Changes in the Spatial Structure of Ecological Land and Ecosystem Service Values in the Nine Main Urban Districts of Chongqing City, 1988-2013: Postprint

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Abstract

Against the backdrop of rapid urbanization, the most effective means to understand the causes and patterns of urban ecosystem service function degradation is to conduct accurate assessments of ecological land use structure and ecosystem service value. Employing RS and GIS technologies, ecosystem service value assessment, and other methods, this study performed interpretation and comparative analysis of remote sensing imagery from four time periods (1988, 1996, 2004, and 2013) in the nine main districts of Chongqing municipality. The results indicate that: between 1988 and 2013, the urbanization level in the nine main districts of Chongqing underwent acceleration, deceleration, and saturation stages, with improvements in urbanization level exerting a significant influence on urban construction land growth; ecological land in these districts primarily provided ecosystem services including food production, raw material provision, waste treatment, soil formation and protection, climate regulation, gas regulation, biodiversity, and water conservation, exhibiting characteristics of "two decreases and three increases" in structural changes; over the 25-year period, the total ecosystem service value decreased by 260.60$\times10^{6}$ yuan, demonstrating an overall declining trend, with farmland experiencing the greatest loss at 24.50%; spatially, as urban construction land expanded toward the "south-north-west" direction, ecosystem service value reduction was most severe in the area between Zhongliang Mountain and Tongluo Mountain, with the primary causes being substantial farmland reduction and negative ecological impacts from urban construction land expansion. The results demonstrate a significant correlation between ecological land spatial patterns and ecosystem service changes in the nine main districts. After urbanization reaches saturation, construction land growth should be strictly controlled, intensive and econom-

ical utilization promoted, farmland protection strengthened, and forest land, water bodies, and grassland maintained to preserve regional ecological balance. This study provides information and decision-making references for scientifically rational urban ecological land layout and protection.

Full Text

Preamble

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Changes in the Spatial Structure of Ecological Land and Ecosystem Service Values in Nine Key Districts of Chongqing City from 1988 to 2013

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Changes in the Spatial Structure of Ecological Land and Ecosystem Service Values in Nine Key Districts of Chongqing City from 1988 to 2013

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Understanding and grasping the causes and patterns of degradation in urban ecosystem service functions can be most effectively achieved through accurate assessment of ecological land structure and its ecosystem service values. This study employs remote sensing (RS), geographic information system (GIS) technologies, and ecosystem service value assessment methods to analyze the nine key districts of Chongqing' s main urban area.

Abstract: Against the Background of Rapid Urbanization

Accurate assessment of ecological land structure and ecosystem service values represents the most effective approach for understanding the causes and patterns of urban ecosystem service degradation. Using Landsat imagery from 1988, 1996, 2004, and 2013, this study employs remote sensing, GIS technologies, and ecosystem service value assessment methods to interpret and comparatively analyze the nine key districts of Chongqing' s main urban area. The results reveal that from 1988 to 2013, the urbanization level in these districts experienced an acceleration phase, followed by a deceleration phase, and finally reached saturation. The increasing urbanization level had a significant impact on urban construction land expansion. Ecological land in Chongqing’ s nine districts primarily provides ecosystem services including food production, raw material provision, waste treatment, soil formation and protection, climate regulation, gas regulation, biodiversity conservation, and water source conservation. The overall trend shows a decline in ecosystem service values, with a total loss of 260.60$\times10^{6}$ Yuan over the 25-year period. Farmland experienced the greatest loss in ecosystem service value, accounting for 24.50% of the total ecosystem service value. Spatially, as construction land expanded westward, northward, and southward, the most severe reduction in ecosystem service value occurred in the region between Zhongliang Mountain and Tongluo Mountain. The primary cause of the overall decline in ecosystem service values across the study area stems from substantial farmland reduction and the negative ecological impacts of construction land expansion. The findings demonstrate a strong correlation between spatial patterns of ecological land and changes in ecosystem service values across different urbanization levels in Chongqing’ s nine districts. Once urbanization reaches saturation, strict controls should be implemented on construction land growth, promoting intensive and economical land use while strengthening farmland protection and grassland maintenance.

Keywords: urbanization; ecological land; ecosystem service value; land use structure; Chongqing City

1. Introduction

Urbanization has become the most prominent characteristic of human social development [1]. Coordinated development between urbanization and the ecological environment represents a critical issue both domestically and internationally [2]. Cities are natural-social complex ecosystems dominated by human activities [3], serving as humanity’ s primary habitat [4]. Human activities in urban areas often lead to changes in other environmental factors [5-6]. Current high-speed urbanization has triggered a series of ecological and environmental problems, including biodiversity loss and habitat destruction [8-9], enhanced heat island effects [10-11], and environmental pollution [12-13]. Urban ecological land can protect urban ecosystems and biological habitats while improving residents’ quality of life, with both its quantity and spatial distribution exerting important influences on urban ecological security [14-16]. Research on optimal allocation of urban ecological land based on land use/cover has become a hotspot for comprehensively addressing the conflict between high-speed urbanization-induced construction land expansion and natural ecological protection [17-19].

Dong Yawen et al. [20] first proposed the concept of ecological land in China. Although foreign studies have not classified ecological land separately, the concept permeates their land classification systems [21]. In recent years, domestic scholars have conducted various analyses of the ecological land concept based on land ecological functions, classifying ecological land types according to land cover types, land use intensity, and ecological service quality [21-24]. Ecosystem services refer to the environmental conditions and utilities formed and maintained by ecosystems that humans depend on for survival and development [25]. Current ecosystem service assessments can be divided into monetary value assessment and physical quantity assessment [26]. Following Costanza et al.' s [27] publication on global ecosystem service value assessment in *Nature*, numerous scholars have focused on ecosystem services and valuation methods [28-33]. Xie Gaodi et al. [31] modified the ecosystem service value coefficients based on China' s actual conditions, establishing ecosystem service value coefficients for China' s terrestrial systems that have been widely used by Chinese scholars to estimate ecosystem value changes [30-32].

Rapid urbanization is characterized by intense human activity, which also impacts natural ecosystems and causes changes [34]. The high-speed urbanization process inevitably alters urban land use patterns, leading to changes in ecosystem services. Related scholars have studied land use structure [35-36], landscape patterns [37], and ecological environmental effects of land use change [38] in Chongqing' s main urban area, concluding that during specific periods, ecosystem service values continued to decline, with conversion from agricultural land to construction land being the most significant, and changes in forest land having the most substantial impact on ecosystem service values.

This study takes the nine districts of Chongqing' s main urban area under rapid urbanization as the research object, employing integrated remote sensing and GIS technologies to address scientific questions regarding urban ecological land spatial structure changes and ecosystem service value evolution during the urbanization process. It quantitatively analyzes the relationship between urban ecological land and ecosystem service values in Chongqing' s nine districts from 1988 to 2013, aiming to provide important scientific foundations for rational planning, layout, and protection of urban ecological land and sustainable urban development.

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2. Study Area

The nine districts of Chongqing' s main urban area are located in the western core region of Chongqing Municipality, including Yuzhong, Dadukou, Jiangbei, Shapingba, Jiulongpo, Nan' an, Beibei, Yubei, and Banan districts, covering a total area of 5,468.71 km^2. The terrain is dominated by mountains and hills (87.87% of the area), with fewer tablelands and plains [39]. Multiple branches of the Huaying Mountains, including Jinyun Mountain, Zhongliang Mountain, Tongluo Mountain, and Mingyue Mountain, extend from north to south through the city. The Yangtze River and Jialing River converge at Chaotianmen in Yuzhong District before cutting northeastward through the city, forming the basic controlling geomorphological units of the nine districts. The study area has a multi-year average temperature of 17–18.8°C, multi-year average precipitation of 975.1-1301.7 mm, and relative humidity of 77%-83%.

In 2013, the GDP of the nine districts reached 808.53 billion Yuan, with an urbanization rate of 66.87%. The urbanization process has accelerated since Chongqing became a municipality directly under the central government.

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3. Methods

3.1 Land Classification

Based on relevant research on ecological land concepts and types [20-24] and considering Chongqing' s actual land use conditions, land types in the nine districts were classified into forestland, farmland, water area, grassland, unused land, and built-up area by merging land types according to the "Current Land Use Classification" (GB/T 21010-2007) standard. From the perspective of land ecological functions and service quality, and combining classification methods from domestic scholars [14,16], forestland, water area, grassland, and unused land were identified as ecological land. Specific classification details are shown in Table 1 .

3.2 Data Sources and Technical Processing

Landsat TM/ETM remote sensing images from 1988, 1996, 2004, and 2013 were used as primary data sources. Supervised classification and visual interpretation were performed on the four periods of remote sensing imagery using ArcGIS 10.0 to obtain land use types for each category in the nine districts. Classification accuracy was verified using a random sampling method, with Kappa coefficients of 0.78 (1988), 0.81 (1996), 0.73 (2004), and 0.84 (2013), meeting the required precision standards.

3.3 Land Use Dynamic Degree

Single Land Use Type Dynamic Degree Formula:

The dynamic degree (K) of a specific land use type during the study period is calculated as:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\%$$

where U_a and U_b represent the area of a particular land use type at the beginning and end of the study period, respectively, and T is the study period length. When T is set as one year, K represents the annual change rate of that land use type.

Comprehensive Land Use Dynamic Degree Formula:

The comprehensive dynamic degree (LC) is calculated as:

$$LC = \frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{2\sum_{i=1}^{n} LU_i} \times \frac{1}{T} \times 100\%$$

where LU_i is the area of land use type i at the monitoring start time, ΔLU_{i-j} is the absolute value of the area converted from land use type i to non-i types during the monitoring period, and T is the monitoring period length. When T is set as one year, LC represents the annual comprehensive change rate.

3.4 Urban Land Ecosystem Service Value Assessment Method

Ecosystem service functions are influenced by multiple factors, resulting in various calculation models [41]. Based on the research results of Costanza et al. [27] and Xie Gaodi et al. [30-32], ecosystem service value coefficients were determined. Combining Xie Gaodi et al.’ s [31,42] value equivalent conversion method, the per-unit-area ecosystem service values for Chongqing’ s nine districts were established (Table 2).

The ecosystem service value assessment formula is:

$$ESV = \sum (A_i \times VC_i)$$

$$ESV_f = \sum (A_i \times VC_{fi})$$

where ESV represents the total ecosystem service value of the study area, A_i is the area of land use type i, VC_i is the ecosystem service value coefficient for land use type i, ESV_f is the value of the f-th ecosystem service function, and VC_{fi} is the ecosystem service value coefficient for the f-th function of land use type i.

3.5 Urbanization Level

Urbanization level refers to the proportion of urban population to total population, reflecting both regional urban development level and overall regional economic development. The calculation formula is:

$$Y = \frac{U}{P} \times 100\%$$

where Y is the urbanization level, U is the non-agricultural population, and P is the total regional population [43].

4. Results and Analysis

4.1 Annual Construction Land Spatial Structure Changes in Chongqing' s Nine Districts

Based on land use distribution maps for 1988, 1996, 2004, and 2013, construction land in 1988 was mainly concentrated between Zhongliang Mountain and Tongluo Mountain, with slow urban development during this period. From 1988 to 1996, the land use change rate was only 3.19%, and the comprehensive dynamic degree was 3.56%, indicating minimal changes in the overall spatial structure of construction land.

Since Chongqing became a municipality, the urbanization process accelerated. From 1996 to 2004, construction land increased from 3.56% to 5.23%, with the comprehensive dynamic degree rising to 0.26%. The single dynamic degree of construction land reached 1.14% during this period, primarily due to conversion from agricultural land. After 2002, the center of construction land gradually shifted northward. With the official establishment of the Liangjiang New Area in 2010, urban construction land exhibited a patchy development pattern and expanded rapidly. From 2004 to 2013, the comprehensive dynamic degree reached 19.51%, and the single dynamic degree of construction land peaked at 6.88%. Ecological land was gradually occupied by construction land, with fragmentation intensifying, particularly in the Mingyue Mountain area (Figure 1 [Figure 1: see original paper]).

4.2 Annual Ecological Land Spatial Structure Changes in Chongqing' s Nine Districts

The changes reflect quantitative structural variations of different land use types in the study area. From 1988 to 2013, farmland proportion declined the most, dropping from 71.81% to 54.22%. Throughout the study period, except for a slight increase in 1996, farmland consistently decreased, with the most severe reduction occurring between 1996 and 2004 as urban construction land expanded westward, northward, and southward.

Forestland proportion increased from 26.09% at the beginning to the end of the study period. Following the implementation of the "Chongqing Forestland Protection and Management Regulations" in 1998, forestland growth concentrated in Jinyun Mountain, Zhongliang Mountain, Tongluo Mountain, Mingyue Mountain, and transition zones between mountainous areas and construction land.

Water area proportion increased significantly, rising from 2.67% to 3.33%, with the largest growth occurring after 2004. This growth primarily resulted from increased reservoir surface areas in various districts and protection policies for the Yangtze River, Jialing River, and surrounding lakes.

Since implementing the Grain for Green Program in 2000, grassland proportion increased from 1.93% to 7.36%, with an average annual growth rate of 4.7%, mainly in eastern Yubei District.

Unused land, primarily bare land, showed low proportions, first increasing then decreasing throughout the study period, from 0.07% to 0.81% and finally to 0.02%.

The ecological land structure gradually shifted from a farmland-dominated landscape to coordinated development among various ecological land types. Policy implementation significantly influenced this structural optimization, with the most dramatic changes occurring during 1996-2004 (Figure 2 [Figure 2: see original paper], Figure 3 [Figure 3: see original paper], Table 3).

4.3 Ecosystem Service Value Changes in Chongqing’ s Nine Districts (1988-2013)

Based on land use change data and per-unit-area service value coefficients, ecosystem service value changes caused by land use structure changes during urbanization were assessed. Farmland provides ecosystem services including food production, raw material provision, and waste treatment. From 1988 to 2013, the ecosystem service value of the nine districts showed a declining trend, with farmland experiencing the greatest loss, accounting for 24.50% of the total ecosystem service value. Although farming technology improvements and superior seed varieties increased grain yields from 5,650,200 tons to 5,963,100 tons, the substantial farmland area reduction during the study period led to decreased value in raw material provision and waste treatment, representing the main reason for farmland ecosystem service value decline.

Forestland provides services including soil formation and protection, and biodiversity maintenance. In 2013, forestland occupied only 26.09% of the area but contributed 53.03% of total ecosystem service value, making it the primary contributor. With the implementation of forest projects, forestland area increased by 4.95%, while its ecosystem service value increased by 23.4%. Given Chongqing’ s special mountainous terrain, forestland is mainly distributed in mountainous areas and transition zones to construction land, playing crucial roles in water conservation, water quality improvement for the Yangtze River, and ensuring normal operation of the Three Gorges Project.

Water areas provide water conservation and recreational cultural services. The Yangtze and Jialing Rivers create unique hydrological landscapes, and scattered reservoirs and lakes provide substantial ecological services. During the study period, water area ecosystem service value increased by 109.37$\times$10^{6}$ Yuan, reflecting government protection policies. However, attention must also be paid to connectivity between tributaries and water pollution/eutrophication from sewage discharge and aquaculture feed.

Grassland provides waste treatment, habitat provision, and nutrient cycling services. Influenced by the Grain for Green Program, grassland ecosystem service value increased by 239%. However, grassland represents a relatively fragile ecosystem type, requiring protection against degradation, overgrazing, and secondary reclamation.

Unused land, primarily bare land, has low area proportions and simple ecological service functions. When optimizing, conversion to ecological land types with more service functions should be prioritized (Table 4).

4.4 Relationship Between Urbanization Level and Construction Land Changes

Based on statistical yearbooks, urbanization levels for the nine districts were calculated. Drawing on Logistic and Northam urbanization curve research [44-52], the urbanization level experienced acceleration, deceleration, and saturation phases from 1988 to 2013. Phase boundaries primarily follow Chen Yanguang et al.' s [45] macro-level corrections to Logistic curve stage divisions.

From 1988-1996, despite high initial urbanization levels, growth was slow at only 0.78% annually. From 1996-2004, the transition from acceleration to deceleration occurred, with annual growth of 3.82%. After 2002, growth slowed, marking the transition from deceleration to saturation. Post-2004, urbanization growth rates significantly decelerated while construction land growth peaked at 19.5% annually, the fastest period in the study area.

Long-term correlation between urbanization level and construction land is significant. Construction land expansion is an inevitable result of urbanization advancement, while construction land increase contributes limitedly to urbanization level improvement [53-54]. The main reason for ecosystem service value decline across the study area stems from farmland reduction and negative ecological impacts from construction land expansion (Figure 4 [Figure 4: see original paper], Figure 5 [Figure 5: see original paper]).

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5. Conclusions

This study collected four periods of remote sensing data for Chongqing' s nine districts, covering large time spans with relatively equal intervals, effectively revealing land structure changes from 1988-2013. Monetary assessment of ecosystem services provided by ecological land yielded the following main conclusions:

1. Urban spatial evolution in Chongqing' s nine districts experienced three phases: 1988-1996 as slow growth with minimal construction land expansion and ecological benefit reduction; 1996-2004 as steady growth with rapid construction land increase and initial ecological benefit decline; and 2004-2013 as rapid growth with patch development patterns. Ecological land structure showed a "two declines, three growths" pattern, with farmland experiencing the greatest loss.

2. Government policies including the Grain for Green Program and water body protection measures significantly alleviated ecological benefit reduction and improved ecological land structure. During 2004-2013, forestland, water area, and grassland ecosystem service values increased by 530.27$×10^{6}, 203.32×10{6}, and26.16×10^{6}$ Yuan respectively.

3. Overall ecological benefits in Chongqing's nine districts continue to decline, with total ecosystem service value decreasing by 260.60$×10^{6}$ Yuan. The primary causes are substantial farmland reduction and negative ecological impacts from construction land expansion. Strong correlation exists between ecological land spatial patterns and ecosystem service value changes. Once urbanization reaches saturation, strict construction land growth control should be implemented to promote intensive land use while strengthening farmland and grassland protection to maintain regional ecological balance. This research provides information and decision-making references for scientifically rational urban ecological land layout and protection.

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