

Assessment and Optimization Strategies of Ecosystem Service Value in Chengdu

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Abstract:

Rapid urbanization has profoundly transformed land use and land cover (LULC), leading to supply-demand imbalances in regional ecosystem services (ESs). Integrating the long-term ecosystem service value (ESV) assessment with urban development research is critical for identifying the evolutionary patterns of ESV during urban expansion. This study selected Chengdu—the birthplace of the Park City concept—as the research area. Using LULC datasets for 2005, 2015 and 2025, this study quantified regional ESV across the 20-year period via the equivalent factor method (EFM), the LULC dynamic degree index, and the land use transfer matrix. The paper further analyzed the spatio-temporal evolutionary characteristics of ESV, identified how urbanization and ecological policies reshaped ESV spatial patterns, and proposed targeted ESV optimization strategies adapted to the construction demands of the Park City. The results showed that, from 2005 to 2025 in Chengdu, cropland area shrank continuously, construction land expanded dramatically, and forest coverage grew consistently. The total regional ESV increased from 14.98 billion CNY to 30.45 billion CNY, registering an overall growth rate of 103.23%. High-value ESV zones are predominantly concentrated in the western Longmen and Qionglai Mountains, the eastern Longquan Mountains, and along major river corridors. In contrast, low-value zones correspond to the central construction land. The water regulation service acts as the dominant contributor to total ESV growth. Nevertheless, the continuous negative growth of water supply service value constitutes a prominent constraint on regional ecosystem services. This study provides quantitative evidence to support territorial spatial planning, urban ecological management, and ecological product value realization in Chengdu. Additionally, it provides empirical references for ESV assessments of megacities throughout Southwest China.

Keywords:

Ecosystem Service Value, Land Use and Land Cover, Rapid Urbanization, Equivalent Factor Method, Park City, Chengdu

1. Introduction

At present, global urbanization continues to accelerate. Dramatic land use and land cover (LULC) changes have occurred, as natural and semi-natural ecosystems are rapidly converted to construction land, altering the structure and functions of regional ecosystems [1,2,3]. Imbalanced supply of ecosystem services (ESs) and differentiated gains and losses of ecological value have become prominent contradictions limiting

urban sustainable development [4,5,6,7,8]. Scholars worldwide have extensively studied ecosystem service value (ESV) evaluation [9,10,11], with methods generally classified into three categories: physical evaluation, monetary evaluation and emergy evaluation [12]. Among these approaches, the equivalent factor method (EFM) for monetary evaluation is widely adopted for national and regional ESV accounting, owing to its low data demand, strong operability and suitability for large-scale long-term sequential research [1,13]. Costanza et al. [14] established the theoretical foundation for global ESV assessment. Combined with China's ecological conditions. Gaodi Xie et al. [10,13] developed the terrestrial ESs equivalent value per unit area for China, which has become the mainstream methodological foundation for relevant domestic studies.

Chengdu is a major central city in Western China [15], the core of the Chengdu-Chongqing Twin-City Economic Circle [16], where the Park City concept was first proposed [17]. In 2022, the State Council officially approved the construction of the Park City Demonstration Zone in Chengdu [18]. The first national standard for park cities, developed under the leadership of Chengdu, was released in 2026 [19]. It requires ecological values to be embedded throughout the entire urban development process, coordinates ecological conservation, urban construction and food security, and fosters a new development pattern featuring harmonious coexistence between human and nature. Nevertheless, amid rapid urbanization and industrial upgrading, dramatic spatio-temporal conversions occur among cropland, forest, construction land and other land types [20]. ESs are confronted with multiple pressures including encroachment from urban expansion, structural and functional differentiation, and spatial heterogeneity of service values. Therefore, land use planning decisions require assessments of ESV as quantitative support [6,21]. Existing studies mostly focus on static ESV accounting for a single time point. Insufficient attention has been paid to long-term temporal dynamics and policy-driven LULC evolution, as well as the spatio-temporal differentiation of ESV. Such limitations hinder the provision of precise decision support for optimizing ecological spatial patterns and promoting ESV in the Park City Demonstration Zone [22].

Accordingly, this study adopts LULC and socio-economic datasets of Chengdu for 2005, 2015, and 2025. Using the EFM, LULC dynamic index, transfer matrix, and spatial analysis. It systematically evaluates the temporal and spatial evolution characteristics of ESV quantity, structure, and spatial pattern in Chengdu over the past 20 years. This paper further identifies the impacts of urbanization and ecological protection policies on ESV growth and spatial differentiation, and proposes targeted ESV promotion countermeasures for Park City construction. The research findings can provide a quantitative basis for the spatial supervision of ecological conservation redlines, permanent basic farmland protection, intensive urban development, and ecological product value realization in Chengdu. Furthermore, they provide typical case references for ESV assessment and high-quality development of megacities in Southwest China.

2. Materials and Methods

2.1. Study Area

Chengdu, the capital of Sichuan Province and the core city of Southwest China, is situated in the western Sichuan Basin and the hinterland of the Chengdu Plain. It is geographical location between 102°54'–104°53' E and 30°05'–31°26' N (Figure 1),

covering a total area of 14,335 km². Its administrative jurisdiction includes 12 urban districts, 5 county-level cities and 3 counties [23]. The terrain slopes from the northwest toward the southeast. The western part consists of mid-high mountains formed by the remnant ranges of the Longmen Mountains and Qionglai Mountains, dominated by forest land. This zone serves as a core region for water regulation, biodiversity conservation and soil conservation. The central part of the study area forms the heartland of the Chengdu Plain, characterized by flat terrain and dense river networks. Chengdu features a subtropical humid monsoon climate, with a mean annual temperature of 17.8 °C and annual precipitation of approximately 1068 mm [23]. In the region's hot-rainy season, the main streams and tributaries of the Min River and Tuo River systems traverse the entire study area.

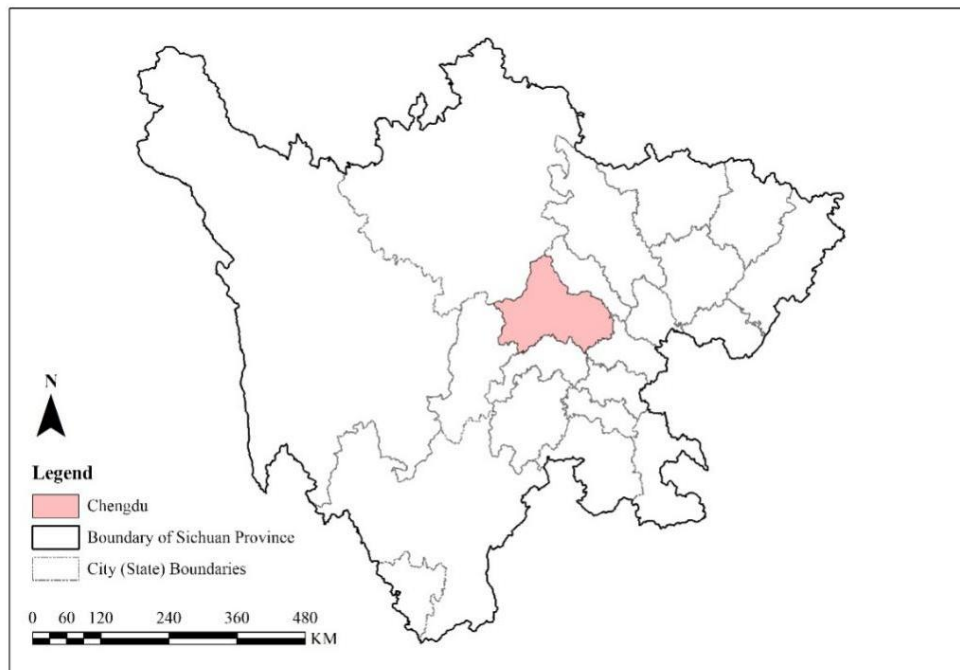


Figure 1. Location of the study area.

Source: redrawn by the authors based on data from the National Platform for Common GeoSpatial Information Services

2.2. Data Sources

The LULC datasets for Chengdu in 2005, 2015 and 2025 are obtained from products developed by the team led by Professor Xin Huang's at Wuhan University [24], with a spatial resolution of 30 m. Other socio-economic datasets are sourced from the Chengdu Statistical Yearbook [23] and the Compilation of National Cost-Benefit Data of Agricultural Products [25].

2.3. Methods

2.3.1. LULC Dynamic Index

This study adopts the LULC dynamic index to characterize temporal changes in LULC across Chengdu during the study period [26]. The calculation formula is expressed as Equation (1):

$$K = \frac{A_j - A_i}{A_i} \times \frac{1}{T} \times 100\% \quad (1)$$

where K denotes the LULC dynamic index for a single LULC type; A_i and A_j represent the initial and final areas of the corresponding LULC type, respectively; and T refers to the study period.

2.3.2. Calculation of ESV

(1) Standard Equivalent Table of ESV Per Unit Area

This study adopts the framework of the Millennium Ecosystem Assessment (MA) to classify ESs into four categories: provisioning services, regulating services, supporting services and cultural services [27]. Referring to the findings of Gaodi Xie et al. [13], this study further subdivides them into 11 service functions, including food production, raw materials, water supply, gas regulation, climate regulation, waste treatment, water regulation, soil conservation, nutrient cycling, biodiversity and aesthetic landscape.

For the basic equivalent used in ESV accounting, this study adopts the terrestrial ESs equivalent value per unit area for China revised by Gaodi Xie et al. [13] (Table 1). Combined with local conditions of the study area, the equivalent system is adjusted based on the sown area proportion of the three major local grain crops and LULC types (Table 2). The LULC dataset adopted in this study is the high-resolution Chinese LULC product released by Professor Xin Huang's team at Wuhan University [24], which supports spatial ESV accounting. The equivalent coefficient for construction land is set to 0 [28].

Table 1. Gaodi Xie et al. (2015) Ecosystem service equivalent value per unit area.

ESs		Provisioning			Regulating				Supporting			Cultural
Primary classification	Secondary classification	FP	RM	WS	GR	CR	WT	WR	SC	NC	BD	AL
Cropland	Dry cropland	0.85	0.40	0.02	0.67	0.36	0.10	0.27	1.03	0.12	0.13	0.06
	Paddy field	1.36	0.09	-2.63	1.11	0.57	0.17	2.72	0.01	0.19	0.21	0.09
Forest	Coniferous forest	0.22	0.52	0.27	1.70	5.07	1.49	3.34	2.06	0.16	1.88	0.82
	Coniferous and mixed forest	0.31	0.71	0.37	2.35	7.03	1.99	3.51	2.86	0.22	2.60	1.14
	Broad-leaved forest	0.29	0.66	0.34	2.17	6.50	1.93	4.74	2.65	0.20	2.41	1.06
	Shrub land	0.19	0.43	0.22	1.41	4.23	1.28	3.35	1.72	0.13	1.57	0.69
Grassland	Steppe	0.10	0.14	0.08	0.51	1.34	0.44	0.98	0.62	0.05	0.56	0.25
	Bush	0.38	0.56	0.31	1.97	5.21	1.72	3.82	2.40	0.18	2.18	0.96
	Meadow	0.22	0.33	0.18	1.14	3.02	1.00	2.21	1.39	0.11	1.27	0.56
Wetland	Wetland	0.51	0.50	2.59	1.90	3.60	3.60	24.23	2.31	0.18	7.87	4.73
Wasteland	Desert	0.01	0.03	0.02	0.11	0.10	0.31	0.21	0.13	0.01	0.12	0.05
	Bare land	0.00	0.00	0.00	0.02	0.00	0.10	0.03	0.02	0.00	0.02	0.01
Water	Water system	0.80	0.23	8.29	0.77	2.29	5.55	102.24	0.93	0.07	2.55	1.89
	Snow/Ice	0.00	0.00	2.16	0.18	0.54	0.16	7.13	0.00	0.00	0.01	0.09

FP—food production, RM—raw materials, WS—water supply, GR—gas regulation, CR—climate regulation, WT—waste treatment, WR—water regulation, SC—soil conservation, NC—nutrient cycling, BD—biodiversity, AL—aesthetic landscape.

Table 2. Gaodi Xie et al. (2015) Ecosystem service equivalent value per unit area based on the sown area proportion of three major local grain crops.

ESs		Cropland	Forest	Shrub	Grassland	Water	Snow/Ice	Barren
Provisioning	FP	1.16	0.27	0.29	0.16	0.80	0.00	0.00
	RM	0.21	0.63	0.50	0.24	0.23	0.00	0.00
	WS	-1.59	0.33	0.27	0.13	8.29	2.16	0.00
Regulating	GR	0.94	2.07	1.69	0.83	0.77	0.18	0.02
	CR	0.49	6.20	4.72	2.18	2.29	0.54	0.00
	WT	0.14	1.80	1.50	0.72	5.55	0.16	0.10
	WR	1.75	3.86	3.59	1.60	102.24	7.13	0.03
Supporting	SC	0.41	2.52	2.06	1.01	0.93	0.00	0.02
	NC	0.16	0.19	0.16	0.08	0.07	0.00	0.00
	BD	0.18	2.30	1.88	0.92	2.55	0.01	0.02
Cultural	AL	0.08	1.01	0.83	0.41	1.89	0.09	0.01

(2) Economic Price of One Standard Equivalent ES

When applying the EFM, the benchmark ESV per unit area of cropland forms the foundation for regional ESV accounting. With reference to statistical datasets from the Chengdu Statistical Yearbook (2006, 2016, 2025) [23] and the Compilation of National Agricultural Products Cost and Benefit Data [25], this study calculates the grain yield per unit area in Chengdu and the national average market price. Based on the principle that the ESV per unit area of cropland equals 1/7 of the market economic value of its average grain yield, the economic price of one standard equivalent ES is quantified [29]. The specific calculation formula is shown in Equation (2):

$$V_a = \frac{1}{7} \times \frac{\sum_{i=1}^n (m_i \times p_i \times q_i)}{M} \quad (2)$$

Where V_a denotes the economic value of production service function of cropland per unit area (CNY/hm²); i refers to grain crop type, and the dominant grain crops in the study area are rice, wheat and maize [23]; p_i is the national average market price of the i th grain crop (CNY/t); q_i represents the yield per unit area of the i th grain crop (t/hm²); m_i denotes the planting area of the i th grain crop (hm²); M is the total planting area of all n grain crops (hm²).

(3) Calculation of Total ESV

The total ESV was calculated using Equation (3) [30]:

$$ESV = \sum_{i=1}^n \sum_{j=1}^m V_a \times Q_{ij} \times A_i \quad (3)$$

where V_a denotes the economic value of the production service function of cropland ecosystems per unit area (CNY/hm²); Q_{ij} refers to the equivalence coefficient of the value of the j th service function per unit area of the i th LULC type; A_i refers to the area of the i th LULC type (hm²); i stands for LULC types, and j represents ES categories. In this study, $n=8$ and $m=11$; ESV is the total regional ecosystem ESs (CNY).

2.3.3. Annual ESV Change Rate

To reveal the annual variation trend of ESV for individual LULC types, the annual change rate of ESV for each LULC type was calculated using Equation (4) [26]:

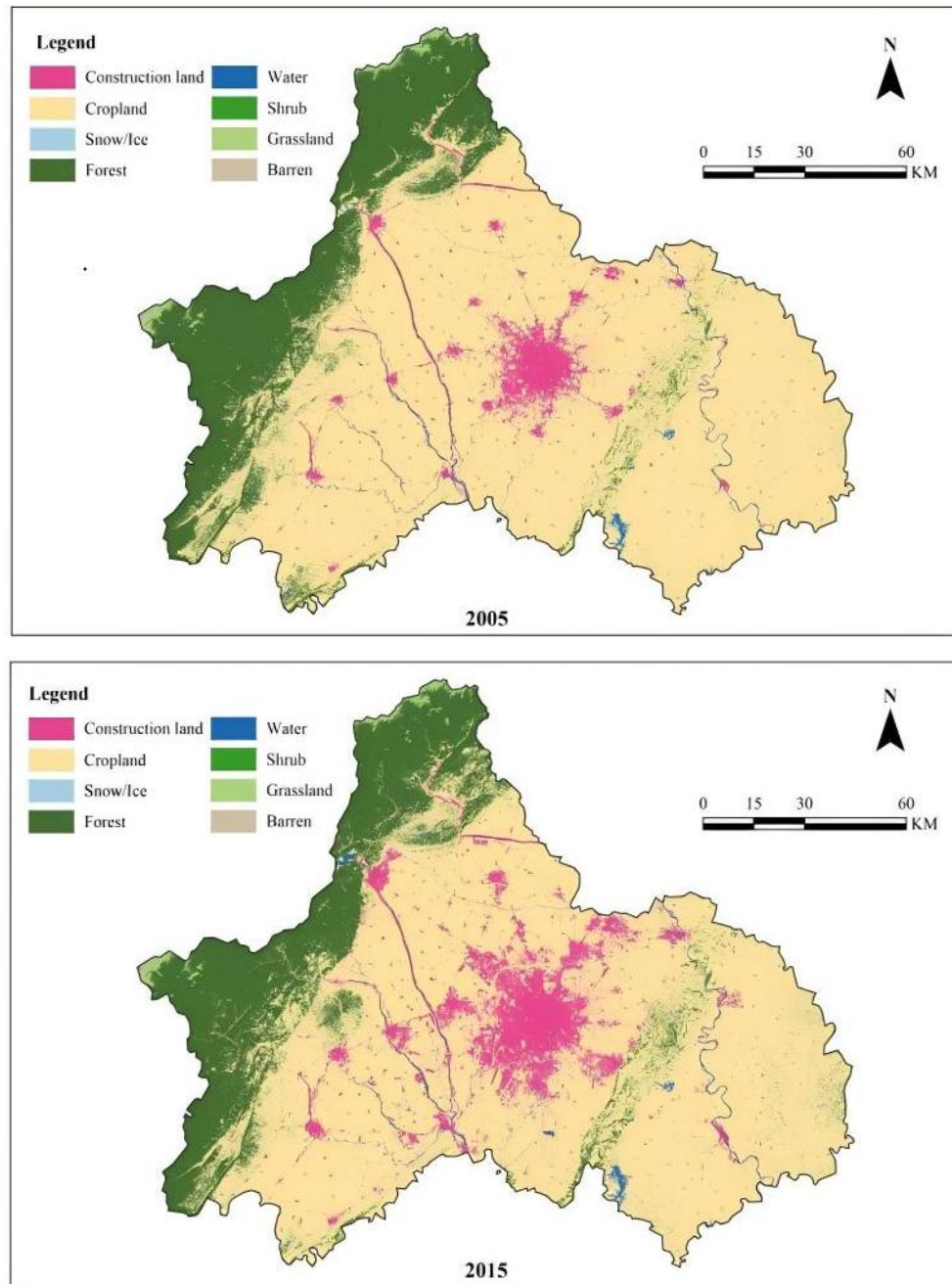
$$ESV_{cr} = \frac{ESV_j - ESV_i}{ESV_i} \times \frac{1}{T} \times 100\% \quad (4)$$

where ESV_{cr} denotes the annual change rate of ESV for a single LULC type; ESV_i and ESV_j are the initial and final ESV values of the corresponding LULC type, respectively; T is the research period.

3. Results

3.1. Spatio-Temporal Changes in LULC

The LULC datasets of Chengdu for 2005, 2015 and 2025 were adopted in this study, with the coordinate system of GCS_WGS_1984 (Figure 2).



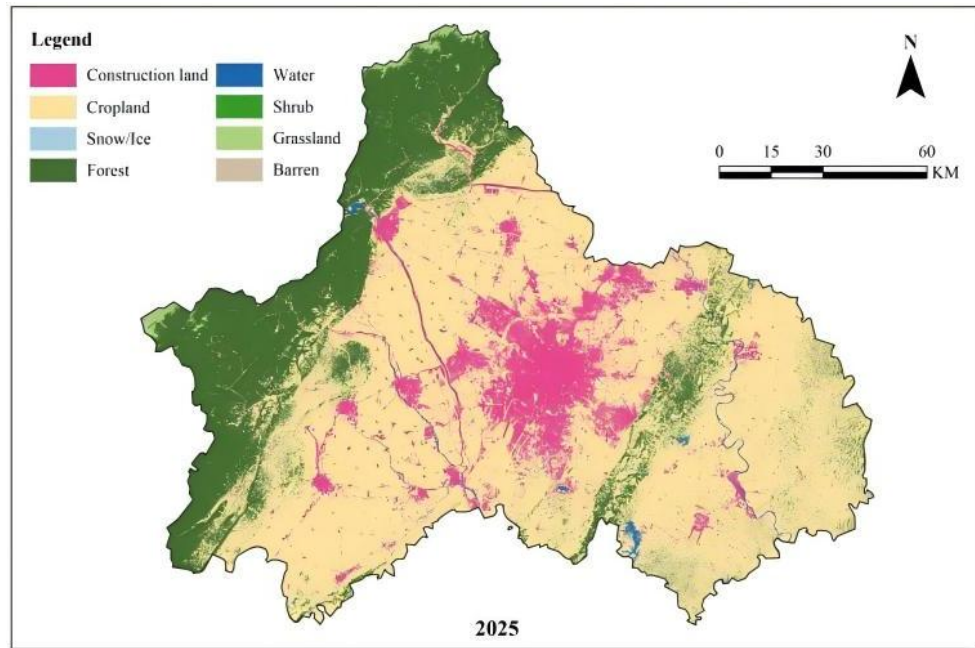


Figure 2. LULC status maps of Chengdu in 2005, 2015 and 2025.

Source: redrawn by the authors based on the dataset developed by Professor Xin Huang's team, Wuhan University

ArcGIS 10.8.2 was used to quantify the LULC status of Chengdu in the three periods (Table 3). The LULC dynamic index (K) was calculated via Equation (1) to obtain the annual change rates of different LULC types (Table 4). Meanwhile, a LULC transfer matrix was generated in ArcGIS 10.8.2 (Table 5). Origin 2026 was further applied to visualize the matrix data as a chord diagram (Figure 3), so as to reveal the mutual conversion relationships among various LULC types during the study period.

Table 3. LULC status of Chengdu, 2005 to 2025.

LULC	2005		2015		2025	
	Area(hm ²)	Proportion (%)	Area(hm ²)	Proportion (%)	Area(hm ²)	Proportion (%)
Cropland	1,062,063.69	74.09	993,635.00	69.32	914,601.83	63.81
Forest	281,412.42	19.63	284,599.27	19.85	333,526.30	23.27
Shrub	95.17	0.01	818.54	0.06	753.57	0.05
Grassland	9654.13	0.67	11,073.28	0.77	10,872.49	0.76
Water	12,559.28	0.88	14,077.47	0.98	11,275.22	0.79
Snow/Ice	56.94	0.00	45.65	0.00	20.94	0.00
Barren	566.82	0.04	712.63	0.05	721.55	0.05
Construction land	67,000.01	4.67	128,446.62	8.96	161,636.56	11.28

Table 4. LULC changes in Chengdu from 2005 to 2025.

LULC	2005–2015		2015–2025		2005–2025	
	Area change (hm ²)	$K(\%)$	Area change (hm ²)	$K(\%)$	Area change (hm ²)	$K(\%)$
Cropland	−68,428.69	−0.64	−79,033.17	−0.80	−147,461.86	−0.69
Forest	3186.85	0.11	48,927.03	1.72	52,113.88	0.93
Shrub	723.37	76.01	−64.97	−0.79	658.40	34.59

Grassland	1419.15	1.47	-200.79	-0.18	1218.36	0.63
Water	1518.19	1.21	-2802.25	-1.99	-1284.06	-0.51
Snow/Ice	-11.29	-1.98	-24.71	-5.41	-36.00	-3.16
Barren	145.81	2.57	8.92	0.13	154.72	1.36
Construction land	61,446.61	9.17	33,189.94	2.58	94,636.55	7.06

Table 5. LULC transfer matrix of Chengdu from 2005 to 2025 (hm²).

2005/ 2025	Cropland	Forest	Shrub	Grassland	Water	Snow/Ice	Barren	Construction land
Cropland	888,014.2	72,874.4	48.0	1227.4	3026.3	No Cropland into Snow/Ice	253.5	94,993.9
Forest	20,026.5	260,720.2	780.4	472.0	9.6	No Forest into Snow/Ice	4.5	47.3
Shrub	1.4	25.4	4.6	80.0	No shrub into water	No Shrub into Snow/Ice	No shrub into barren	No shrub into construction land
Grassland	218.4	300.0	6.9	8952.3	33.1	1.8	176.0	84.8
Water	4281.7	135.0	0.2	53.6	7304.5	0.8	12.4	1039.3
Snow/Ice	No Snow/Ice into cropland	1.3	No Snow/ Ice into shrub	6.8	11.2	14.9	24.4	No Snow/Ice into construction land
Barren	0.5	0.2	0.2	282.7	2.3	4.6	276.5	No barren into construction land
Construction land	522.7	0.2	No construction land into shrub	0.9	1041.6	No Construction land into Snow/Ice	No Construction land into barren	66,011.0

The overall spatio-temporal evolution of LULC in Chengdu from 2005 to 2025 is jointly dominated by two driving factors (Figure 2, Figure 3, Table 3, Table 4, Table 5). Rapid urbanization triggered the large-scale conversion of cropland to construction land [31]. Against the backdrop of ecological civilization construction, forestry policies in Chengdu have driven the continuous expansion of forest area [32]. Cropland represents the LULC type with the largest area of net outflow. During the study period, a total of 172,423.44 hm² of cropland was transferred out, mainly to construction land and forest, accounting for 55.09% and 42.26% of the total transferred-out area, respectively. Construction land is dominated by land inflow; 98.78% of its newly-increased area originates from cropland, and it exhibits strong spatial stability with only a small proportion of reverse conversion. This phenomenon directly reflects the occupation of agricultural space caused by urban expansion. Among ecological land types, forests are dominated by land inflow, with 99.37% of their newly-increased area converted from cropland. Forests also maintain a high retention rate, resulting in considerable net area gain. Consequently, forests have become the primary growing component of regional ecological land. Changes in other LULC types remain relatively moderate.

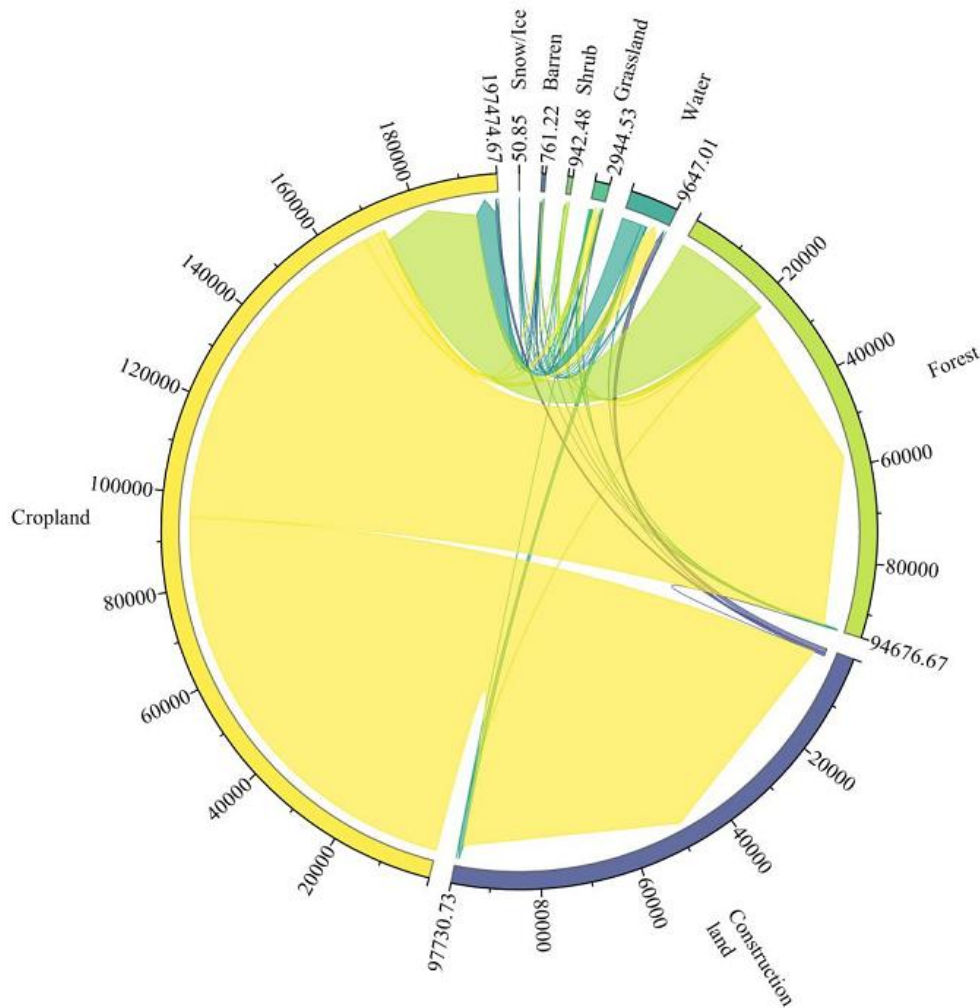


Figure 3. Chord diagram of LULC transfer in Chengdu from 2005 to 2025.

3.2. Calculation of ESV

Referring to the standard equivalent coefficients proposed by Xie Gaodi et al. [13], this study determined the localized per unit area ESV equivalents (Table 2) based on the sown-area proportion of the three major local grain crops. Using the economic price of one standard equivalent ES (Equation (2)), the economic values of the production service function of cropland ecosystems in 2005, 2015 and 2025 were calculated as 1270.4 CNY/hm², 2026.7 CNY/hm² and 2500.2 CNY/hm², respectively. The per unit area ESV for Chengdu was consequently obtained (Table 6, Table 7, Table 8). Combined with the area of each LULC type in Chengdu for 2005, 2015 and 2025, Equation (3) was applied to compute the total economic ESV in Chengdu for the three periods, as well as the composition of total economic value across all LULC types and all ESs types (Table 9, Table 10, Table 11, Figure 4, Figure 5).

Table 6. Per unit area ESV of Chengdu in 2005 (CNY/hm²).

ESs		Cropland	Forest	Shrub	Grassland	Water	Snow/Ice	Barren
Provisioning	FP	1473.7	343.0	368.4	203.3	1016.3	0.0	0.0
	RM	266.8	800.4	635.2	304.9	292.2	0.0	0.0
	WS	-2019.9	419.2	343.0	165.2	10,504.6	2744.1	0.0
Regulating	GR	1194.2	2629.7	2147.0	1054.4	978.2	228.7	25.4
	CR	622.5	7876.5	6001.3	2769.5	2909.2	686.0	0.0

Supporting	WT	177.9	2286.7	1905.6	914.7	7000.7	203.3	127.0
	WR	2223.2	4903.7	4560.7	2032.6	129,886.1	9058.0	38.1
	SC	520.9	3201.4	2617.0	1283.1	1181.5	0.0	25.4
	NC	203.3	241.4	203.3	101.6	88.9	0.0	0.0
	BD	228.7	2921.9	2388.4	1168.8	3239.5	12.7	25.4
Cultural	AL	101.6	1283.1	1054.4	520.9	2399.1	114.3	12.7

Table 7. Per unit area ESV of Chengdu in 2015 (CNY/hm²).

ESs		Cropland	Forest	Shrub	Grassland	Water	Snow/Ice	Barren
Provisioning	FP	2351.0	547.2	587.7	324.3	1621.4	0.0	0.0
	RM	425.6	1276.8	1013.4	486.4	466.1	0.0	0.0
	WS	-3222.4	668.8	547.2	263.5	16,798.2	4377.7	0.0
Regulating	GR	1905.1	4185.3	3485.1	1682.2	1560.6	364.8	40.5
	CR	993.1	12,565.5	9566.0	4418.2	4621.1	1094.4	0.0
	WT	283.7	3648.1	3040.1	1459.2	11,248.2	324.3	202.7
	WR	3546.7	7792.0	7235.9	3242.7	207,196.2	14,450.4	60.8
Supporting	SC	830.9	5107.3	4175.0	2047.0	1884.8	0.0	40.5
	NC	324.3	385.1	324.3	162.1	141.9	0.0	0.0
	BD	364.8	4661.4	3810.2	1864.6	5168.1	20.3	40.5
Cultural	AL	162.1	2046.9	1682.2	830.9	3830.5	182.4	20.3

Table 8. Per unit area ESV of Chengdu in 2025 (CNY/hm²).

ESs		Cropland	Forest	Shrub	Grassland	Water	Snow/Ice	Barren
Provisioning	FP	2900.2	675.1	725.1	400.0	2000.2	0.0	0.0
	RM	525.0	1575.1	1250.1	600.0	575.0	0.0	0.0
	WS	-3975.3	825.1	675.1	325.0	20,726.7	5400.4	0.0
Regulating	GR	2350.2	5175.4	4225.3	2075.2	1925.2	450.0	50.0
	CR	1225.1	15,501.2	11,801.0	5450.4	5725.5	1350.1	0.0
	WT	350.0	4500.4	3750.3	1800.1	13,876.1	400.0	250.0
	WR	4375.4	9650.8	8975.7	4000.3	255,620.4	17,826.4	75.0
Supporting	SC	1025.1	6300.5	5150.4	2525.2	2325.2	0.0	50.0
	NC	400.0	475.0	400.0	200.0	175.0	0.0	0.0
	BD	450.0	5750.5	4700.4	2300.2	6375.5	25.0	50.0
Cultural	AL	200.0	2525.2	2075.2	1025.1	4725.4	225.0	25.0

Table 9. Summary of ESV in Chengdu in 2005 (10⁴ CNY).

ESs		Cropland	Forest	Shrub	Grassland	Water	Snow/Ice	Barren	Total of ESs	Proportion of ESs
Provisioning	FP	156,516.3	9652.4	3.5	196.3	1276.4	0.0	0.0	167,644.9	11.19
	RM	28,335.9	22,524.2	6.0	294.4	367.0	0.0	0.0	51,527.5	3.44
	WS	-214,526.2	11,796.8	3.3	159.5	13,193.0	15.6	0.0	-189,358.0	-12.64
Regulating	GR	126,831.6	74,003.0	20.4	1017.9	1228.5	1.3	1.4	203,104.3	13.56
	CR	66,113.5	221,654.5	57.1	2673.7	3653.7	3.9	0.0	294,156.4	19.63
	WT	18,894.1	64,350.6	18.1	883.1	8792.4	1.2	7.2	92,946.6	6.20
	WR	236,118.0	137,996.2	43.4	1962.3	163,127.5	51.6	2.2	539,301.2	36.00
Supporting	SC	55,322.9	90,091.4	24.9	1238.7	1483.9	0.0	1.4	148,163.2	9.89
	NC	21,591.8	6793.3	1.9	98.1	111.7	0.0	0.0	28,596.7	1.91
	BD	24,289.4	82,225.9	22.7	1128.4	4068.6	0.1	1.4	111,736.5	7.46

Cultural	AL	10,790.6	36,108.0	10.0	502.9	3013.1	0.7	0.7	50,426.0	3.37
Total of LULC		530,277.8	757,196.4	211.5	10,155.2	200,315.8	74.3	14.4	1,498,245.4	100%
Proportion of LULC		35.39	50.54	0.01	0.68	13.37	0.00	0.00	100%	-

Table 10. Summary of ESV in Chengdu in 2015 (10⁴ CNY).

ESs		Cropland	Forest	Shrub	Grassland	Water	Snow/Ice	Barren	Total of ESs	Proportion of ESs
Provisioning	FP	233,603.6	15,573.3	48.1	359.1	2282.5	0.0	0.0	251,866.6	3.34
	RM	42,289.1	36,337.6	83.0	538.6	656.2	0.0	0.0	79,904.4	3.34
	WS	-320,188.9	19,034.0	44.8	291.8	23,647.6	20.0	0.0	-277,150.8	-11.59
Regulating	GR	189,297.4	119,113.3	285.3	1862.7	2196.9	1.7	2.9	312,760.2	13.08
	CR	98,677.9	357,613.2	783.0	4892.4	6505.3	5.0	0.0	468,476.9	19.59
	WT	28,189.4	103,824.7	248.8	1615.8	15,834.6	1.5	14.4	149,729.3	6.26
	WR	352,412.5	221,759.8	592.3	3590.7	291,679.8	66.0	4.3	870,105.4	36.38
Supporting	SC	82,561.1	145,353.4	341.7	2266.7	2653.3	0.0	2.9	233,179.2	9.75
	NC	32,223.6	10,959.9	26.5	179.5	199.8	0.0	0.0	43,589.3	1.82
	BD	36,247.8	132,663.1	311.9	2064.7	7275.4	0.1	2.9	178,565.9	7.47
Cultural	AL	16,106.8	58,254.6	137.7	920.1	5392.4	0.8	1.4	80,813.9	3.38
Total of LULC		791,420.3	1,220,486.9	2903.1	18,582.2	358,323.8	95.0	28.9	2,391,840.2	100%
Proportion of LULC		33.09	51.03	0.12	0.78	14.98	0.00	0.00	100%	-

Table 11. Summary of ESV in Chengdu in 2025 (10⁴ CNY).

ESs		Cropland	Forest	Shrub	Grassland	Water	Snow/Ice	Barren	Total of ESs	Proportion of ESs
Provisioning	FP	265,252.8	22,516.4	54.6	434.9	2255.3	0.0	0.0	290,514.0	9.54
	RM	48,016.6	52,533.7	94.2	652.3	648.3	0.0	0.0	101,945.2	3.35
	WS	-363,581.7	27,519.3	50.9	353.4	23,369.8	11.3	0.0	-312,277.1	-10.26
Regulating	GR	214,949.7	172,613.2	318.4	2256.3	2170.7	0.9	3.6	392,312.8	12.88
	CR	112,047.9	517,005.8	889.3	5925.9	6455.6	2.8	0.0	642,327.3	21.10
	WT	32,011.1	150,100.2	282.6	1957.2	15,645.6	0.8	18.0	200,015.5	6.57
	WR	400,174.9	321,879.6	676.4	4349.3	288,217.5	37.3	5.4	1,015,340.4	33.35
Supporting	SC	93,755.8	210,138.2	388.1	2745.5	2621.7	0.0	3.6	309,653.0	10.17
	NC	36,584.1	15,842.5	30.1	217.4	197.3	0.0	0.0	52,871.5	1.74
	BD	41,157.1	191,794.3	354.2	2500.9	7188.5	0.1	3.6	242,998.7	7.98
Cultural	AL	18,292.0	84,222.1	156.4	1114.5	5328.0	0.5	1.8	109,115.3	3.58
Total of LULC		898,660.3	1,766,165.2	3295.3	22,507.7	354,098.4	53.8	36.1	3,044,816.7	100%
Proportion of LULC		29.51	58.01	0.11	0.74	11.63	0.00	0.00	100%	-

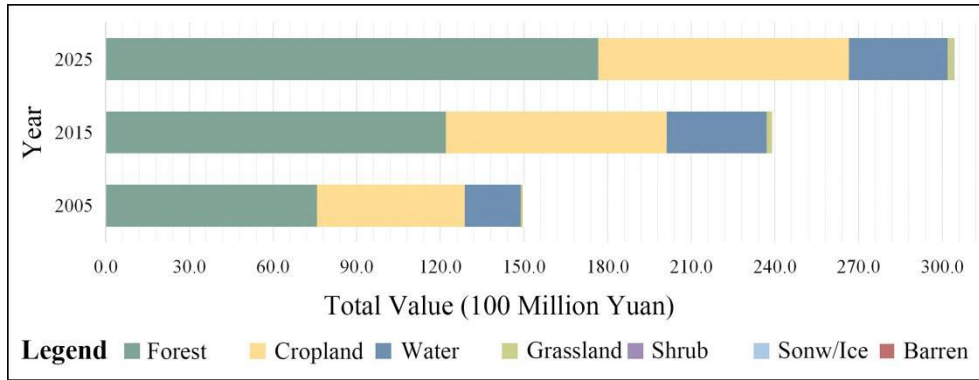


Figure 4. *ESV composition of LULC in Chengdu in 2005, 2015 and 2025*

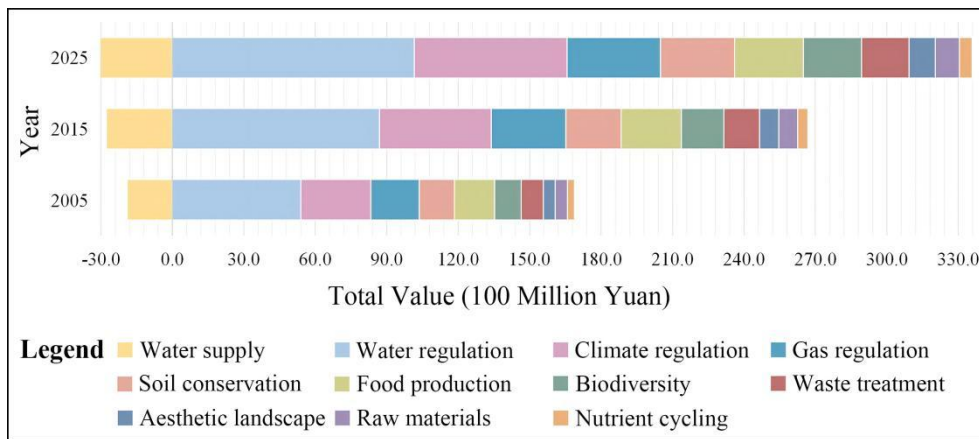


Figure 5. *Value composition of ESs in Chengdu in 2005, 2015 and 2025*

In terms of per unit area value, the per unit area ESV of all LULC types in Chengdu exhibited a consistent upward trend over the study period (Table 6, Table 7, Table 8). Among all LULC types, water has the highest per unit area value, reaching 159,496.3 CNY/hm², 254,537.1 CNY/hm² and 314,050.2 CNY/hm² in 2005, 2015 and 2025, respectively, followed by forest and shrub. Affected by the negative value of water supply, cropland showed distinctly lower per unit area value compared with other ecological land types.

In terms of total value, the total ESV of Chengdu increased from 14.98 billion CNY in 2005 to 30.45 billion CNY in 2025 (Table 9, Table 10, Table 11, Figure 4, Figure 5), presenting a sustained upward trend. Regarding the ESV of different LULC types, forest consistently contributed the largest proportion. Their total ESV rose from 7.57 billion CNY to 17.66 billion CNY, with its share of the regional total ESV climbing from 50.54% to 58.01%. Cropland ranked second in ESV contribution. Its total ESV expanded from 5.30 billion CNY to 8.99 billion CNY, yet, its share fell from 35.39% to 29.51%. Water maintained stable total ESV, consistently exceeding 3.50 billion CNY throughout the study period. Shrub, grassland, barren, and Snow/Ice made minor contributions to overall ESV, with each land type individually accounting for less than 1%. Among all ESs categories, water regulation exhibited the most prominent value growth, rising from 5.39 billion CNY to 10.15 billion CNY and occupying for over 33% of total ESV. Driven by continuous cropland shrinkage, the water supply service value sustained negative growth., All other ESV grew steadily over the study period.

3.3. Spatio-temporal Changes in ESV

3.3.1. Temporal Variations in ESV

To explore the temporal dynamic evolution trends of ESV, this study calculated the annual ESV change rate for each individual LULC category for the three intervals 2005–2015, 2015–2025, and 2005–2025, based on Equation (4). Detailed calculation outcomes for each time interval are presented in Table 12, Table 13, and Table 14.

Table 12. Summary of ESV changes in Chengdu, 2005 to 2015 (10^6 CNY).

ESs		Cropland		Forest		Shrub		Grassland		Water		Snow/Ice		Barren		Total Value of ESs	
		Value	%	Value	%	Value	%	Value	%	Value	%	Value	%	Value	%	Value	%
Provisioning	FP	770.87	29.5	59.21	1.3	0.45	1.7	1.63	1.9	10.06	0.6	0.00	0.0	0.00	0.0	842.22	9.4
	RM	139.53	5.3	138.13	3.0	0.77	2.9	2.44	2.9	2.89	0.2	0.00	0.0	0.00	0.0	283.77	3.2
	WS	-1056.63	-40.5	72.37	1.6	0.42	1.5	1.32	1.6	104.55	6.6	0.04	21.0	0.00	0.0	-877.93	-9.8
Regulating	GR	624.66	23.9	451.10	9.7	2.65	9.8	8.45	10.0	9.68	0.6	0.00	1.8	0.01	10.0	1096.56	12.3
	CR	325.64	12.5	1359.59	29.3	7.26	27.0	22.19	26.3	28.52	1.8	0.01	5.3	0.00	0.0	1743.20	19.5
	WT	92.95	3.6	394.74	8.5	2.31	8.6	7.33	8.7	70.42	4.5	0.00	1.6	0.07	50.0	567.83	6.4
	WR	1162.95	44.5	837.64	18.1	5.49	20.4	16.28	19.3	1285.52	81.4	0.14	69.4	0.02	15.0	3308.04	37.0
Supporting	SC	272.38	10.4	552.62	11.9	3.17	11.8	10.28	12.2	11.69	0.7	0.00	0.0	0.01	10.0	850.16	9.5
	NC	106.32	4.1	41.67	0.9	0.25	0.9	0.81	1.0	0.88	0.1	0.00	0.0	0.00	0.0	149.93	1.7
	BD	119.58	4.6	504.37	10.9	2.89	10.7	9.36	11.1	32.07	2.0	0.00	0.0	0.01	10.0	668.29	7.5
Cultural	AL	53.16	2.0	221.47	4.8	1.28	4.7	4.17	5.0	23.79	1.5	0.00	0.9	0.01	5.0	303.88	3.4
Total value of LULC		2611.43	100	4632.91	100	26.92	100	84.27	100	1580.08	100	0.21	100	0.14	100	8935.95	100
ESV_{cr}		-	4.9	-	6.1	-	127.3	-	8.3	-	7.9	-	2.8	-	10.1	-	6.0

Table 13. Summary of ESV changes in Chengdu, 2015 to 2025 (10^6 CNY).

ESs		Cropland		Forest		Shrub		Grassland		Water		Snow/Ice		Barren		Total Value of ESs	
		Value	%	Value	%	Value	%	Value	%	Value	%	Value	%	Value	%	Value	%
Provisioning	FP	316.49	29.5	69.43	1.3	0.07	1.7	0.76	1.9	-0.27	0.6	0.00	0.0	0.00	0.0	386.47	5.9
	RM	57.27	5.3	161.96	3.0	0.11	2.9	1.14	2.9	-0.08	0.2	0.00	0.0	0.00	0.0	220.41	3.4
	WS	-433.93	-40.5	84.85	1.6	0.06	1.6	0.62	1.6	-2.78	6.6	-0.09	21.0	0.00	0.0	-351.26	-5.4
Regulating	GR	256.52	23.9	535.00	9.8	0.33	8.5	3.94	10.0	-0.26	0.6	-0.01	1.8	0.01	10.0	795.53	12.2
	CR	133.70	12.5	1593.93	29.2	1.06	27.1	10.34	26.3	-0.50	1.2	-0.02	5.3	0.00	0.0	1738.50	26.6
	WT	38.22	3.6	462.76	8.5	0.34	8.6	3.41	8.7	-1.89	4.5	-0.01	1.6	0.04	50.0	502.86	7.7
	WR	477.62	44.5	1001.20	18.3	0.84	21.4	7.59	19.3	-34.62	81.9	-0.29	69.4	0.01	15.0	1452.35	22.2
Supporting	SC	111.95	10.4	647.85	11.9	0.46	11.8	4.79	12.2	-0.032	0.7	0.00	0.0	0.01	10.0	764.74	11.7

	NC	43.60	4.1	48.83	0.9	0.04	0.9	0.38	1.0	-0.02	0.1	0.00	0.0	0.00	0.0	92.82	1.4
	BD	49.09	4.6	591.31	10.8	0.42	10.8	4.36	11.1	-0.87	2.1	0.00	0.0	0.01	10.0	644.33	9.9
Cultural	AL	21.85	2.0	259.67	4.8	0.19	4.8	1.94	5.0	-0.64	1.5	0.00	0.9	0.00	5.0	283.01	4.3
Total value of LULC		1072.40	100	5456.78	100	3.92	100	39.26	100	-42.25	100	-0.41	100	0.07	100	6529.76	100
ESV_{cr}		-	1.4	-	4.5	-	1.4	-	2.1	-	-0.1	-	-4.3	-	2.5	-	2.7

Table 14. Summary of ESV changes in Chengdu, 2005 to 2025 (10^6 CNY).

ESs		Cropland		Forest		Shrub		Grassland		Water		Snow/Ice		Barren		Total Value of ESs	
		Value	%	Value	%	Value	%	Value	%	Value	%	Value	%	Value	%	Value	%
Provisioning	FP	1087.36	29.5	128.64	1.3	0.51	1.7	2.39	1.9	9.79	0.6	0.00	0.0	0.00	0.0	1228.69	7.9
	RM	196.81	5.3	300.09	3.0	0.88	2.9	3.58	2.9	2.81	0.2	0.00	0.0	0.00	0.0	504.18	3.3
	WS	-1490.55	-40.5	157.22	1.6	0.48	1.5	1.94	1.6	101.77	6.6	-0.04	21.0	0.00	0.0	-1229.19	-7.9
Regulating	GR	881.18	23.9	986.10	9.8	2.98	9.7	12.38	10.0	9.42	0.6	0.00	1.8	0.02	10.0	1892.09	12.2
	CR	459.34	12.5	2953.51	29.3	8.32	27.0	32.52	26.3	28.02	1.8	-0.01	5.3	0.00	0.0	3481.71	22.5
	WT	131.17	3.6	857.50	8.5	2.64	8.6	10.74	8.7	68.53	4.5	0.00	1.6	0.11	50.0	1070.69	6.9
	WR	1640.57	44.5	1838.83	18.2	6.33	20.5	23.87	19.3	1250.90	81.3	-0.14	69.4	0.03	15.0	4760.39	30.8
Supporting	SC	384.33	10.4	1200.47	11.9	3.63	11.8	15.07	12.2	11.38	0.7	0.00	0.0	0.02	10.0	1614.90	10.4
	NC	149.92	4.1	90.49	0.9	0.28	0.9	1.19	1.0	0.86	0.1	0.00	0.0	0.00	0.0	242.75	1.6
	BD	168.68	4.6	1095.68	10.9	3.31	10.7	13.73	11.1	31.20	2.0	0.00	0.0	0.02	10.0	1312.62	8.5
Cultural	AL	75.01	2.0	481.14	4.8	1.46	4.7	6.12	5.0	23.15	1.5	0.00	0.9	0.01	5.0	586.89	3.8
Total value of LULC		3683.83	100	10,089.69	100	30.84	100	123.53	100	1537.83	100	-0.21	100	0.22	100	15,465.71	100
ESV_{cr}		-	6.9	-	13.3	-	14.5	-	12.2	-	7.7	-	-2.8	-	15.1	-	10.3

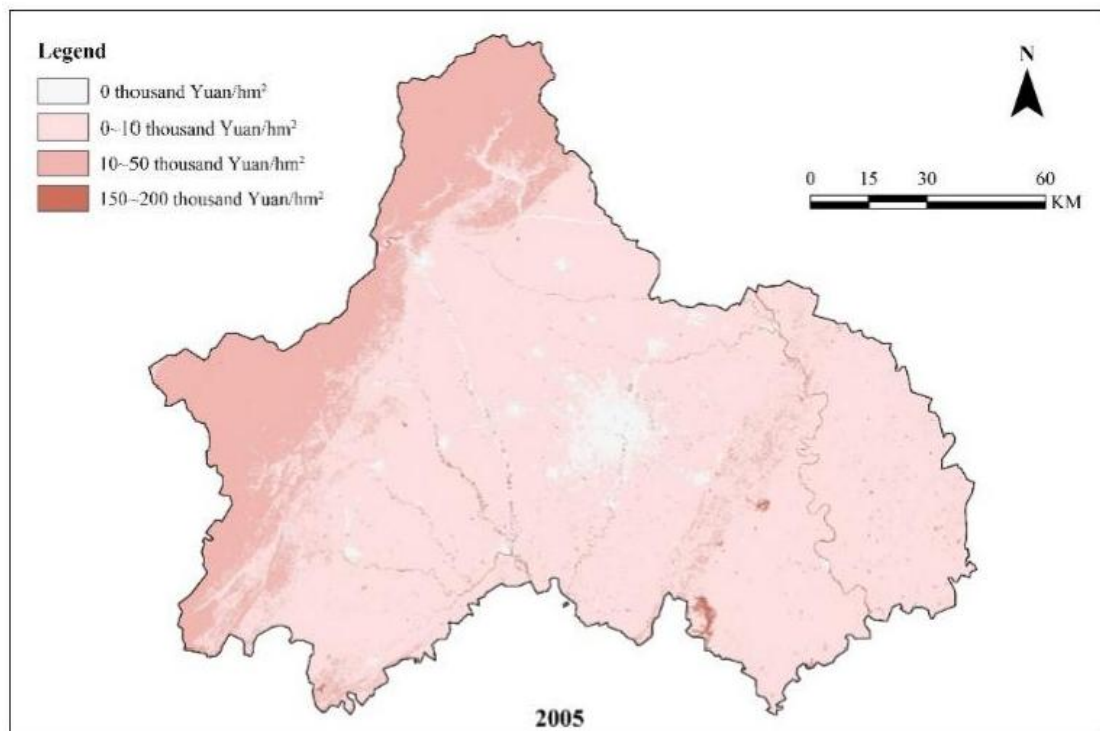
In terms of individual LULC types, the ESV of various LULC types in Chengdu changed substantially from 2005 to 2025. Benefiting from the continuous expansion of forest area, forests exhibited the largest ESV increase, with a total value growth of 10.09 billion CNY over the 20-year period and an annual change rate of 13.3%. Although cropland area decreased during the study period, its total ESV increased by 3.68 billion CNY at an annual rate of 6.9%, driven by the improvement in per unit area ESV, which maintained its fundamental ESs functions. The total ESV of water rose by 1.54 billion CNY, with an annual change rate of 7.7%. Shrub, grassland, and barren all showed positive ESV growth. Shrub exhibited the highest annual ESV change rate of 145.8%, primarily attributable to its substantial areal expansion after 2005. Snow/Ice was the only land type that experienced ESV decline, with an annual change rate of -2.8%, consistent with its continuous area shrinkage during the study period. In terms of phased changes, all LULC types achieved rapid ESV growth from 2005 to 2015. Nevertheless,

the growth rate decreased markedly during 2015 to 2025, and Snow/Ice ESV even shifted to negative growth in this stage.

In terms of ESs types, regulating services dominated the total ESV from 2005 to 2025, accounting for the maximum proportion of 72.45%. Water regulation and climate regulation served as the core drivers of ESV growth. Over the 20-year study period, their service values increased by 4.76 billion CNY and 3.48 billion CNY, jointly contributing 53.3% to the total ESV. Supporting services such as soil conservation and nutrient cycling, and cultural services such as aesthetic landscape maintained a steady growth trend, collectively contributing 24.29% to the total ESV. Provisioning services exhibited distinct internal differentiation. While food production and raw material supply grew steadily, water supply value sustained a continuous decline, occupying for -7.9% of the total ESV. This deficiency has become the primary constraint on the overall ESs functions of Chengdu. In terms of phased characteristics, all service types experienced rapid value growth during 2005 to 2015, with water regulation and climate regulation showing particularly prominent growth rates. From 2015 to 2025, the overall growth rate slowed down, accompanied by a declining proportion of water regulation and a rising proportion of climate regulation.

3.3.2. Spatial Change of ESV

Judging from the spatial distribution of ESV (Figure 6), high-value ESV areas in Chengdu are mainly distributed across the western Longmen Mountains, the remnant ridges of Qionglai Mountains, the eastern Longquan Mountains, and along major water systems. These areas are dominated by ecological land types including forest and water, resulting in high per unit area ESV. By 2025, the extent of high-value areas had expanded remarkably and formed the core pole supporting the city's total ESV. Cropland mostly fell within medium-value zones in terms of per unit area value. The central construction land exhibited nearly zero ecological supply capacity.



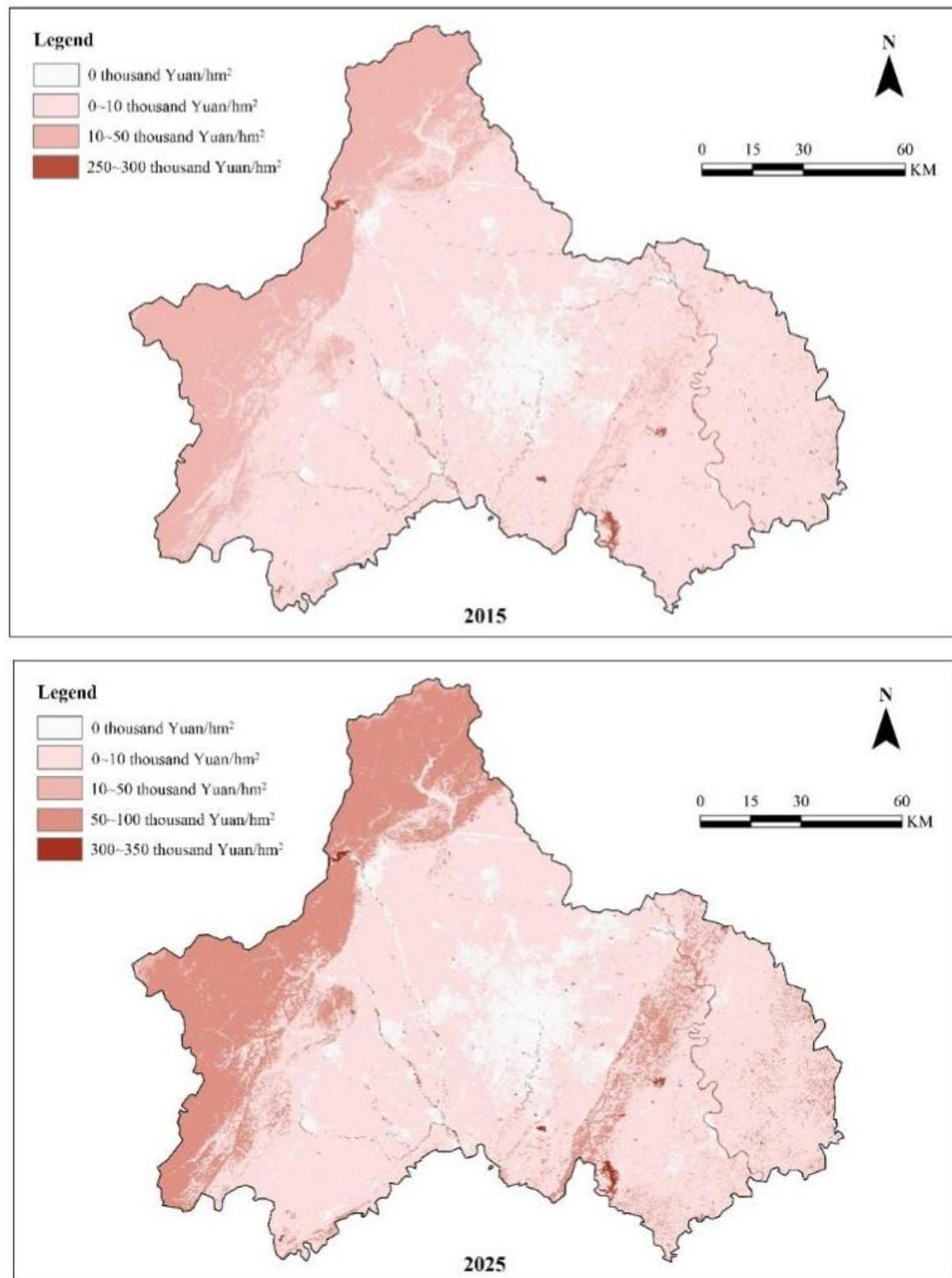


Figure 6. Spatial distribution of per unit area ESV in Chengdu in 2005, 2015 and 2025

Source: redrawn by the authors based on the dataset developed by Professor Xin Huang's team, Wuhan University.

Over the past 20 years, the spatial pattern of ESV in Chengdu has undergone substantial changes (Figure 7). A total area of 12,455 km² experienced an increase in per unit area ESV, which was primarily dominated by existing forest and cropland with improved per unit area values. These two land types collectively accounted for 92.2% of the total ESV-elevated area. In detail, the area with an ESV increment of 0–10 thousand CNY/hm² reached 8888.2 km². This zone was mainly distributed over existing

cropland accounting for 99.9% of this interval, with an average per unit area value increase of 4832.8 CNY/hm².

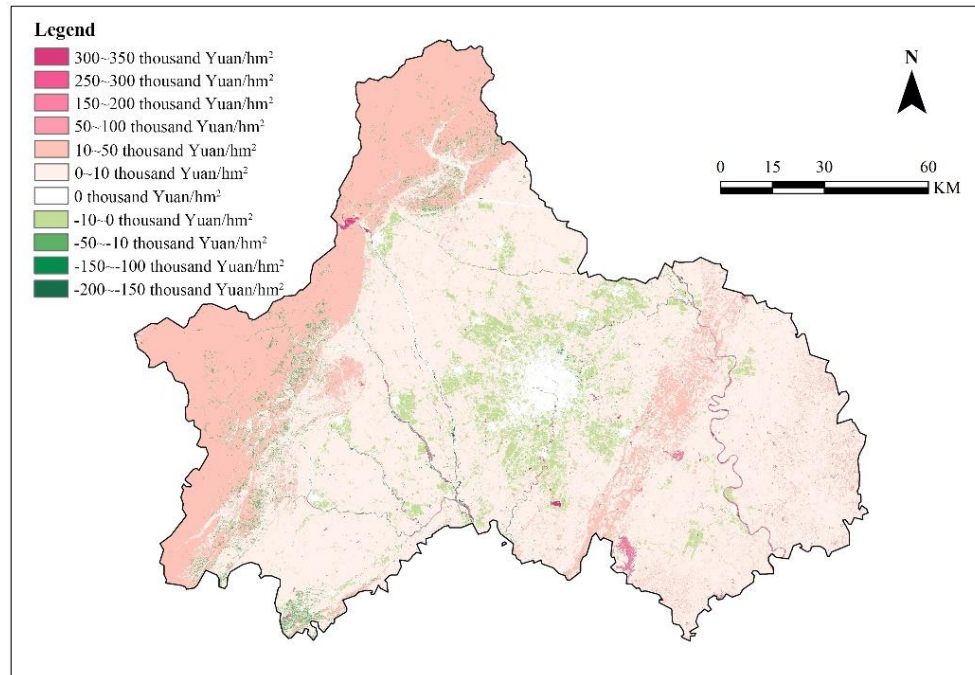


Figure 7. Spatial distribution of changes in per unit area ESV in Chengdu, 2005 to 2025.

Source: redrawn by the authors based on the dataset developed by Professor Xin Huang's team, Wuhan University.

The area with an ESV growth of 10–200 thousand CNY/hm² covered 3525.5 km², predominantly located in existing forest ecological land and occupying 74% of this grading range, with a mean per unit area enhancement of 26,047.3 CNY/hm². The high-increase zone, with an ESV growth exceeding 200 thousand CNY/hm², spanned 41.2 km². This area was sporadically distributed and mainly derived from cropland converted to water, contributing 73.5% of this interval with a prominent per unit area value increase of 309,057.3 CNY/hm². ESV growth areas were mainly distributed across the cropland regions of the Chengdu Plain, the western Longmen Mountains and remnant ridges of the Qionglai Mountains, as well as the eastern Longquan Mountains and riparian zones of major water systems.

A total of 1219.1 km² of land experienced a decline in per unit area ESV, mainly consisting of cropland converted to urban land and forest converted to cropland, both of which have lower per unit area values. These two transformation types accounted for 94.3% of the total ESV-declined land area. In detail, the area with per unit area ESV decrease ranging from 0–10 thousand CNY/hm² reached 960.2 km². This interval was primarily dominated by cropland converted to urban land, accounting for 98.9% of this range, with an average per unit area value reduction of 4992.9 CNY/hm². The area with an ESV decrease of 10–200 thousand CNY/hm² covered 258.9 km². This interval mainly consisted of forests converted into cropland, accounting for 77.4% of this range, with a mean per unit area value reduction of 17,081.3 CNY/hm². ESV reduction areas were mainly distributed along urban fringes, corresponding to newly expanded urban construction zones.

The spatial distribution of per unit area ESV changes clearly reflects the impacts of LULC restructuring, urbanization, and ecological protection policies on ESV in

Chengdu over the 20-year period. It provides scientific guidance for Park City construction, ecological conservation, and territorial spatial optimization in Chengdu.

4. Discussion

4.1. LULC Change

Driven by the rigid demand from the construction of a major central city in western China, as well as population and industrial agglomeration, urban space expanded rapidly, with urban area increasing by 141.25% during the study period. Owing to low development costs, plain cropland constituted the primary land source for urban expansion. A total of 98.78% of newly-added construction land originated from cropland conversion, demonstrating the typical feature of “occupying cropland for urban construction [33].” With continuous urban expansion, the “sprawling” pattern of urban development has contributed to a negative growth in ESV [34]. Policies including Park City exploration and practice [35], as well as the Grain for Green Program [36], contributed to an 18.52% increase in forest area over the 20-year period, making forests the dominant land type for ESV growth. This confirmed the effectiveness of ecological restoration in improving regional ESs functions [37]. Cropland transitions toward construction land and forest brought improvements in ecological-space quality on the one hand, yet triggered continuous cropland loss, with a 13.88% decline over two decades, reflecting the trade-off between food security and ecological conservation. Water showed an increasing-then-decreasing trend, while continuous shrinkage of Snow/Ice reveals conservation pressures on water resources and alpine ecosystems amid urban development. These LULC types constituted the primary constraint on ESs functioning in Chengdu.

From 2005 to 2025, Chengdu's land use pattern exhibited distinct evolutionary characteristics: continuous shrinkage of cropland, accelerated expansion of construction land, and steady growth of ecological land. This pattern was not driven by a single factor but stemmed from the long-term synergistic effects of urbanization, ecological civilization policies, and territorial spatial governance. It further reveals the evolutionary patterns of land and spatial structures in megacities under the dual pressures of urban development and ecological protection.

4.2. ESV Change

In terms of economic price of one standard equivalent ES, the per unit area provision service value of cropland ecosystems increased markedly from 1270.4 CNY/hm² in 2005 to 2500.2 CNY/hm² in 2025 across the three study periods. This upward trend was driven by multiple factors, including temporal changes in grain prices and crop yields, adjustments in planting structures, the transformation and upgrading of agricultural development patterns, and phased revisions of food security policies [23]. Furthermore, this study did not conduct the consumer price index (CPI) based price inflation adjustment [38]. Therefore, inflation effects moderately enlarged the inter-period ESV disparities throughout the study duration.

In terms of the temporal variation in total ESV, the total ESV of Chengdu increased from 14.98 billion CNY to 30.45 billion CNY between 2005 and 2025, representing a growth rate of 103.23%. This substantial increase was primarily attributed to the continuous rise in the economic price of one standard equivalent ES over the past two decades. Despite the ongoing shrinkage of cropland area in Chengdu, steady improvements in regional grain yield and agricultural market prices jointly elevated the

benchmark accounting coefficients for ESV assessment. The temporal evolution of ESV exhibited a phased trend of “rapid growth followed by steady improvement.” During the first stage (2005–2015), ESV experienced a rapid increase due to the implementation of the Grain for Green Program [36] and urban ecological construction [39]. In the second stage (2015–2025), the rigid constraints of the Three Zones and Three Lines territorial spatial planning were fully implemented [40]. Accordingly, ecological protection and restoration shifted from large-scale quantitative expansion to high-quality stock optimization, which correspondingly slowed the ESV growth rate. These findings indicate that urban development does not necessarily occur at the cost of ESs degradation. Through scientific territorial spatial planning and strict land use regulation, rapidly urbanizing regions can achieve a win-win outcome of socioeconomic advancement and ecological conservation [41].

In terms of spatial changes in total ESV, high ESV were predominantly concentrated in the western Longmen and Qionglai Mountains, the eastern Longquan Mountains, and riparian zones of major water systems constitute. The spatial coverage of these high-value ecological zones continued to expand throughout the 20-year study period. Central construction land belong to low-value zones, while plain cropland areas form a medium-value buffer zone that sustains basic production functions. This spatial pattern clearly reflects the rule that “ecological functions are determined by natural conditions, and value losses are dominated by urban expansion [42].”

4.3. Comprehensive Changes

In terms of value contributions of different LULC types, cropland has the second-lowest per unit area ESV. Nevertheless, supported by the largest land-area base across the whole study area, its total ESV ranks second. Forest accounts for the second-largest area in Chengdu, and its per unit area ESV is second only to water. Such dual advantages make forest the core support for regional total ESV. Water yield the highest per unit area ESV among all land types. However, their proportion has long remained below 1%, and the limited land scale restricts the growth of their total ESV, with its overall contribution staying stable between 11% and 15%. In conclusion, the total ecological value of an individual land type is jointly determined by two factors: per unit area value and land use scale.

4.4. Implications for Urban Sustainable Development

(1) Territorial spatial optimization.

It is essential to strictly delineate the ecological conservation redline, permanent basic farmland, and urban development boundaries to constrain disorderly urban expansion. A holistic ecological pattern characterized by western forest conservation, central farmland protection, eastern ecological restoration, and water corridor connectivity should be established to alleviate ecological landscape fragmentation and maintain regional ecological integrity.

(2) Ecological restoration.

Forest and water should be regarded as core ecological conservation targets. Relevant initiatives, including natural forest protection and water system connectivity projects, should be vigorously promoted. In response to potential water supply risks, it is necessary to strengthen paddy field protection, rainwater regulation, and water-saving urban construction, so as to enhance the water regulation capacity of urban ecosystems.

(3) High-quality urban development.

The single production-oriented function of cropland should be transformed by developing ecological agriculture and recreational agriculture, thereby improving the comprehensive ESV of cropland ecosystems. Construction land should shift from extensive expansion to intensive stock quality improvement. Increasing urban green spaces, pocket parks, and ecological corridors can effectively strengthen the ESs supply capacity of construction land.

(4) Ecological value transformation.

Relying on the ecological advantages of high-ESV regions, the development of eco-tourism, forest health preservation, and green agriculture can facilitate the sustainable transformation of ecological benefits into economic benefits. Furthermore, establishing ecological compensation mechanisms and carbon sink trading systems helps build a virtuous cycle mechanism of “protection-value increment-ecological feedback” for regional sustainable development.

5. Conclusions

5.1. Research Conclusions

This study analyzes the land-use pattern and evolutionary characteristics of ESV in Chengdu from 2005 to 2025. The overall pattern is jointly driven by rapid urbanization and ecological civilization construction. In terms of LULC changes, cropland decreased by 147,461.86 hm², and was mainly converted to construction land and forest, with area increments of 94,636.55 hm² and 52,113.88 hm² respectively. Shrub, grassland and water exhibited an increasing-then-decreasing trend. Snow/Ice continued to shrink, while barren maintained relatively steady growth. Although cropland was continuously occupied by construction land, gains in forest ESV generated by ecological restoration offset and then exceeded the ecological losses induced by cropland loss and urban expansion. Over the study period, the total ESV of Chengdu kept growing, rising from 14.98 billion CNY in 2005 to 30.45 billion CNY in 2025, representing an increase of 103.23%. Spatially, ESV high-value areas are concentrated in the western Longmen Mountains and Qionglai Mountains foothills, the eastern Longquan Mountains, and river riparian zones. Construction land in the central plain areas formed contiguous low ESV zones. In terms of land based ESV contribution, forest served as the primary dominant type in the study area. Its contribution share rose from 50.54% to 58.01%, indicating a continuous strengthening of its dominant status. Although cropland maintained a relatively high total ESV, its contribution share exhibited a continuous downward trend. Water maintained a stable ESV contribution of over 10%, whereas all other land types contributed less than 1%. In terms of ESs category contribution, regulation services dominant Chengdu's total ESV, consistently accounting for more than 70% throughout the study period. Water regulation and climate regulation were the two core functional components supporting such regulatory services. Supporting services and cultural services improved steadily. For provisioning services, food production and raw materials kept increasing, while the long-term negative growth of water supply capacity represents the most prominent ecological weakness. These conclusions can provide quantitative support for Park City construction, territorial spatial pattern optimization, and the realization of ecological product value in Chengdu. They also offer references for sustainable ecological governance of megacities in Southwest China.

5.2. Limitations and Future Prospects

The economic price of one standard equivalent ES adopted in this study was calculated based on the annual current grain prices. Although the total cropland area decreased over the past two decades, continuous increases in grain prices and cropland productivity led to a significant rise in the standard equivalent value [23]. In addition, this study did not employ the CPI for inflation adjustment, failing to eliminate monetary value disparities across different years, which may overestimate the apparent ESV variations during the study period [38]. Furthermore, the LULC dataset used in this study has spatial resolution limitations, which constrains the effective identification of fine-scale ecological units, including small green spaces, scattered water bodies, and fragmented forest patches within construction land. All artificial construction land was uniformly assigned an equivalent value of zero [28], which to some extent underestimates the ecological service contributions of internal urban ecological spaces. In addition, this study adopted static equivalent coefficients, which cannot dynamically reflect the functional improvements generated by ecological restoration projects or capture the ESV variations caused by the increasing scarcity of ecological resources during rapid urbanization. Consequently, certain deviations inevitably exist in the ESV estimation results.

Future research can be optimized in three aspects. First, future studies can fully incorporate Chengdu's topographic features, vegetation types, and ecological functional zoning to construct a localized ESV equivalent system, thereby improving the accounting accuracy for major land categories such as forest and cropland. Second, the CPI can be introduced for price deflation, and a dynamic equivalent correction model can be established to reduce estimation errors caused by price fluctuations and static coefficient settings. Third, high-precision LULC data can be applied to optimize the current evaluation framework. By incorporating artificial ecological elements, including urban green spaces and greenways, future ESV accounting can more comprehensively and accurately reflect the actual service supply capacity of complex urban ecosystems. This improvement can comprehensively reflect the actual ESs supply capacity of construction land.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

Conceptualization: Li, J.; Wang, L.Y. Methodology: Li, J.; Wang, L.Y. Software: Wang, L.Y. Validation: Li, J.; Wang, L.Y. Formal analysis: Wang, L.Y. Investigation: Wang, L.Y. Resources: Wang, L.Y. Data Curation: Wang, L.Y. Writing – original draft preparation: Wang, L.Y. Writing – review and editing: Li, J. Visualization: Wang, L.Y. Supervision: Li, J. Project administration: Li, J. Funding acquisition: Li, J.

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