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Spatiotemporal Evolution and Driving Forces of Built-up and Cropland Landscapes in the Taihu Basin: Postprint

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Abstract

Using land use datasets from 2000, 2010, and 2015 as data sources, this study employs gridding, landscape gradient, Logistic regression model, and CLUE-S model to analyze the spatiotemporal evolution characteristics and driving mechanisms of construction land and cultivated land landscapes in the Taihu Lake Basin. The research results indicate: during 2000-2015, the trend of increasing construction land landscape area and decreasing cultivated land landscape area in the basin was significant. High construction land landscape gradient zones were mainly concentrated in urban areas along the Shanghai-Nanjing railway line, gradually expanding to surrounding areas, especially in the surrounding areas of Suzhou, Wuxi, Changzhou, Shanghai, and Hangzhou, where the degree of dynamic change was most significant, while the dynamic change amplitude was relatively smaller in existing large city centers and the western and southwestern hilly areas. The changes in both landscape types were deeply influenced by natural environment and socio-economic factors, with the latter being the primary driving factor. Based on CLUE-S model simulations, the spatiotemporal evolution of the two landscape types in 2030 under different scenarios showed significant differences; under the natural development scenario, the area of construction land in high landscape gradient value intervals was the largest; under the ecological protection scenario, the increase in construction land was significantly reduced, but cultivated land still decreased substantially, mostly converted to ecological land; whereas under the cultivated land protection scenario, the area of cultivated land in high landscape gradient value intervals was the largest. The study reveals the spatial regularity of the process of cultivated land being occupied by construction land in the basin, thus providing a basis for land management decision-making and urban planning and construction in the Taihu Lake Basin, and offering certain reference and guidance for resolving the contradiction between economic construction and land use in the basin.

Full Text

Preamble

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Analysis of Spatial-Temporal Evolution and Its Driving Forces of Construction Land and Cultivated Land Landscape in Taihu Lake Basin

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Abstract: Based on land-use satellite image datasets from 2000, 2010, and 2015, this study integrated grid transformation, landscape gradient analysis, logistic regression modeling, and the CLUE-S model to analyze the spatial-temporal evolution and driving mechanisms of construction land and cultivated land landscapes in Taihu Lake Basin. The results showed that from 2000 to 2015, construction land area increased significantly while cultivated land area decreased substantially. High-gradient construction land landscapes were concentrated along the Shanghai-Nanjing railway corridor and gradually expanded to surrounding areas, particularly in the peripheral zones of metropolises. The most prominent changes occurred in Suzhou, Wuxi, Changzhou, Shanghai, and Hangzhou. The maximum increase in construction land reached 0.92 km^2 per unit area, and the proportion of construction land with high landscape gradient values ($50 < DI$ 100) increased from 3.02% to 31.27%. The maximum reduction of cultivated land was 0.95 km^2. However, changes remained relatively small in the centers of original metropolises and the western and southwestern hilly areas. Both landscape types were deeply influenced by natural environment and socio-economic factors, with the latter being the dominant driving force. According to CLUE-S model simulations, significant differences existed in the spatial-temporal evolution of both landscapes under different scenarios for 2030. The natural development scenario would yield the largest area of high-gradient construction land. Under ecological protection scenarios, construction land increase would slow down, but cultivated land would still be significantly reduced, mostly converted to ecological land. Under cultivated land protection scenarios, the area of high-gradient cultivated land would be the largest. This study reveals the spatial regularity of cultivated land being occupied by construction land in the basin, providing a basis for land management decision-making and urban planning in Taihu Lake Basin, and offering references for resolving contradictions between economic development and land use.

Keywords: grid transformation; landscape gradient; spatial-temporal evolution; driving forces; CLUE-S model; Taihu Lake Basin

Introduction

In landscape ecology, a landscape is a geographic unit composed of different ecosystem types forming a mosaic pattern with repetitive configurations and high spatial heterogeneity—an inherently heterogeneous and patchy spatial unit [3]. Landscape pattern refers to the arrangement of landscape elements with varying shapes and sizes in space, representing the type, number, spatial distribution, and configuration of landscape composition units [4]. Research on spatial-temporal dynamics constitutes a core component and hot topic in landscape ecology [5-8], serving as the spatial manifestation of landscape heterogeneity. With advancing urbanization, construction land continuously expands while large areas of cultivated land are occupied. As the most fundamental land resource, the increasing reduction of cultivated land during urbanization will impact regional ecosystem coordination [9], while spatial expansion of construction land represents a significant characteristic of urbanization [10]. Consequently, the spatial-temporal evolution of construction land and cultivated land landscapes has become a hot research area in landscape pattern studies. Scholars have conducted extensive research on the spatial-temporal evolution and driving mechanisms of construction land and cultivated land landscapes separately [11-15].

Landscape pattern exhibits hierarchical characteristics that depend on scale dependency, making scale effects a prerequisite for correctly understanding landscape patterns [16-17]. Gradient analysis effectively reveals the spatial distribution patterns of research objects, facilitating better analysis of their temporal dimensions. Recently, many scholars have integrated landscape ecology with gradient analysis, though most landscape gradient studies are based on transects [16-21], with few examining the entire study area. Analysis of driving mechanisms behind landscape pattern evolution is also a current research hotspot [22]. Among various quantitative analysis methods for driving factors, regression model analysis offers strong variable interpretability [23] and better analyzes relationships between multiple independent variables and a single dependent variable [24]. The CLUE-S model demonstrates significant advantages in simulating competitive transfer relationships among multiple landscape types [25-26] and scenario simulation prediction [27-28], enabling better spatial expression of future landscape patterns. This study employs grid technology, landscape gradient analysis, logistic regression modeling, and CLUE-S model to reveal the spatial-temporal evolution characteristics and driving mechanisms of construction land and cultivated land landscapes in Taihu Lake Basin from 2000-2015, and conducts simulation predictions for future landscape patterns under different scenarios, providing references for sustainable land use, development, and urban planning in Taihu Lake Basin.

1. Study Area Overview

Taihu Lake Basin is located at 119°11 -121°53 E, 30°28 -32°15 N, adjacent to the Qiantang River and Hangzhou Bay in the south, bordered by Tianmu Mountain in the west, and representing the core region of the Yangtze River Delta. Surrounded by rivers on three sides and facing the sea, the basin includes southern Jiangsu Province, Jiaxing and Huzhou cities in Zhejiang Province, and parts of Hangzhou City, covering most of Shanghai. The region features a subtropical monsoon climate with hot, rainy summers and mild, humid winters. The terrain slopes from high in the west to low in the east, with plains in the east and mountainous hills in the west, forming a dish-shaped topography [29-30]. Natural vegetation is dominated by subtropical evergreen broad-leaved forests, with deciduous broad-leaved forests and bamboo forests also distributed in hilly areas. In 2000, the basin' s total population exceeded the national average population density. With superior natural conditions and a strong economic foundation, Taihu Lake Basin has become one of China' s regions with the most rapid urbanization and social development, though its per capita cultivated land area is only 0.04 hm^2, less than the national average.

2. Data Sources and Processing

Land-use datasets from 2000, 2010, and 2015 served as data sources. The 2000 data were obtained from the National Earth System Science Data Sharing Platform (http://www.geodata.cn/), with original data used as classification reference samples. Combined with actual conditions in Taihu Lake Basin, Landsat 8 OLI remote sensing data from Geospatial Data Cloud (http://www.gscloud.cn/) were radiometrically calibrated and atmospherically corrected, then classified using decision tree methods. Accuracy assessment referenced the "Technical Regulations for the Second National Land Survey" [31] issued by the Ministry of Land and Resources in 2007 and classification categories from the sharing platform' s original data. The study area was divided into six primary landscape types: cultivated land, forest land, grassland, construction land, water bodies, and unused land. Based on principles of scientificity, representativeness, and accessibility in driving factor selection, 11 driving factors were constructed for logistic regression analysis of construction land transfer-in and cultivated land transfer-out changes during 2000-2010 and 2010-2015. DEM data were obtained from ASTER GDEM V2 global digital elevation data from Geospatial Data Cloud; population data were obtained from the Chinese Academy of Sciences Resource and Environmental Science Data Center (http://www.resdc.cn/). Transportation network data were used to calculate distances to county centers, railways, highways, county roads, and rivers. After spatial processing and rasterization of driving factors, multi-layer raster attribute data with spatial consistency were extracted to obtain slope and other parameters. Changed and unchanged landscapes were separately sampled for driving mechanism analysis.

[Figure 1: see original paper] Location of the study area
[Figure 2: see original paper] Distribution of landscape type patches in Taihu Lake Basin
I: Cultivated land; II: Forest land; III: Grassland; IV: Construction land; V: Water bodies; VI: Unused land

3. Methods

3.1 Grid Method

Establishing a grid over the study area allows focusing a particular landscape type within individual grid cells rather than dispersing it uniformly across the entire basin, thereby compensating for the limitation of using basin averages to represent landscape distribution and enabling more reasonable analysis of basin landscape spatial-temporal evolution characteristics [32]. Grid analysis methods are closely related to grid size and exhibit scale effects [33]. Referencing relevant grid landscape ecology studies [34-35], the optimal landscape sample area is 2-5 times the average patch area. This study selected 6 km × 6 km grids as the basic evaluation units.

3.2 Landscape Gradient

Landscape gradient refers to the area occupancy rate of a particular landscape type within a unit grid, effectively reflecting landscape change characteristics and trends [36-38]. Larger gradient values indicate denser distribution of a landscape type, with spatio-temporal changes in gradient values reflecting disturbance and degradation processes [36]. The expression is:

$$DI = CA / CAi$$

where DI is the landscape gradient value for a certain type, CA is the area of that landscape within a unit grid, and CAi is the total area of different landscape types within the unit grid. This study overlaid spatial grids with construction land and cultivated land landscape data from different periods, calculated the area percentage of both landscape types in each grid, and interpolated to obtain landscape gradients. Based on actual basin conditions and referencing relevant studies [36-38], the natural breaks method in ArcGIS was used to classify landscape gradient levels.

3.3 Logistic Regression Model

The logistic regression model is established for dichotomous dependent variables with continuous or mixed independent variables [39-40]. The model form is:

P = 1 / (1 + e^(-(+ ixi)))

where P is the probability of event occurrence, xi are factors influencing probability distribution, is the constant term, and i are regression coefficients. Regarding goodness-of-fit, the ROC method [23,41] was used for testing, indicating that selected driving factors have good explanatory power and the model fits well.

3.4 CLUE-S Model

The CLUE-S model includes non-spatial and spatial modules. The spatial module, based on natural and socio-economic driving factor analysis, accounts for both natural and socio-economic factors in landscape pattern driving forces [42] to calculate demand changes for landscape types in simulated years. Using rasterized layers of driving factors as the foundation, spatial allocation of landscape type demands for simulated years is conducted according to landscape type probabilities and rules [43]. Model inputs include: 1. Policy restriction areas: No restricted areas were set, allowing landscape changes throughout the entire study area. 2. Landscape type conversion rules and elasticity coefficients: By setting all elements in the transfer matrix to 1, all landscape types were defined as convertible. After multiple simulation adjustments, the conversion elasticity parameters for three scenarios are shown in Table 1. 3. Landscape type demand file settings: The Markov model probability transfer matrix was adjusted for different scenarios, then linear interpolation was used to obtain the demand file for the CLUE-S model. 4. Relationship between spatial patterns and driving factors: Stepwise regression analysis calculated quantitative relationships between landscape type spatial patterns and driving factors.

The ROC method [41,43] was used to test regression effects, obtaining ROC values for each landscape type. Selected driving factors showed good explanatory power for all landscape types. The Kappa index [44] tested consistency between simulated and actual landscape type maps, with overall accuracy for three scenario simulations reaching 0.85.

4. Results and Analysis

4.1 Spatial-Temporal Evolution Analysis of Construction Land and Cultivated Land Landscapes

From 2000 to 2015, the trend of increasing construction land landscape area and decreasing cultivated land landscape area was evident. High-gradient construction land areas were concentrated along the Shanghai-Nanjing railway corridor cities and gradually expanded outward, especially in Shanghai and Hangzhou peripheries, where dynamic changes were most significant. The maximum construction land increase reached 0.92 km^2 per unit area, with the proportion of high-gradient construction land ($50 < DI$ 100) increasing from 3.02% to 31.27%. The maximum cultivated land reduction was 0.95 km^2. In contrast, changes remained relatively small in centers of original metropolises and western/southwestern hilly areas. Both landscape types were deeply influenced by natural environment and socio-economic factors, with the latter being the dominant driving force.

[Figure 3: see original paper] Distribution of construction land and cultivated land landscape gradient in Taihu Lake Basin

In 2000, high-gradient construction land landscapes were mainly concentrated in the Shanghai-centered zone and peripheries of Suzhou, Changzhou, and southern Hangzhou, occupying relatively small areas. Construction land with gradient values in the 50-100 interval accounted for only 3.02% of the basin area. Cultivated land landscapes were relatively dense in other areas, with cultivated land area reaching 25,298.06 km² (68.69% of total basin area). By 2010, construction land landscapes showed clear spatial expansion trends, with the scale of existing construction land agglomeration areas expanding, especially near Shanghai where landscape gradient values increased significantly. Construction land in Kunshan and Jiangyin also increased further, with gradient values in the 50-100 interval reaching 12% of basin area. The maximum unit area change reached 0.33-1 km². However, due to relatively high existing urbanization levels in city centers, increases there were smaller. Over the 10-year period, construction land increased by 3,990.78 km², with 97.58% converted from cultivated land (17.92% of cultivated land changes). The maximum unit area reduction of cultivated land reached 0.30-1 km².

From 2010 to 2015, high-gradient construction land areas expanded further, especially in the northern basin. Landscape gradient decreases were more pronounced, making areas surrounding towns and transportation routes hotspots for landscape changes. With improving urbanization levels and rapid economic growth, large areas of cultivated land were converted to construction land, particularly in northwestern urban peripheries. Construction land unit area increases reached 0.31-0.69 km², with 94.51% of increases converted from cultivated land (27.21% of cultivated land changes). Some areas showed cultivated land expansion trends, with maximum unit area increases reaching 0.34-0.87 km², as population surges increased land demand, leading to conversion of some forest land to cultivated land.

ELA parameters for different landscape types under future forecast scenarios

4.2 Driving Mechanism Analysis Using Logistic Regression

Logistic regression analysis of construction land transfer-in and cultivated land transfer-out changes during 2000-2010 and 2010-2015 showed good model explanatory power, with ROC statistics indicating significant results. The determined driving factors demonstrated good explanatory capability.

In the first phase (2000-2010), important explanatory variables for construction land transfer-in were, in order: total population change rate, distance to railways, distance to county centers, distance to highways, and elevation/slope. In the second phase (2010-2015), important variables were total population change rate, distance to highways, distance to county centers, distance to railways, and distance to county roads. Total population change rate showed positive regression coefficients throughout the study period, indicating that population influx into towns created enormous carrying pressure, leading to increased construction land for infrastructure. In both phases, regression coefficients for distances to railways and highways were negative, indicating that construction land expansion probability decreased with increasing distance from transportation arteries. The convenient transport conditions brought by major traffic routes became important drivers of economic growth, leading to construction land expansion. The correlation with distance to county centers shifted from negative to positive as construction land expansion patterns changed from inward infilling to outward expansion.

For cultivated land transfer-out, distances to railways and highways were important driving factors in both phases. Elevation’ s regression coefficient changed from negative to positive, indicating that the “National Land Use Master Plan Outline (2006-2020)” protected high-quality paddy fields in water network-dense lowland areas. Cultivated land transfer-out also showed positive correlation with distance to rivers, as water network-dense areas’ high-quality paddy fields received protection. In the second phase, the positive regression coefficient for distance to county centers indicated that after initial inward infilling development had occupied most nearby cultivated land, outward expansion increased the probability of cultivated land transfer-out in areas farther from county centers.

Logistic regression model fitting results for construction land changes
Logistic regression model fitting results for cultivated land changes

4.3 Spatial-Temporal Evolution Analysis Under Different Simulation Scenarios

Three scenarios were simulated for 2030: natural development, ecological protection, and cultivated land protection. The natural development scenario followed 2010-2015 trends without significant policy interference. The ecological protection scenario, considering Taihu Lake Basin as an ecological construction demonstration area, strengthened protection of ecological land (forest, grassland, water bodies) by reducing transfer probabilities from water bodies and cultivated land to construction land, and adding cultivated land-to-grassland transfer probability. The cultivated land protection scenario referenced the “National Land Use Master Plan Outline (2006-2020)” to strictly protect high-quality cultivated land by reducing cultivated land-to-construction land transfer probability.

[Figure 6: see original paper] Distribution of construction land and cultivated land landscape gradient in 2030 under three simulation scenarios

Under these three scenarios, significant differences existed in spatial-temporal evolution of both landscape types. The natural development scenario showed the largest area of high-gradient construction land (12,713.85 km², 34.52% of study area) and the largest cultivated land reduction (2,942.06 km²). The ecological protection scenario significantly reduced construction land increase (only 315.82 km² at 0.18% speed), but cultivated land still decreased substantially, mostly converted to ecological land, causing grassland area to surge. The cultivated land protection scenario resulted in the highest cultivated land landscape gradient values, with high-gradient cultivated land area reaching 16,022.37 km² (43.51% of basin area), while construction land increase was minimal (637.55 km² at 0.28% speed), effectively controlling construction land occupation of cultivated land.

5. Conclusion and Discussion

Using land-use data from 2000, 2010, and 2015, and employing grid technology, landscape gradient analysis, logistic regression, and CLUE-S modeling, this study analyzed spatial-temporal evolution characteristics and driving mechanisms of construction land and cultivated land landscapes in Taihu Lake Basin, yielding the following conclusions:

1. From 2000-2015, construction land landscape area increased significantly while cultivated land landscape area decreased substantially. High-gradient construction land concentrated along the Shanghai-Nanjing railway corridor, especially in Suzhou, Wuxi, Changzhou, and Shanghai peripheries, where the Yangtze River Delta development strategy and Shanghai' s economic radiation drove large-scale cultivated land conversion. The proportion of high-gradient construction land ($50 < \mathrm{DI}$ 100) increased from 3.02% to 31.27%, while high-gradient cultivated land decreased from 68.69% to 30.84%. Maximum unit area changes were 0.92 km^2 for construction land increase and 0.95 km^2 for cultivated land decrease. Original metropolis centers and western/southwestern hilly areas showed relatively small change amplitudes.
2. Driving factors for construction land transfer-in and cultivated land transfer-out showed stage-specific differences, influenced by both natural environment and socio-economic factors. Total population change rate and distances to railways/highways were important driving factors for construction land transfer-in throughout both phases, with the latter being more significant. Correlation with distance to county centers shifted from negative to positive as expansion patterns changed from inward infilling to outward expansion. Cultivated land transfer-out was significantly affected by distances to railways/highways, with elevation' s regression coefficient changing from negative to positive as high-quality paddy fields in water network-dense areas received protection.
3. Significant differences existed in spatial-temporal evolution under three 2030 scenarios. Natural development showed maximum construction land increase and cultivated land decrease. Ecological protection slowed construction land increase but cultivated land still decreased substantially, converting mostly to ecological land. Cultivated land protection effectively improved cultivated land occupation by construction land, with high-gradient cultivated land area reaching 43.51% of the basin.

This study's grid-based landscape evolution analysis compensates for limitations of basin-average representations. However, differences under varying grid sizes require further exploration. Due to data limitations, the precision and comprehensiveness of the driving factor indicator system need improvement. Future research should integrate policy implementation, value concepts, and other dynamic driving factors to construct dynamic driving force models. The CLUE-S simulation scale was set to 300m×300m based on Taihu Lake Basin area, achieving good results. However, different simulation scales affect result precision—overly large scales reduce driving factor impacts and decrease precision, while overly small scales increase data volume, causing long computation times and data errors. Selection of appropriate simulation scales warrants further investigation.

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