Temporal and Spatial Analysis of the Ecosystem Service Values in the Three Gorges Reservoir Area of China Based on Land Use Change

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Abstract

The Three Gorges Reservoir area (TGRA) has complex geological conditions and a fragile ecological environment. The construction of the Three Gorges Project triggered a series of ecological and environmental issues and social disputes, which have attracted much attention in recent years. However, it is still unclear how the temporal and spatial characteristics of ecosystem service value (ESV) in the TGRA changed in each stage of the Three Gorges Project along with the implementation of some ecological restoration projects. Based on four periods of land use data from 2000 to 2018, the changes in land use were studied and the ecosystem service values (ESVs) were estimated. Then, we analysed the spatial distribution and dynamic changes in ecosystem services. The results showed that from 2000 to 2018, grassland and construction land were the largest land use types showing area reductions and increases and the conversion of cropland to forestland, grassland and construction land represented the most important land type changes. In the past 18 years, due to the increase in forestland and water area, the ESVs increased by 2.7 billion yuan, with a growth rate of 3.46%. From the perspective of contribution rate, the conversion of cropland to forestland had the largest contribution rate to the increase in ESV. The ESV was higher in the northeast and lower in the southwest, and its changes have significant positive autocorrelation in spatial distribution. The hot spots of ESV change were mainly distributed in the main stream of the Yangtze River and the reservoir area. This research provides a reference for land resource allocation and experience for the ecological environment protection and sustainable development of the Yangtze River Basin.

Keywords Land use change • Ecosystem service value • Spatial correlation • Equivalent value factor • Human activities • Three Gorges Reservoir area

1 Introduction

Ecosystem services refer to the benefits that humans obtain directly or indirectly from the ecosystem, including provisioning services, regulation services, supporting services and cultural services (Assessment 2005; Costanza et al. 1997). The sustainable development of the social economy depends on the sustainable supply of ecosystem services (Liu & Wu 2021; Zhou et al. 2016). However, the advancement of social technology has greatly accelerated the plundering of natural resources by humans and destroyed the ecological environment. Humans gain economic prosperity at the expense of ecosystem services (Cao et al. 2021). Therefore, it is imperative to evaluate ecosystem service value (ESV) to alleviate the increasingly scarce ecosystem services and help people clearly recognize the important role of ecosystem services in human survival. Global scholars have been researching the value of ecosystem services for approximately 30 years. In 1997, two milestone studies were published: one by Daily (1997), which was titled “Nature’s Services: Societal Dependence on Natural Ecosystems”, and the other by Costanza et al. (1997), which was

77 titled “The Value of the World’s Ecosystem Service and Nature Capital” and published in the journal
78 Nature. The latter paper systematically calculated the total value of ecosystem services worldwide
79 and depicted its spatial distribution. The publication of these studies has triggered a global research
80 boom on ecological capital and ecosystem services, which has become a frontier issue.

81 Land use change (LUC) is a significant way for humans to affect ecosystems (Yu et al. 2020), and
82 LUC can change the functions and products of ecosystem services (Hasan et al. 2020; Li et al. 2021;
83 Liang et al. 2021; Wu et al. 2018). A previous assessment (2005) pointed out that LUC has been the
84 most important driving force leading to changes in the value of terrestrial ecosystem services since
85 the 1950s. As an important part of human well-being, LUC and its impact on ecosystem services
86 have received widespread attention worldwide (Fei et al. 2018; Gashaw et al. 2018; Li et al. 2021;
87 Schirpke et al. 2020; Tan et al. 2020). Liu et al. (2020) assessed the value of ecosystem services in
88 the Bohai Rim coastal zone and found that the decrease in saltwater wetland area and the increase
89 in construction land area were the reasons for the decrease in ESV. Wu et al. (2020) estimated the
90 value of ecosystem services in Jiangsu Province and proposed that rapid urbanization in the region
91 has placed great pressure on ecosystem services. Taking Yongshou County on the Loess Plateau as
92 an example, Zhang et al. (2020a) found that the implementation of the ecological restoration project
93 changed the rural land use structure, greatly improved the ecological environment, and had a
94 significant positive impact on ecosystem services. Existing studies mostly focus on the impact of a
95 single land use type change on the value of ecosystem services (Wang et al. 2019a). However, few
96 related studies have deeply analysed the changes in the value of ecosystem services brought about
97 by the conversion between various land types in the process of LUC. Therefore, clarifying the
98 impact of different land use transfer types on ESV can further reveal the impact mechanism of LUC
99 on ESV and provide guidance for the optimization of land use.

100 In terms of the value estimation of ecosystem services, there are two main methods: the functional
101 value evaluation method and the equivalent factor method. The functional value evaluation method
102 is a common method for evaluating the characteristics of ecosystem services in small-scale regions
103 by obtaining monitoring data from fixed point observations and combining them with related
104 ecological models (Fu & Zhang 2014; Zhang et al. 2020c). This method requires a large amount of
105 data, the process is complicated, and some parameters are not easy to obtain. The most widely used
106 value assessment method is the equivalent factor method. This method does not require complex
107 model calculations and requires less data (Wang & Dun 2015). On the basis of Costanza et al. (1997)
108 and combined with the actual situation in China, Chinese scholars Xie et al. (2008) conducted a
109 questionnaire survey of 700 professionals with ecological backgrounds in China and proposed a
110 value equivalent table suitable for the Chinese region. This table is used by many scholars to
111 estimate changes in the value of ecosystem services in China. Because the value assessment method
112 easily summarizes and compares different services, it is more suitable for the comparative study of
113 ecosystem service changes under different land use change scenarios.

114 The Three Gorges Reservoir area (TGRA) is a typical ecologically fragile area in China (Huang et
115 al. 2019; Zhang et al. 2020b), and it is also an ecological barrier area of strategic significance in the
116 Yangtze River Basin (Li et al. 2019a). As the world’s largest hydroelectric project, the Three Gorges
117 Project has affected the ecosystem of the TGRA (Yuan et al. 2013; Zheng 2016), including soil
118 erosion (Huang et al. 2020; Xiao et al. 2020), water quality (Holbach et al. 2013; Li et al. 2019b;
119 Xiang et al. 2021) and biodiversity (Wu et al. 2003), which has attracted widespread attention from
120 ecologists worldwide. With the rapid economic development in the upper reaches of the Yangtze

River and the construction and impoundment of the Three Gorges Dam, the land use pattern in the reservoir has changed greatly, and the value of ecosystem services closely related to it has also changed. Since 2000, the Chinese government has paid more attention to the ecological environment of the TGRA. Ecological projects, such as the Grain for Green Program and Natural Forest Protection Program, have been implemented successively, and a large number of other land use types have been converted to forest and grassland.

Previous studies have been conducted on the LUC in the TGRA and its impact on the ecosystem (Chu et al. 2018; Yan et al. 2014). A study showed that the LUC characteristics are different in different stages of the Three Gorges Dam construction. During the period from 1990 to 2010, water impoundment and inundation, resettlement and relocation, and urbanization led to the expansion of water area and the reduction of cropland (Shao et al. 2013). Guo and Zhou (2016) estimated the total value of ecosystem services in the TGRA from 2000 to 2014 and explored the relationship between changes in land use and ecosystem services before and after the completion of water storage in the reservoir area. However, research on the specific characteristics of LUC and its ecological effects in different construction periods of the Three Gorges Project is limited. The lack of this knowledge hinders our ability to formulate the most reasonable and effective sustainable development measures for different stages.

Taking the TGRA as the research object, this paper used the equivalent factor method to calculate the value of ecosystem services in the study area and studied the impact of LUC on ecosystem services. The study aims to (1) analyse the spatiotemporal characteristics of LUC; (2) assess the temporal and spatial changes in ESV and its spatial heterogeneity; and (3) analyse the impact of LUC on ESV.

2 Materials and methods

2.1 Study area

The TGRA lies at the junction of the Sichuan Basin and the middle and lower reaches of the Yangtze River Plain, located at 105° 50'-111° 65'E and 28° 56'-31° 44'N (Fig. 1). Covering an area of approximately 58000 km², it contains 26 (4 in Hubei Province and 22 in Chongqing City) districts or counties. The area is located in a subtropical humid climate, with high temperature and rain in summer and mild and humid temperatures in winter. The average annual temperature is approximately 18 °C, and the average annual precipitation is 1100 mm. With the construction of the Three Gorges Project and socioeconomic development of the TGRA, the land use patterns have changed, which may affect ecosystem services.

Fig. 1 Location of the Three Gorges Reservoir area

2.2 Data sources

The data of this study mainly include land use data, digital elevation models and socioeconomic data. The land use data with a spatial resolution of 1×1 km in 2000, 2005, 2010 and 2018 were obtained from the Resource and Environment Data Cloud Platform of the Chinese Academy of Sciences. These data are based on Landsat-8 remote sensing images and are generated by manual visual interpretation. The land use types were divided into cropland, forestland, grassland, water, construction land, and bare land. The socioeconomic statistics data were obtained from the Chongqing Statistical Yearbook, Yichang Statistical Yearbook, Enshi Statistical Yearbook, National Farm Product Cost-benefit Survey, and China Yearbook of Agricultural Price Survey.

2.3 Ecosystem services valuation

In 1997, Costanza et al. (1997) began to evaluate the value of global ecosystem services. Based on their research results and combined with the characteristics of China's ecosystem, Chinese scholars Xie et al. (2015) formulated the equivalent factor table of ESV in China. In this study, we modified the table of equivalent value factors based on the equivalent value factor table proposed by Xie et al. (2015) and the actual situation in the study area. Specifically, the equivalent value of cropland was multiplied by the corresponding equivalent value of the proportion of paddy field and dry land in the study area. The equivalent value of forestland was determined based on the average value of coniferous forest, mixed coniferous broad-leaved forest, broad-leaved forest and shrub forest. The equivalent value of grassland was determined based on the average value of shrubs and meadows. We determined that the equivalent value of the construction land was 0 according to related research. When calculating the ESV, the average grain price of the TGRA was revised according to the consumer price index (CPI) to construct an ESV coefficient suitable for the region. The ESV model was revised as follows:

$$a_i = \frac{CPI}{100} \quad (i = 0, 1, 2, \dots, n) \quad (1)$$

$$\frac{a_1}{a_0} \times \frac{a_2}{a_1} \times \frac{a_3}{a_2} \times \cdots \times \frac{a_n}{a_{n-1}} = \frac{a_n}{a_0} \quad (2)$$

$$VC = VC_0 \times \frac{a_n}{a_0} \quad (3)$$

$$VC_0 = \frac{1}{7} \sum_{i=1}^n \frac{p_i q_i m_i}{M} \quad (4)$$

where a_i is the unit *CPI* of i-year; a_1/a_0 is the initial chained *CPI*; VC is the unit price of the ESV; VC_0 is the economic value of the cropland's production services; p_i is the average grain output of the study area; q_i is the average grain price of the study area; m_i is the average grain area of the study area; and M is the total grain area of the study area. According to the characteristics of the study area, we selected rice, corn, soybean, and potato as the main types of food crops.

According to the value equivalent factor table and the unit price of the ESV, we calculated the value coefficient of ecosystem services per unit area in the study area (Table 1).

Table 1 Value coefficient of ecosystem services per unit area in the study area (yuan/hm²)

Ecosystem services type		Cropland	Forestland	Grassland	Water	Bare land	Construction land
Provisioning services	Food production	1298.15	327.82	393.38	1049.01	0.00	0.00
	Raw material production	406.49	760.53	590.07	301.59	0.00	0.00
	Water supply	-944.11	393.38	327.82	10870.35	0.00	0.00
Regulation services	Gas regulation	1035.90	2504.51	2045.57	1009.67	26.23	0.00
	Climate regulation	550.73	7487.29	5402.39	3002.79	0.00	0.00
	Purification environment	157.35	2189.80	1783.31	7277.49	131.13	0.00
	Hydrological regulation	1258.81	4904.11	3960.01	134063.22	39.34	0.00
Supporting services	Soil conservation	970.33	3042.12	2491.39	1219.47	26.23	0.00
	Maintain nutrient cycle	183.58	236.03	196.69	91.79	0.00	0.00
	Biodiversity	196.69	2779.87	2268.48	3343.71	26.23	0.00
Cultural services	Aesthetic landscape	91.79	1219.47	996.56	2478.28	13.11	0.00
Total		5205.70	25844.93	20455.66	164707.37	262.25	0.00

The ESV was calculated using the following equations:

$$ESV_k = \sum_f A_k \times VC_{kf} \quad (5)$$

$$ESV_f = \sum_k A_k \times VC_{kf} \quad (6)$$

$$ESV = \sum_k A_k \times VC_k \quad (7)$$

where ESV_k , ESV_f , and ESV refer to the ESVs of land use type k , ecosystem service function f and the entire value, respectively; A_k is the area of land use type k ; VC_{kf} is the value coefficient for land use type k with the ecosystem service function j ; and VC_k represents the value coefficient of land use type k .

2.4 Ecological contribution rate of land use change

The contribution of the ecosystem service value of land use change refers to the change rate of the regional ecosystem service value caused by the transformation of land use type i to land use type j . The formula is as follows:

$$EL_{i-j} = \frac{(VC_j - VC_i) \times LUC_{i-j}}{\sum_{i=1}^n \sum_{j=1}^n [(VC_j - VC_i) \times LUC_{i-j}]} \times 100\% \quad (8)$$

where EL_{i-j} is the contribution of land use change to the ecosystem service value; VC_j and VC_i represent the value coefficients of land use types i and j , respectively; and LUC_{i-j} is the area of land use type i changed to land use type j during the study period. We calculated the sensitivity index by adjusting 50% of the value coefficient of various land use types.

2.5 Sensitivity analysis

Due to the uncertainty in the selection of the value coefficient, we conducted a sensitivity analysis to reflect the dependence of the ESV on the value coefficient over time. We calculate the sensitivity index by adjusting 50% of the value coefficient of various land use types up and down. The coefficients of sensitivity (CS) calculation process is as follows:

$$CS = \left| \frac{(ESV_e - ESV_i) / ESV_i}{(VC_{ek} - VC_{ik}) / VC_{ik}} \right| \quad (9)$$

where CS is the coefficient of sensitivity; ESV_i represents the initial ecosystem service values; ESV_e represents the value of ecosystem services after adjustment; VC_{ik} represents the initial value coefficient of land use type i ; and VC_{ek} represents the value coefficient of land use type i after adjustment. If $CS > 1$, then ESV is elastic to the coefficient; that is, a 1% VC change will lead to a more than 1% ESV change. If $CS < 1$, then ESV is inelastic for the coefficient and the calculated results are reliable.

2.6 Spatial auto-correlation analyses

2.6.1 Global spatial auto-correlation

In this study, Moran's I, a global spatial autocorrelation model, was used to measure whether the spatial distribution of ecosystem service value was correlated. The calculation formula is as follows:

$$I = \frac{n}{\sum_{i=1}^n \sum_{j=1}^n W_{ij}} \times \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2} \quad (10)$$

where I is the Moran index; x_i and x_j are the observations of space unit i and space unit j , respectively; W_{ij} is the spatial weight matrix; $\bar{x}$ is the average of observations; and n is the sample size. The Moran's I index ranges from 1 to -1 . When Moran's $I > 0$, it indicates a positive spatial correlation, and the larger the value is, the more obvious the spatial correlation; when Moran's $I < 0$, it indicates a negative spatial correlation, and the smaller the value is, the greater the spatial difference; when Moran's $I = 0$, the space presents randomness.

2.6.2 Hot spot analysis

To further study the local performance of ecosystem service changes in space, we used the Getis-Ord G^* to analyse the local spatial autocorrelation. The specific formula is as follows:

$$Gi^* = \frac{\sum_{j=1}^n w_{ij} x_j - \bar{X} \sum_{j=1}^n w_{ij}}{\sqrt{\frac{n \sum_{j=1}^n w_{ij}^2 - (\sum_{j=1}^n w_{ij})^2}{n-1}}} \quad (11)$$

$$\bar{X} = \frac{\sum_{j=1}^n x_j}{n} \quad (12)$$

$$S = \sqrt{\frac{1}{n} \sum_{j=1}^n x_j^2 - (\bar{X})^2} \quad (13)$$

where x_j is the attribute value of element j ; w_{ij} is the spatial weight between elements i and j ; n is the total number of elements; $\bar{X}$ is the mean value of elements; S is the standard deviation of the

elements; and G_i^* is the Z-score. The higher the Z-score, the closer the clustering of high values (hot spots); the lower the Z-score, the closer the clustering of low values (cold spots).

3 Results

3.1 Land use change during 2000-2015

The temporal and spatial changes in land use are shown in Table 2 and Fig. 2. From 2000 to 2018, forestland was the most important land use type, accounting for more than 46%, followed by cropland and grassland. The area of forestland increased from 46.12% in 2000 to 47.61% in 2018. Cropland area decreased from 38.58% in 2000 to 37.24% in 2018. Grassland was mainly distributed in the southwest region. From 2010 to 2018, its area decreased significantly from 12.88% to 10.35%. The distribution of construction land was relatively concentrated, most of which was located in the urban area of Chongqing, and the area experienced an obvious change, with an increase of 1215.9 km² from 2000 to 2018. Water was mainly distributed in the main stream of the Yangtze River and the reservoir area, and its area continued to expand. The proportion of water increased from 1.34% in 2000 to 1.9% in 2018. Bare land covered less area and changed slightly.

From 2000 to 2018, the total land use transfer area in the TGRA was 22010.6 km² (Table 3). Cropland, forestland and grassland were the main types of land transfer. The largest transferred area was cropland. The area transferred from other land types to cropland was 8458.71 km², of which forestland contributed the most, accounting for 67.38%. The area of cropland transferred to other land use types was 9227.47 km², and the cropland area was reduced by 768.76 km² in total. The area transferred from other land types to forestland was 8308.07 km², and the area of forestland transferred to other land use types was 7453.24 km², where the forestland increased by 854.83 km². Grassland was mainly transformed into forestland and cropland, accounting for 45.53% and 51.98% of the change, respectively. A total of 3151.55 km² of other land types was transferred into grassland, of which cropland contributed the most. In the transferred area of construction land, cropland contributed the most, with an area of 1091.56 km², accounting for 79.39%, followed by forestland and water, where the transferred areas were 182.92 km² and 63.37 km², respectively, accounting for 13.30% and 4.61%. The water area of 373.02 km² did not change. The area transferred from other land types to water was 713.76 km². The area of water transferred to other land types was 399.33 km², and the water area increased by 314.43 km².

Table 2 Area of land use types in Three Gorges Reservoir area from 2000 to 2018

Land use type	2000		2005		2010		2018	
	Area(km ²)	%	Area(km ²)	%	Area(km ²)	%	Area(km ²)	%
Cropland	22171.98	38.58	21913.74	38.13	21584.95	37.56	21399.64	37.24
Forestland	26507.15	46.12	26739.09	46.53	26779.74	46.60	27361.98	47.61
Grassland	7560.83	13.16	7409	12.89	7404.21	12.88	5948	10.35
Water	772.34	1.34	858.42	1.49	943.31	1.64	1090.37	1.90
Bare land	9.56	0.02	7.17	0.01	7.17	0.01	3.5	0.01
Construction land	449.54	0.78	543.99	0.95	752.02	1.31	1665.44	2.90

Fig. 2 Spatial distribution of land use/cover types in the Three Gorges Reservoir area

Table 3 Transition matrix of land use/cover change (km²) in the Three Gorges Reservoir area from 2000 to 2018

2000	2018						The area of transferred out
	Cropland	Forestland	Grassland	Water	Construction land	Bare land	
Cropland	12931.37	6010.17	1793.37	329.98	1091.56	2.39	9227.47
Forestland	5699.32	19012.07	1315.14	254.66	182.92	1.2	7453.24
Grassland	2474.85	2167.58	2789.28	82.49	35.87	0.00	4760.79
Water	206.83	93.26	35.87	373.02	63.37	0.00	399.33
Construction land	75.32	34.67	7.17	43.04	289.33	0.00	160.2
Bare land	2.39	2.39	0	3.59	1.2	0.00	9.57
The area of transferred in	8458.71	8308.07	3151.55	713.76	1374.92	3.59	22010.6

3.2 Change in ecosystem service value from 2000—2018

3.2.1 Temporal change of ecosystem service value

Based on the land use data, the ESVs were estimated (Table 4). From 2000 to 2018, the total value of ecosystem services showed an upward trend, increasing from 78.5 billion yuan to 81.2 billion yuan, with a total increase of 2.7 billion yuan. The ESV of forestland accounted for the largest proportion at more than 62%. Although the value of forestland ecosystem services increased, the share declined first and then increased. The ESV of water increased the most, with an increase of 3.8 billion yuan, which was because of its high value coefficient. The ESVs of cropland and

grassland decreased by 3.48% and 21.33%, respectively. The value of bare land decreased slightly, and the construction land remained unchanged.

Table 4 Ecosystem service value of different land use types (cropland, forestland, grassland, water, construction land, bare land) in the Three Gorges Reservoir area from 2000 to 2018 (10⁴ yuan)

Land use types	2000		2005		2010		2018	
	ESV	%	ESV	%	ESV	%	ESV	%
Cropland	837069.25	10.66	827319.79	10.39	814906.83	10.11	807910.73	9.95
Forestland	4968394.41	63.29	5011868.31	62.93	5019487.59	62.28	5128620.33	63.15
Grassland	1121658.05	14.29	1099133.89	13.80	1098423.28	13.63	882392.81	10.87
Water	922569.62	11.75	1025393.23	12.88	1126795.38	13.98	1302460.36	16.04
Bare land	18.18	0.01	13.64	0.0001	13.64	0.0001	6.83	0.0001
Construction land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	7849709.50	100	7963728.87	100	8059626.72	100	8121391.06	100

As shown in Table 5, in terms of the ecosystem service functions, the ESV of regulation services was the largest, accounting for 68%, followed by supporting services and provisioning services, while cultural services accounted for approximately 4%, providing the lowest ESV. Supporting services value and culture services value initially increased and then decreased, while provisioning services value continuously increased. Among the ESVs of regulation services, hydrological regulation contributed the most, reaching more than 40%, followed by climate regulation and gas regulation, which accounted for approximately 34% and 14%, respectively. From 2000 to 2005, the ESV of food production and maintenance of the nutrient cycle declined, while the value of other ecosystem service functions increased. From 2005 to 2010, the ecosystem services that increased in value were the water supply, climate regulation, purification environment, hydrological regulation, biodiversity and aesthetic landscape. From 2010 to 2018, the value of ecosystem services of water supply and hydrological regulation increased while the value of other ecosystem service functions decreased.

Table 5 Ecosystem service value of different ecosystem service functions in the Three Gorges Reservoir area from 2000 to 2018 (10⁸ yuan)

Ecosystem services functions		Value			
		2000	2005	2010	2018
Provisioning services	Food production	29.92	29.75	29.52	29.18
	Raw material production	24.56	24.57	24.51	24.18
	Water supply	0.27	1.15	2.06	3.16
Regulation services	Gas regulation	76.59	76.65	76.53	75.40
	Climate regulation	184.10	184.84	185.10	182.80
	Purification environment	58.48	59.08	59.55	59.34
	Hydrological regulation	211.32	219.85	227.93	239.95
Supporting services	Soil conservation	88.43	88.56	88.49	87.14
	Maintain nutrient cycle	8.62	8.61	8.58	8.45
	Biodiversity	70.91	71.30	71.54	70.65
Cultural services	Aesthetic landscape	31.77	32.00	32.17	31.88

Total	784.97	796.37	805.96	812.14
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3.2.2 Spatial change of ecosystem service value

Fig. 3 shows the historical spatial distribution of ESV. The spatial distribution of ESV is affected by the spatial pattern of land use in the study area. From 2000 to 2018, the distribution of extremely high value areas of ESV was consistent with the spatial distribution of water, distributed in the main stream of the Yangtze River and the reservoir area. The extremely low areas of ESV were mainly distributed in the urban area of Chongqing, where the main type of land use was construction land. The low areas and high areas of ESV were scattered, and the spatial distribution of low value areas of ecosystem services was consistent with the distribution of cropland. From the perspective of the spatial evolution of ESV from 2000 to 2018, the extremely low areas and extremely high areas of ESV continued to expand due to the increase in construction land and water.

Fig. 3 Spatial distribution of ecosystem service value in the Three Gorges Reservoir area

3.2.3 Sensitivity analysis of ecosystem service value

As shown in Fig. 4, the CS results in 2000, 2005, 2010, and 2018 were less than 1, indicating that the calculation result of CS was inelastic to the value coefficient. The estimation of ESV was in line with reality. Among the various land use types, the CS of forestland was the largest: 0.6228~0.6329. The smallest CS was bare land, which showed that the change in the value coefficient had the weakest impact on the ESV of bare land.

Fig. 4 Coefficient of sensitivity of ecosystem services value

3.3 Impact of land use change on ecosystem service value

The ecological environmental change caused by land use change in the TGRA showed a trend of both improvement and deterioration. According to the calculation of the contribution rate (Table 6), the land use changes improved the ESV in the TGRA during the study period. From 2000 to 2018, the conversion of cropland into forestland was the main factor in the improvement of ESV, with a contribution rate of 24.45%. The continuous expansion of water had a positive influence on the ESV, with an increasing contribution rate from 60.92% for 2000-2005 to 73.66% for 2005-2010. The main types of land use transformation that led to the decrease in the value of ecosystem services included cropland reclamation and construction land occupation, and their contribution rates were 37.12% and 3.18%, respectively. From 2000 to 2005, the conversion of grassland to cropland contributed 3.68% to the reduction in ESV. From 2005 to 2010, the occupation of cropland, forestland, water, and grassland by construction land contributed 11.33% to the reduction in ESV. From 2010 to 2018, the conversion of forestland, water and grassland into cropland was the main reason for the reduction in ESV, with contributions of 23.65%, 7.63% and 7.37%, respectively. The overall change in the value of ecosystem services in the TGRA from 2000 to 2018 was not significant because the two trends of increase and decrease in ESVs occurred at the same time, and they offset each other in a certain area.

Table 6 Contribution of land use/cover change to ecosystem service value in Three Gorges Reservoir area from 2000 to 2018

pattern	2000-2005		2005-2010		2010-2018		2000-2018	
	Land use	Rate of	Land use	Rate of	Land use	Rate of	Land use	Rate of
	conversion	contribution	conversion	contribution	conversion	contribution	conversion	contribution
	type	/%	type	/%	type	/%	type	/%
Ecosystem function improved	2—4	35.96	1—4	39.18	1—2	23.81	1—2	24.45
	1—2	19.43	2—4	17.52	1—4	9.38	1—4	10.37
	1—4	15.02	3—4	11.49	2—4	5.78	2—4	6.97
	3—4	5.09	1—3	5.57	1—3	5.28	1—3	5.39
	5—4	4.85	1—2	5.48	3—2	2.24	3—4	2.35

	3—2	3.71	5—4	5.47	3—4	2.07	3—2	2.30
	1—3	2.69	3—2	2.00	5—4	1.61	5—4	1.40
	Other	1.93			Other	0.63	Other	0.41
	Total	88.69	Total	86.72	Total	50.80	Total	53.64
Ecosystem function deteriorates	3—1	3.68	1—5	5.25	2—1	23.65	2—1	23.18
	2—1	2.43	2—5	2.40	4—1	7.63	3—1	7.44
	1—5	2.18	4—5	2.19	3—1	7.37	4—1	6.50
	2—5	1.06	3—5	1.49	4—2	3.45	4—2	2.55
	4—5	0.97	2—3	0.82	4—5	2.21	4—5	2.06
	3—5	0.60	2—1	0.82	2—3	1.46	2—3	1.40
	2—3	0.38	3—1	0.30	4—3	1.45	1—5	1.12
					Other	1.99	Other	2.10
	Total	11.31	Total	13.28	Total	49.2	Total	46.36

339 1~6 respectively represent 6 types of land use (1: Cropland; 2: Forestland; 3: Grassland; 4: Water; 5: Construction
340 land; 6: Bare land). 1—2 represents the conversion of cropland to forestland, other codes and so on

341 3.4 Spatial auto-correlation analysis

342 3.4.1 Global spatial autocorrelation of ecosystem service value

343 As shown in Table 7, the global Moran's I of the ESV in 2000, 2005, 2010, and 2018 was 0.5294,
344 0.5365, 0.5396, and 0.5135, respectively. The results indicate that the spatial distribution of the ESV
345 in the study area had a strong positive correlation and significant clustering. Moran's I of the ESV
346 first increased and then decreased in the four periods, which shows that the cluster phenomenon of
347 the spatial distribution of the ESV in the study area first strengthened and then weakened. Analysing
348 the spatial autocorrelation of the dynamic changes in ESV, the results show that the global Moran's
349 I decreased, which also had obvious spatial aggregation.

350 **Table 7** Moran's I of the ecosystem service value in Three Gorges Reservoir region

Year	Moran's I	P	Z
2000	0.5294	<0.001	179.63
2005	0.5365	<0.001	182.05
2010	0.5396	<0.001	183.08
2018	0.5135	<0.001	174.24
2000-2005	0.4706	<0.001	160.03
2005-2010	0.4684	<0.001	159.29
2010-2018	0.2940	<0.001	99.71
2000-2018	0.3165	<0.001	107.33

351 3.4.2 Hot spot analysis of ecosystem service value

352 The statistically significant hot spots and cold spots are shown in Fig. 5. From 2000 to 2018, the hot
353 spots of ESV change were mainly distributed in the main stream of the Yangtze River and the
354 reservoir area. This is mainly due to the water impoundment of the Three Gorges Project and
355 ecological policies, which resulted in the conversion of land use types from cropland and forestland
356 to water and cropland to forestland, thus leading to the increase in ESV. The cold spots of ESV
357 change had a small proportion of area and were mainly distributed around water areas (Table 8).

This is because the local residents live by the water, resulting in the increase of construction land around the water, which reduced the value of ecosystem services. From 2000 to 2005, the hot spots of ESV change were mainly distributed in Zigui, Badong, Shizhu and Kaizhou because the conversion of forestland to water or cropland to forestland led to an increase in the value of local ecosystem services. The cold spots of ESV change were scattered. From 2005 to 2010, the hot spot and cold spot areas were reduced at the same time. The hot spots were distributed in the Chongqing section of the TGRA. The increasing water storage height of the Three Gorges Project led to the expansion of the local water area, which increased the ESV. Compared with 2005 to 2010, the area of cold and hot spots expanded from 2010 to 2018. From the spatial perspective of cold and hot spots, the cold spots and hot spots were more concentrated and obvious. In each time period, the area of the hot spots was significantly larger than that of the cold spots, which also verified that the ESV of the TGRA was characterized by rising changes during the study period.

Fig. 5 Spatial distribution of cold spots and hot spots of ecosystem service value changes in the Three Gorges Reservoir area from 2000 to 2018

Table 8 Area proportion of cold spots and hot spots of ecosystem service value changes in Three Gorges Reservoir area from 2000 to 2018

Phases	2000-2005	2005-2010	2010-2018	2000-2018
Cold spot	0.36	0.19	3.33	2.82
Hot spot	1.79	1.27	4.21	4.78
Not significant	97.85	98.54	92.46	92.4

4 Discussion

4.1 Characteristics of land use change in the TGRA for different periods

The main construction projects in each stage of the Three Gorges Project were different, so the relevant land use change characteristics and their driving factors were likely to be different (Fig. 6). Therefore, in this study, we not only analysed the characteristics of LUC and its transfer during the

entire study period (2000–2018) but also for each five-year construction period of the Three Gorges Project, which was missing in most previous studies (Jiang et al. 2008). According to the specific results of the period, we obtained the specific characteristics of land use changes during the three construction periods, which strengthened the practical application of decision makers.

Fig. 6 Main driving factors of land use changes in the Three Gorges Reservoir area from 2000 to 2018

From 2000 to 2005, the closure of the Yangtze River led to the expansion of water. Forestland, cropland, grassland and construction land were transferred into water, and the reservoir area was filled with water up to 135 metres. The increase in water area was also the main feature of LUC in the TGRA from 2005 to 2010, which was due to the continuous storage of water in the reservoir. In October 2010, the Three Gorges Project successfully achieved the experimental water storage target of 175 metres. The Three Gorges Reservoir inundated a land area of 632 km², including two medium-sized cities, Wanzhou and Fuling, and more than 10 small cities. At the same time, the main works of the Three Gorges Project and the resettlement of a million people were also announced to be completed. The water storage of the Three Gorges Project led to inundation at low altitudes, and local residents needed to rebuild their homes in higher altitude areas. Eighty percent of the resettlers resettled the reservoir area, resulting in excessive cultivation of cropland. At the same time, all the submerged professional facilities needed to be rebuilt, such as roads and bridges. The adjustment of regional centre orientation and transportation hubs had a great impact on the layout of construction land, cropland, forestland and grassland in the TGRA. From 2010 to 2018, the policy of the Grain for Green Project showed significant effects, with part of the cropland turning into forestland. Zigui County is the head of the dam of the Three Gorges Project and is the national technology demonstration site for the Grain for Green Project. At the end of 2012, the forest area and forest coverage reached 17.9 hm² and 78.98%, respectively, increasing by 15% and 11.2% compared with before the implementation of the Grain for Green Project. Through ecological construction, the forest area and stock volume in the TGRA have increased substantially, and the forest coverage rate in the reservoir area has reached 58.49%, which was 18% higher than the average level in the Yangtze River Basin. In addition, with the development of the social economy, the average urbanization rate in the reservoir continued to rise, from 42.19% in 2010 to 59.56% in 2018, and the

area of construction land continued to expand.

4.2 Impact of land use change on ESV

The impact of LUC on the value of ecosystem services is very complex, and the changes in land use will lead to changes in ecosystem service structure and function. During the study period, the value of ecosystem services increased due to the implementation of the policy of the Grain for Green Project (Wang et al. 2019b) and the impoundment of the Three Gorges Project, which led to significant changes in land use structure, especially in grassland and water. On the other hand, the expansion of construction land caused by urbanization and resettlement had a certain negative impact on ecosystem services (Chu et al. 2018). Similar to this finding, from 2000 to 2015, the decrease in cropland and the increase in construction land led to a decrease in ecosystem services in Jiangsu Province (Wu et al. 2020). Similarly, the total amount of ecosystem services in Poyang Lake declined due to the decrease in cropland and the sharp increase in construction land (Yuan et al. 2021). The study found that a 1 km² area of cropland transforming to construction land corresponds to an ESV decrease of 2.1×10^6 yuan. The direction of the total change in ESV from 2000 to 2018 revealed by this study is consistent with Wang et al. (2020) research results, but there are certain differences in the results of the value. The reason is the use of different research methods. Wang et al. (2020) used the alternative cost method, shadow engineering method, carbon tax method, market value method and water balance method to quantify the value of ecosystem services in the TGRA from 2000 to 2015.

From the perspective of contribution rate, during the study period, the conversion of cropland to forestland contributed the most to the increase in ecosystem services. It is mainly the implementation of the policy of Grain for Green Project, Natural Forest Protection Program and Yangtze River Basin Shelter Forest Project. It is worth mentioning that although the area of water did not increase much, it has a great impact on the ecosystem of the reservoir area, which is similar to the conclusion of Zhang et al. (2015). They believed that water bodies played major roles in ecosystem services in the Chaohu Lake Basin, which is mainly because the equivalent factor coefficient of water is higher than that of other land use types. Compared with other land use types, water has stronger ecological functions (Acuna-Alonso et al. 2021; Aznar-Sánchez et al. 2019), such as water supply and hydrological regulation. In addition, the increase in water area mainly occurred in the main stream of the Yangtze River and surrounding the reservoir area, so the ESV in the area was high. The conversion of forestland to cropland had the largest contribution rate to the reduction in ESV in the study area. The conversion of forestland to cropland led to the loss of regional ecosystem services. At the same time, the expansion of construction land has adversely affected the value of ecosystem services. In general, the Three Gorges Project water storage and Grain for Green Project have played an important positive role in the value of ecosystem services in the TGRA, and urbanization and resettlement had a certain negative impact on ESVs. Land use changes may significantly affect ecosystems, but they do not necessarily lead to ecosystem degradation (Yi et al. 2016).

4.3 Policy implications

During the study period, the land use changes in the TGRA were active, with a large increase in construction land and decrease in cropland. Future land planning should strengthen the protection of ecological land such as water, forestland and cropland and focus on optimizing and controlling the spatial pattern of land use. It is significant to find the conjunct point between economic

development and the protection of ecological land, which is the fundamental method of determining the sustainable development of the TGRA.

The TGRA is an important ecological barrier area. The construction of the Three Gorges Project has caused a series of impacts on the ecological environment of the region. However, the value of ecosystem services showed a steadily increasing trend during the study period, indicating that the ecological policies of the Grain for Green Project have made effective progress in recent years. In the future, ecological construction should still be given priority, and the core task is to intensify efforts to close mountains and cultivate forests and promote ecological environmental protection policies. Moreover, because of the regional development status and local conditions, the development of green and pollution-free industries should be given priority to ensure the simultaneous development of resources and ecological restoration. While developing the economy, damage to the environment should be minimized to achieve stability and improvement of the regional environment.

The main urban area of Chongqing in the TGRA was the place with the lowest value of ecosystem services. Through the spatial distribution of the ESV, it is possible to identify ecological control areas, formulate reasonable territorial spatial planning, strengthen the control of the ecological protection redline (Yang et al. 2020), and restore the ecosystem. In addition, understanding the ESV of the TGRA can help establish an ecological compensation mechanism and explore ways to realize the value of diversified ecological products (Fan & Chen 2019).

4.4 Limitations

This study used the benefit transfer method to estimate the value of ecosystem services. This method is widely used because of the low cost of collecting primary data and the ability to quickly assess the value. However, it has been criticized due to its uncertainty and reliability. The classification and accuracy of land use data and the method of modifying the equivalent table can affect the evaluation results of ESV. Although our assessment results may not be the most accurate, they can reflect the changing trend of ESV in the TGRA and serve as a reference for further research. In addition, there is a lack of quantitative analysis on the complex driving forces of ESV change, which should be further explored in the future.

5 Conclusions

This study estimated the spatiotemporal changes in ESVs in the TGRA from 2000 to 2018 and analysed the impact of land use on the ESVs. The main research conclusions are as follows:

- (1) Forestland and cropland were the most important land use types from 2000 to 2018, and they accounted for 80% of the TGRA. At the same time, the land use in the study area has also undergone tremendous changes, among which grassland and construction land were the largest land use types with area reduction and increase.
- (2) From 2000 to 2018, due to the expansion of water and the increase in forestland and construction land, the ESV of the study area increased by 2.7 billion yuan, with a growth rate of 3.46%. From the perspective of contribution rate, the conversion of cropland to forestland had the largest contribution rate to the increase in ESV, and the conversion of forestland to cropland had the largest contribution rate to the reduction in ESV.
- (3) The ESV in the study area had prominent spatiotemporal changes, significant spatial correlation and high spatial clustering. From 2000 to 2018, the hot spots of ESV change were mainly distributed in the main stream of the Yangtze River and the reservoir area, and the cold and hot

spots had a small proportion of the area.

(4) The main reasons for the changes in ESV in the study area were the water impoundment of the Three Gorges Project, the Three Gorges Project resettlement, urbanization development and ecological policies, such as the Grain for Green Program.

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