Parameters for carbon storage and habitat quality estimation were derived from existing research and calibrated according to climatic conditions in Gansu Province. DEM data were obtained from the Geospatial Data Cloud (https://www.gscloud.cn/home).

2.2 Methods

2.2.1 Land Use Type Change Analysis The land use transfer matrix can intuitively display dynamic change information between different land use types across different periods, revealing distribution characteristics and spatiotemporal evolution patterns to analyze the impact of land use type transitions on regional carbon storage. The calculation formula is:

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

where S represents land area, i denotes the initial land use type, j denotes the final land use type, and n represents the number of land categories.

2.2.2 InVEST Model Carbon Storage Estimation Carbon stock is calculated by multiplying the average carbon density of four carbon pools (aboveground biomass, belowground biomass, soil organic carbon, and dead organic matter) for each land use type by the corresponding land area. The carbon storage calculation formula is:

$$C_{total} = \sum_{k=1}^{n} (C_{above,k} + C_{below,k} + C_{soil,k} + C_{dead,k}) \times A_k$$

where C_{total} is the regional ecosystem carbon stock (t), $C_{above,k}$, $C_{below,k}$, $C_{soil,k}$, and $C_{dead,k}$ represent aboveground biomass carbon density, belowground biomass carbon density, soil organic carbon density, and dead organic matter carbon density ($\mathrm{t \cdot hm^{-2}}$) for land use type k, respectively, and A_k is the area of land use type k ($\mathrm{hm^2}$). Soil, belowground, and aboveground carbon density data in this study were derived from Ren Xijin et al.' s research, while dead organic carbon density data were calculated using meteorological factor correction formulas proposed by other researchers. The carbon density correction table for Gansu Province is shown in Table 1.

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3 Results

3.1 Land Use Change Analysis

3.1.1 Land Use Structure Changes Land use type areas in Gansu Province from 2000 to 2020 are shown in Table 2. The province is dominated by unused land, grassland, and arable land, with extensive unused land distributed throughout the northwest and large areas of arable land, grassland, and forest land in the southeast. Arable land is primarily dryland, gradually increasing from northwest to southeast.

Between 2000 and 2020, unused land area continuously decreased by 2,706.20 km^2, while grassland area steadily increased by 998.27 km^2. Arable land area decreased by 1,710.19 km^2. Forest land area increased by 862.74 km^2, and water body area increased minimally by 537.83 km^2 due to scarce water resources in the Loess Plateau region. Construction land continued to expand with ongoing urbanization, increasing by 1,995.42 km^2 (55.91% growth), primarily in Jiayuguan, Jinchang, Lanzhou, and Baiyin cities.

3.1.2 Land Use Transfer Types Specific changes in land use types in Gansu Province from 2000 to 2020 are illustrated in Figure 2. Among the six major land use types, grassland showed the largest outflow area (6,181.06 km^2), primarily converting to arable land (45.87%) and unused land (21.27%), with smaller proportions converting to forest land, water bodies, and construction land. Arable land outflow reached 5,233.10 km^2, mainly converting to grassland and construction land. Unused land outflow totaled 4,269.38 km^2, primarily converting to arable land (35.85%) and grassland (36.39%). Forest land outflow was 960.68 km^2, mainly converting to grassland and arable land. Water body and construction land outflows were minimal at 231.34 km^2 and 323.60 km^2, respectively.

Regarding inflow areas, grassland and arable land dominated with 6,244.69 km^2 and 4,473.65 km^2, respectively, primarily receiving transfers from each other. Forest land and unused land had similar inflow areas, mainly receiving transfers from grassland. Water bodies had the smallest inflow area at only 770.43 km^2.

[Figure 2: see original paper]

3.2 Carbon Storage Changes

3.2.1 Temporal Carbon Storage Variation Based on the InVEST Carbon Storage and Sequestration module, carbon storage in Gansu Province for 2000, 2010, and 2020 was calculated (Table 3). Total carbon stocks were 336,892.79$\times 10^{4}$ t, 338,029.01$\times 10^{4}$ t, and 337,224.03$\times 10^{4}$ t, respectively, showing an initial increase followed by a decrease with a cumulative increase of 331.24$\times 10^{4}$ t and a growth rate of 0.10%. Analysis of individual carbon pools revealed that soil organic carbon storage was the largest, accounting for approximately 70% of total carbon storage, followed by belowground carbon storage at about 20%, aboveground carbon storage at roughly 8%, and dead organic matter carbon storage at approximately 2%.

The spatial distribution of carbon storage gradually increased from northwest to southeast (Figure 3). High carbon stock values were concentrated in Gannan Tibetan Autonomous Prefecture, Longnan City, and parts of Wuwei and Qingyang, where extensive grassland and forest land provide good ecological conditions. Medium values were distributed throughout the province but concentrated in the southeast, while low values occurred in the northwest due to large areas of unused land. This pattern aligns with land use type distribution, where forest and grassland areas store more carbon and unused land and construction land store less.

[Figure 3: see original paper]

3.2.2 Impact of Land Use Type Conversion on Carbon Storage Based on the land use transfer matrix and carbon density data for each land use type, the impact of land use type conversion on carbon storage in Gansu Province was analyzed (Figure 4). From 2000 to 2020, carbon stock increased cumulatively by 331.24×10^{4} t, with soil organic carbon storage increasing by 271.61×10^{4} t and vegetation carbon storage increasing by 113.63×10^{4} t. However, due to conversions from arable land, grassland, and forest land, carbon storage decreased cumulatively by $2,790.28\times10^{4}$ t. Specifically, carbon storage reductions from arable land, forest land, and grassland conversions accounted for 85.32% of total regional carbon storage loss, with conversions from arable land to construction land and grassland to unused land being most significant.

Carbon storage increases from water body, construction land, and unused land conversions accounted for 92.71% of total regional carbon storage gain, with unused land converting to arable land and grassland contributing most substantially. Land conversion types with small area fluctuations exhibited minor carbon storage fluctuations, maintaining relatively stable levels, such as construction land converting to grassland and water bodies, and water bodies converting to forest land. Although arable land to grassland conversion had the largest area, it resulted in only a small net carbon storage increase due to increased vegetation carbon but decreased soil carbon, likely requiring substantial recovery time before entering a carbon sequestration phase after conversion.

Large-area conversions from low-carbon-density types (arable land and grassland to forest land, unused land to arable land and grassland) increased carbon storage, while conversions from high-carbon-density types (arable land to construction land, grassland to unused land) decreased carbon storage. Conversions to forest land, which has the highest carbon density, substantially increased vegetation area and carbon accumulation, while forest land conversion to any other type damaged carbon storage accumulation.

[Figure 4: see original paper]

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4 Discussion

This study reveals that from 2000 to 2020, land use type areas in Gansu Province changed significantly, with construction land increasing by 1,995.42 km^2, water bodies, forest land, and grassland increasing by 537.83 km^2, 862.74 km^2, and 998.27 km^2 respectively, while arable land and unused land decreased by 1,710.19 km^2 and 2,706.20 km^2 respectively. Total terrestrial ecosystem carbon storage was 336,892.79$\times10^{4}$ t, 338,029.01$\times10^{4}$ t, and 337,224.03$\times10^{4}$ t for 2000, 2010, and 2020, showing an initial increase followed by decrease, with a cumulative increase of 331.24$\times10^{4}$ t. Land use type conversions were dominated by exchanges among arable land, grassland, and unused land, with carbon storage increasing to some extent and ecological conditions improving, consistent with findings from Ren Xijin et al.

The primary reasons include rapid economic development, population growth, and urbanization forcing conversions to construction land to meet development demands, coupled with major ecological projects implemented in Gansu Province in recent years, including the Grain-for-Green Program and comprehensive ecological protection and restoration initiatives, which spatially explain why land use changes were more dramatic around urban areas. Increased precipitation and temperature benefit vegetation growth, though excessively high temperatures can dry soils and inhibit vegetation. Carbon storage increased across both periods, mainly benefiting from ecological projects such as the Grain-for-Green Program, desertification control, and artificial oasis expansion, which increased the area of high-carbon-density forest land and grassland.

This study also demonstrates that construction land expansion and arable land reduction constrain carbon storage increases, consistent with findings from Xiang Shujiang et al. While research results align with actual conditions, carbon density parameters lacked interannual variation, making land use type change the primary driver of carbon storage variation. Due to current limitations, carbon density data were not measured directly, and factors such as soil microbial activity and vegetation photosynthetic rates were not considered, requiring further investigation.

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5 Conclusions

(1) From 2000 to 2020, land use types in Gansu Province underwent dramatic changes, dominated by conversions among arable land, grassland, and unused land, with carbon storage increasing to some extent.

(2) The conversion of unused land to arable land and grassland to forest land promoted regional carbon stock enhancement, while the conversion of grassland to unused land and arable land to construction land constrained regional carbon stock increase.

(3) Under current "dual carbon" goals, assessing regional terrestrial ecosystem carbon stock and sequestration capacity represents an important indicator for evaluating ecosystem service value and holds significant meaning for achieving China' s carbon peak and neutrality strategic objectives. Gansu Province features fragile ecology and severe soil erosion; therefore, evaluating the relationship between land use types and ecosystem service carbon

storage can provide scientific foundations for ecosystem management and emission reduction policies, holding important significance for coordinating regional ecological protection and construction.

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