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Multi-Dimensional Spatial and Temporal Variations of Ecosystem Service Values in the Li River Basin, 1990–2020

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Abstract: Changing landscape patterns would alter ecosystem components and functions, affecting the supply of ecosystem services. Understanding the spatial and temporal variations of ecosystem services is an important basis for ecosystem management and planning decisions and is of great significance for the realization of regional sustainable development. Based on Landsat TM/OLI remote sensing images from 1990, 2000, 2010, and 2020 in the Li River Basin, we explored the spatial and temporal variabilities of ecosystem services in the Li River Basin over the past 30 years, from both horizontal and vertical dimensions, using modified equivalence factor method and spatial autocorrelation analysis. The research findings are as follows: (1) Forestland has consistently been the dominant landscape type in the Li River Basin, with its area continuously increasing, while farmland, water bodies, and grassland have decreased, and construction land and bare land have increased. (2) The value of ecosystem services in the Li River Basin exhibited an initial increase followed by a decrease trend, with a net increase of 9.20×10^8 yuan. Forestland contributed the most to the value of ecosystem services. (3) Hydrological regulation and climate regulation are the dominant functions of the Li River Basin's ecosystems, accounting for over 50% of the total contribution. (4) The value of ecosystem services per unit area increases with increasing slope and elevation. The segments with slopes ranging from 15 to 25 degrees and elevation zones between 200 and 500 m have the highest total value of ecosystem services. (5) The overall level of ecosystem services in the Li River Basin is relatively high and continues to rise, but areas with a low ecosystem service value are gradually concentrated. (6) The Moran's I values for ecosystem services in all four periods are greater than 0, indicating a significant positive spatial autocorrelation. The overall pattern of ecosystem services is relatively stable, but there are significant spatial variations, which are characterized by lower values in the central area and higher values in the surrounding areas. The research findings provide a scientific basis for watershed ecological environment construction, optimal allocation of land resources, and sustainable landscape management.

Keywords: ecosystem service values; spatial and temporal variation; spatial autocorrelation analysis; China; Guilin; Li River Basin

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1. Introduction

Ecosystem services are the goods and services that support life and are obtained either directly or indirectly through the structures, processes, and functions of ecosystems [1]. They can be categorized into two components: ecosystem goods, which are essential for human livelihoods, and ecological functions, which ensure a high quality of life for people [2,3]. These services form the material foundation and fundamental conditions for human survival and well-being [4]. Past and present irrational human production and living activities lead to the degradation of ecosystem services in many regions, threatening human survival and development [5,6], which has become an increasingly prominent and significant issue and a social focus globally [7–9]. The diversity of landscape-use strategies adopted in human activities directly affects and alters ecosystem structure and processes. Moreover, while altering ecological and environmental drivers, landscape patterns, and material–energy cycles, they also affect the size of products and service capacity that the regional ecosystems deliver to society [10,11], which is ultimately reflected in the ecosystem service value change, thereby having a profound impact on human well-being [12,13]. Correctly understanding the spatiotemporal patterns of ecosystem services is a key foundation for ecosystem management and planning decisions and is of great importance for the achievement of sustainable regional development.

The impact of landscape change on the ecosystem service value has now become one of the topical issues in ecology and planning disciplines which has received increasing attention from researchers [14–16]. Ecosystem service value change becomes an important indicator to measure the ecological effects of landscape change [17,18]. Many researchers have linked landscape types to the nearest ecosystem types, used the ecosystem service value calculation method provided by Costanza, GaodiXie et al. [19,20] to adjust the ecosystem service value coefficients in the context of regional differences, and conducted research on regional ecosystem service value change in the face of landscape change/land-cover change [21–24]. Ecosystem service function can be used as a comprehensive indicator to judge the sustainability level of regional ecosystems [25,26]. Landscape change affects the type and intensity of services provided by the ecosystems by altering their structure, processes, and functions and is decisive for maintaining ecosystem services [27,28]. Terrain differences shape diverse microenvironments, and variations in topography lead to differences in land-use and land-cover types in different environments, which have significant impacts on the processes of landscape element change and the supply of ecosystem services. Taking into account the interrelationships among terrain characteristics, landscape changes, and ecosystem services, it is crucial to develop effective ecological management strategies [29]. Most related studies have focused on quantitative and horizontal spatial changes in ecosystem services [30,31], without necessary explorations of the vertical spatial changes in complex mountain regions yet. In the context of landscape change, it is of great significance for the sustainable management of regional landscapes to focus on quantitative changes in the ecosystem service value and their spatial and temporal differences in complex mountain regions.

The Li River Basin is a world-renowned tourist destination and a typical karst area with a delicate ecological environment. Since 1978, the Li River has been listed as one of the thirteen rivers to be protected by the state and has truly become "China's business card". In recent years, with the accelerated construction of the Guilin International Tourism Resort and the rapid expansion of urbanization and tourist activities, there have been many ecological and environmental issues in the local areas of the Li River Basin, such as environmental pollution, biodiversity reduction, and landscape degradation, which have been of great concern to the whole society. Therefore, it is necessary to reveal the spatial and temporal variation characteristics of ecosystem service values from multi-dimensions caused by the landscape evolution in typical karst regions.

In this study, landscape type data were interpreted from remotely sensed imagery by 3S technology, which is taken as the basic source of information. Then, we introduced the grid method for constructing the ecosystem service value index and combined it with regional DEM data to analyze the changes in ecosystem service value, as well as the spatial and temporal variation caused by landscape changes in the Li River Basin from multiple dimensions. Our objectives were (1) to apply the revised equivalence factor table to measure the value of ecosystem services in the Li River Basin in the four phases in order to clarify the patterns of changes in ecosystem service values and to elucidate the impact of changes in landscape types on the value of ecosystem services in the Li River Basin; (2) to perform a compound analysis of spatial changes in the value of ecosystem services in the Li River Basin in both vertical and horizontal spatial dimensions in order to explore the characteristics of the spatial pattern of ecological service values in the Li River Basin; (3) to conduct a spatial autocorrelation analysis to illustrate the spatial convergence of ecosystem services in the Li River Basin and visualize the clustering and regional correlation of ecosystem service values in the Li River Basin in the grid space. The findings can provide a scientific foundation for the construction of the regional ecological environment, tourism development, landscape optimization, and sustainable management in the Li River Basin.

2. Study Area and Data Sources

2.1. The Study Area

The Li River Basin lies in the northeast portion of the Guangxi Zhuang Autonomous Region, located at the southwest extreme of the Nanling Mountain System (Figure 1), with geographic coordinates from 24°38′10′′N to 25°53′59′′N and 110°07′39′′E to 110°42′57′′E. The Li River begins its journey at Cat Mountain, the highest mountain in Southern China, and then it meanders from north to south through Xing'an County, Lingchuan County, Guilin City, and Yangshuo County, with a length of 164 km and a total area of 5837.93 km^2. The Li River Basin is a narrow belt with a high elevation in high the north, and it is low in the middle and high all around; it also has a typical karst landscape in the middle and lower reaches which is of high ornamental value. The Li River Basin has a moderate climate with a high vegetative cover degree and rich vegetation types. Being the first area in China to develop tourism, the Li River Basin has become a world-renowned tourist destination with rich and diverse tourist resources with a well-developed tourist industry. In 2021, Guilin received a total of 122,391,400 visitors and a total revenue of RMB 150,288 million from tourism, most of which came from counties and districts within the catchment area of the Li River.

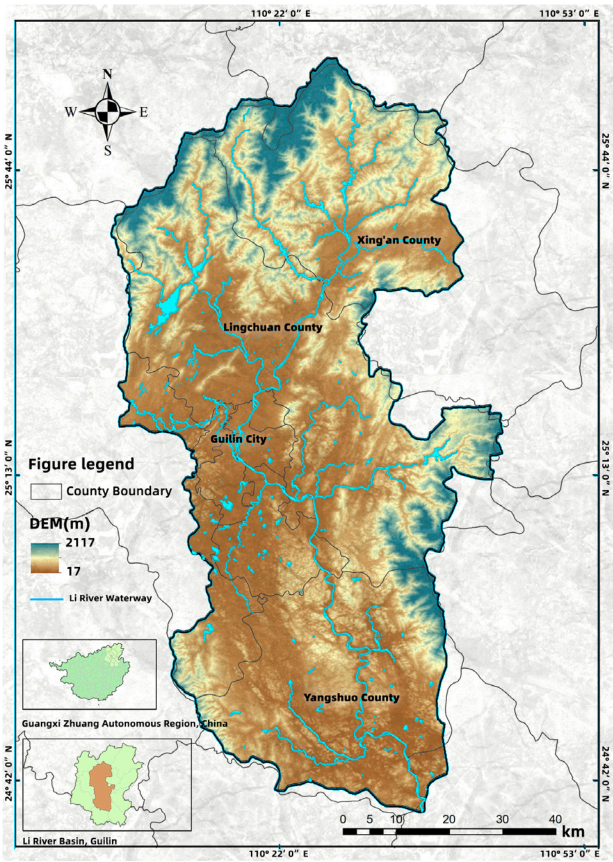

Figure 1. Location of the Li River Basin in Guilin, China.

2.2. Data Information

The study data mainly include (1) Landsat remote-sensing images of the Li River Basin for 1990 (TM), 2000 (TM), 2010 (TM), and 2020 (OLI) from the Geospatial Data Cloud (http://www.gscloud.cn, accessed on 8 April 2022); (2) topographic maps of the counties in the Li River Basin, according to the 2014 land-use status map; (3) and 2018 and 2021 China Agricultural Products Price Survey Yearbook and Guilin City Statistical Yearbook (2016–2019), as well as the relevant plans that involve the Li River Basin. The four phases of remotely sensed imagery, combined with field research, were interpreted using the ERDAS2015 platform in order to classify landscape types, and the overall classification accuracies were calculated as 87.22%, 88.33%, 87.33%, and 89.67%, respectively, which satisfied the needs of the present study (Figure 2).

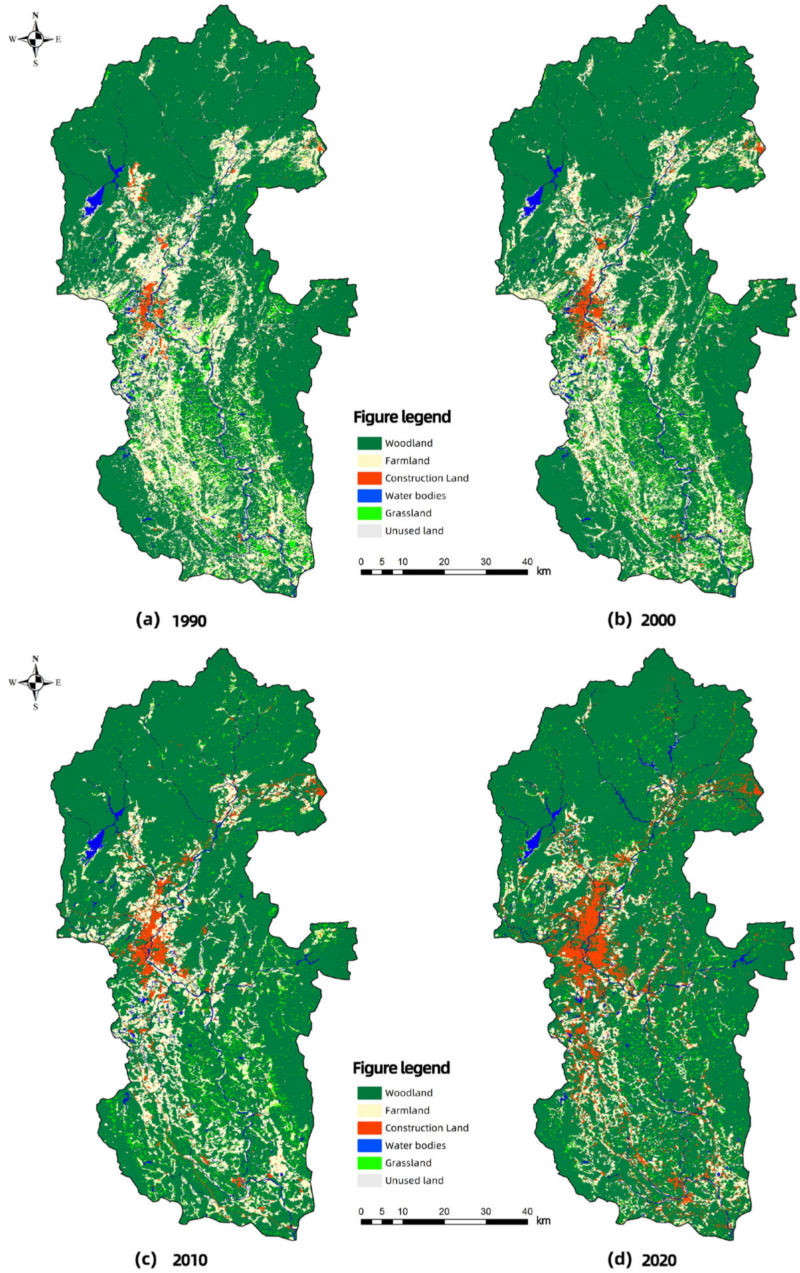

Figure 2. Distribution of landscape types in 1990 (**a**), 2000 (**b**), 2010 (**c**), and 2020 (**d**) in the Li River Basin, Guilin, China.

3. Methods

3.1. Approaches to Estimating Ecosystem Service Values

3.1.1. Ecosystem Service Evaluation and Measurement

GaodiXie et al. improved and extended the unit area value equivalence based on the previous static assessment method research on unit area value equivalence coefficients, coupled with the reliable portion of Contanza's research, and derived the dynamic equivalence factors for the ecosystem service value per unit area of terrestrial ecosystems in China [4]. The equivalence-factor approach is commonly used for determining the value of individual ecosystem service equivalence factors and for estimating value coefficients per unit area across landscape types [32]. Referring to the treatment by GaodiXie et al., one-seventh of the total food production value of agro-ecosystems was used as the value of ecosystem services for one standard equivalent factor. The value of food production in agro-ecosystems was mainly calculated based on the sown area of the three main food products, namely rice, maize, and soybean, as well as the grain yields and the average price of each food crop in the national market [33], and the specific model for the calculation is as follows:

$$\mathrm{Ea} = 1/7\sum_{i=1}^{n}\frac{m_i P_i q_i}{M} \quad (i = 1, 2, n) \tag{1}$$

where Ea represents the ecosystem service economic value of a single factor (yuan/hm^2); i is the crop type, and pi is the mean price of i food crops (yuan/kg); qi is the unit production of i food crops (kg/hm^2); mi is the area of i food crops (hm^2); M is the total area of all food crops; and 1/7 represents the economic value provided by natural ecosystems without human input. Specifically, it refers to one-seventh of the economic value of food production services provided by a unit area of existing farmland.

In this study, ecosystem service function in the Li River Basin was estimated using the results of GaodiXie et al. [4] and the ecosystem service value calculations established by Costanza et al. [19], as follows:

$$\mathrm{ESV} = \sum(A_k \times VC_k) \tag{2}$$

$$\mathrm{ESV}_k = \sum(A_k \times VC_{fk}) \tag{3}$$

where ESV is the total value of ecosystem services, VC_k is the ecosystem value coefficient, A_k is the area of k land-use types, ESV_k is the single ecosystem service value, and VC_{fk} is the value coefficient of a single service function.

3.1.2. Value Coefficient of Ecosystem Services per Unit Area in the Li River Basin

According to the data of the Guilin City Yearbook (2016–2019), the average grain unit area production in the Li River Basin from 2015 to 2018 was calculated as 4409.33 kg/hm^2. Rice is the main grain crop in the Li River Basin, with a small amount of corn and soybean planted, based on the data from 2015 to 2018, published in the China Agricultural Products Price Survey Yearbook (2018–2021). The average annual prices of rice (indica), maize, and soybean in the Li River basin were calculated to be 2.80 yuan/kg, 2.09 yuan/kg, and 6.06 yuan/kg, respectively. Therefore, the economic value of one ecosystem service value equivalent factor in the Li River Basin was 2303.07 yuan/hm^2.

Referring to related studies [34–37], the landscape type was linked to the similar ecosystem types. Given that building lands had a significant negative effect on ecosystems in terms of regulating hydrology and purifying the environment [38,39], the two equivalent factors were extrapolated based on the study by Shi Yao et al. [40], and they were found to be −7.55 and −2.46, respectively. We obtained the equivalent value factors (Table 1) for the Li River Basin per unit area and the ecological service value coefficients for different landscape types (Table 2) in the Li River Basin.

Table 1. Ecosystem service equivalence values per unit area in the Li River Basin.

Ecosystem Type		Farmland	Forest	Grassland	Wetland	Urban	Desert
Land-Use Type		**Cultivated Land**	**Forestland**	**Grassland**	**Water**	**Built-Up Land**	**Bare Land**
Provisioning services	Food production	1.36	0.29	0.38	0.8	0	0
	Raw material production	0.09	0.66	0.56	0.23	0	0
	Water supply	−2.63	0.34	0.31	8.29	0	0
Regulating services	Gas regulation	1.11	2.17	1.97	0.77	0	0.02
	Climate regulation	0.57	6.5	5.21	2.29	0	0
	Environmental purification	0.17	1.93	1.72	5.55	−2.46	0.1
	Hydrological regulation	2.72	4.47	3.82	102.24	−7.55	0.03
Supporting services	Soil retention	0.01	2.65	2.4	0.93	0	0.02
	Nutrient cycling	0.19	0.2	0.18	0.07	0	0
	Biodiversity conservation	0.21	2.41	2.18	2.55	0	0.02
Cultural services	Aesthetic landscape	0.09	1.06	0.96	1.89	0	0.01

Table 2. Ecosystem service value coefficients for a variety of land types in the Li River Basin (Yuan/hm^2).

Ecosystem Type		Farmland	Forest	Grassland	Wetland	Urban	Desert
Land-Use Type		**Cultivated Land**	**Forestland**	**Grassland**	**Water**	**Built-Up Land**	**Bare Land**
Provisioning services	Food production	3132.18	667.89	875.17	1842.46	0.00	0.00
	Raw material production	207.28	1520.03	1289.72	529.71	0.00	0.00
	Water supply	−6057.07	783.04	713.95	19,092.45	0.00	0.00
Regulating services	Gas regulation	2556.41	4997.66	4537.05	1773.36	0.00	46.06
	Climate regulation	1312.75	14,969.96	11,998.99	5274.03	0.00	0.00
	Environmental purification	391.52	4444.93	3961.28	12,782.04	−5665.55	230.31
	Hydrological regulation	6264.35	10,294.72	8797.73	235,465.88	−17,388.18	69.09
Supporting services	Soil retention	23.03	6103.14	5527.37	2141.86	0.00	46.06
	Nutrient cycling	437.58	460.61	414.55	161.21	0.00	0.00
	Biodiversity conservation	483.64	5550.40	5020.69	5872.83	0.00	46.06
Cultural services	Aesthetic landscape	207.28	2441.25	2210.95	4352.80	0.00	23.03
——	Total	8958.94	52,233.63	45,347.45	289,288.62	−23,053.7307	460.61

3.2. A Grid-Based Method of Valuing Ecosystem Services

Current regional studies of the ecosystem service value tend to base their assessments on landscape types and administrative regions, which have difficulty revealing the ecosystem service value spatial differences in depth, while the problem can be better addressed by the grid method [41,42]. In this study, the grid method was used for ecosystem service value evaluation, and the ecosystem service value index (ESVI) was calculated for each grid cell as the ecosystem service value level at the central point of the grid network, with the following formula:

$$\mathrm{ESVI_k} = \sum_{i=1}^{n} \frac{\mathrm{A_{ki}}}{\mathrm{A_k}} \mathrm{E_i} \tag{4}$$

where $\mathrm{ESVI_k}$ is the index of the ecosystem service value of the kth grid cell, $\mathrm{A_k}$ is the total grid cell area, $\mathrm{A_{ki}}$ refers to the total area of landscape type i within the kth grid cell, $\mathrm{E_i}$ is the ecosystem service value coefficient of landscape type i, and n is the number of landscape types (Table 1).

3.3. The Spatial Autocorrelation Analysis of Ecosystem Service Values

The spatial autocorrelation analysis is an effective tool for quantifying the spatial relationship and correlation degree of variables, including global and local spatial autocorrelations. In order to further explore the geospatial correlation and heterogeneity of ecosystem service values in the Li River Basin, the ecosystem service value in the Li River Basin was evaluated based on a 2 km × 2 km grid unit and spatial autocorrelation analysis.

Global spatial autocorrelation is a general description of the spatial characteristics of related variables across the region [43]. The global Moran's index (Moran's I) reflects the spatial autocorrelation of the ecosystem service values in the regional aggregate, with values between −1 and 1. The values greater than 0 and less than 0 denote a positive and negative correlation, respectively, and equal to 0 denotes no correlation. The calculation formula is as follows:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(X_i - \bar{X})(X_j - \bar{X})}{\left(\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\right)\sum_{i=1}^{n}(X_i - \bar{X})\frac{2}{n}} \quad i \neq j \tag{5}$$

where n is the total number of spatial locations; X_i and X_j are the values of the variable x at the pairwise adjacent spatial locations, respectively; W_{ij} denotes the spatial weight matrix of the neighborhood or distance; and x is the average value of variables.

The local spatial autocorrelation reveals the correlation degree between a local small area variable and the same variable in surrounding cells [44]. The spatial autocorrelation degree of the Li River Basin grid cells is reflected by the local spatial autocorrelation index LISA, which is calculated by the following formula:

$$LISA_i = \frac{(X_i - \bar{X})}{\sum_i (X_i - \bar{X})2/n}\sum_j W_{ij}(X_j - \bar{X}) \quad i \neq j \tag{6}$$

where X_i, X_j, W_{ij}, and $\bar{x}$ are of equal significance. A value of $LISA_i$ less than 0 indicates spatial aggregation of similar values, and greater than 0 indicates spatial aggregation of high or low values around this regional unit.

4. Results

4.1. Overall Landscape Change in the Li River Basin

For the past 30 years, forestland has been the dominant landscape in the Li River Basin, accounting for more than 70% of the total area, and reaching as high as 79.5% in 2020. There was a continuous increase in forestland from 4178.61 km^2 in 1990 to 4641.23 km^2 in 2020, representing a net increase of 462.62 km^2 (Table 3). Cultivated land, the second largest landscape type in the basin, decreased from 1284.60 km^2 in 1990 to 553.97 km^2 in 2020, with a net decrease of 730.63 km^2, representing a decrease of 56.88%. Although the proportion of construction land is small, it has been growing rapidly, with a net increase of 296.35 km^2 or 360.44%, which is much higher than the other landscape types. The area of water showed a trend of first decreasing and then increasing, going from 111.72 km^2 in 1990 to 106.01 km^2 in 2010, and then rising to 110.66 km^2 in 2020, resulting in an overall decrease of 1.06 km^2. The grassland displayed a fluctuating pattern of decrease, increase, and then decrease again, with a net decrease of 28.22 km^2. Bare land experienced both an increase and a decrease, but its proportion within the study period remained below 0.5%, showing no significant overall change (Figure 2).

4.2. Changes in the Ecosystem Service Value over Time

4.2.1. Variation in Total Ecosystem Service Value

During the study period, the ecosystem service value in the Li River Basin showed a trend of rising and then declining, from 267.81 × 10^8 yuan in 1990 to 278.52 × 10^8 yuan in 2010, and then decreasing slightly to 277.01 × 10^8 yuan in 2020, representing an overall net increase of 9.20 × 10^8 yuan, or 3.44% (Table 4). According to the ESV of different landscape types, forestland ESV increased rapidly and contributed the most to the overall ESV, increasing from 81.50% in 1990 to 87.51% in 2020, which is much higher than other landscape types. Cultivated land and construction land ESV decreased rapidly by 6.55×10^8 yuan and 6.83×10^8 yuan, respectively. The grassland showed a fluctuating decrease by 1.28×10^8 yuan overall, and there was a slight decrease in water which had little impact on the overall ESV. The period from 2000 to 2010 saw the highest increase in the ESV. From 2010 to 2020, compared to other periods, the forest ESV exhibited a smaller range of variation, while the ESV for other landscape types showed greater fluctuations.

Table 3. Landscape-type change characteristics in the Li River Basin from 1990 to 2020.

Landscape Type	1990		2000		2010		2020		1990–2020	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area Change (km^2)	Area Change (%)
Forestland	4178.61	71.58	4334.78	74.25	4527.73	77.56	4641.23	79.50	462.62	11.07
Cultivated Land	1284.60	22.01	1102.88	18.89	834.82	14.30	553.97	9.49	−730.63	−56.88
Construction land	82.22	1.41	119.10	2.04	176.93	3.03	378.57	6.48	296.35	360.44
Water	111.72	1.91	110.64	1.90	106.01	1.82	110.66	1.90	−1.06	−0.95
Grassland	167.77	2.87	154.80	2.65	175.11	2.99	139.55	2.39	−28.22	−16.82
Bare Land	13.01	0.22	15.73	0.27	17.33	0.30	13.95	0.24	0.94	7.23

Table 4. Changes in total ecosystem service value in the Li River Basin from 1990 to 2020.

Year	Type of Statistics	Forestland	Cultivated Land	Construction Land	Water	Grassland	Bare Land	Total
1990	Value (10^8/year)	218.26	11.51	−1.90	32.32	7.61	0.01	267.81
	Ratio (%)	81.50	4.29	−0.71	12.07	2.84	0.01	100
2000	Value (10^8/year)	226.42	9.88	−2.75	32.01	7.02	0.01	272.59
	Ratio (%)	83.06	3.62	−1.01	11.74	2.58	0.01	100
2010	Value (10^8/year)	236.50	7.48	−4.08	30.67	7.94	0.01	278.52
	Ratio (%)	84.91	2.68	−1.46	11.01	2.85	0.01	100
2020	Value (10^8/year)	242.43	4.96	−8.73	32.01	6.33	0.01	277.01
	Ratio (%)	87.51	1.79	−3.15	11.55	2.29	0.01	100
1990–2000	Value change (10^8/year)	8.16	−1.63	−0.85	−0.31	−0.59	0.00	4.78
	Ratio (%)	3.74	−14.16	47.22	−0.96	−7.75	0.00	1.78
2000–2010	Value change (10^8/year)	10.08	−2.40	−1.33	−1.34	0.92	0.00	5.93
	Ratio (%)	4.45	−24.29	48.36	−4.19	13.11	0.00	2.18
2010–2020	Value change (10^8/year)	5.93	−2.52	−4.65	1.34	−1.61	0.00	−1.51
	Ratio (%)	2.51	−33.69	113.97	4.37	−20.28	0.00	−0.54
1990–2020	Value change (10^8/year)	24.17	−6.55	−6.83	−0.31	−1.28	0.00	9.20
	Change rate (%)	11.07	−56.91	359.47	−0.96	−16.82	0.00	3.44

4.2.2. Changes in the Functional Value of Individual Ecosystem Services

With respect to the composition of ecosystem service values (Figure 3), the hydrologic and climatic regulation of the Li River Basin ecosystem in different study periods occupied the first two positions and comprised more than 50% of the total, with regulating services being the dominant ecosystem function of the Li River Basin, much more than other functions. Soil retention and biodiversity were consistently ranked 3 to 4, and supporting services were also important ecosystem functions within the catchment. Based on the individual service value trends, the functions of raw material production, water supply, climate regulation, soil retention, biodiversity, and aesthetic landscape continued to increase. Climate regulation increased the most, with a net increase of 5.62×10^8 yuan, and the water supply function had the largest increase of 210.17%, mainly influenced by the later period (2010–2020). At this period, in addition to the area increase of forestland and water, the government was more focused on the protection and restoration of the Li River water source and water system. Food production, hydrological regulation, and nutrient cycling functions continued to decrease by 2.01 × 10^8 yuan, 5.47 × 10^8 yuan, and 0.11 × 10^8 yuan, respectively, with the largest decrease in food production being 28.03%.

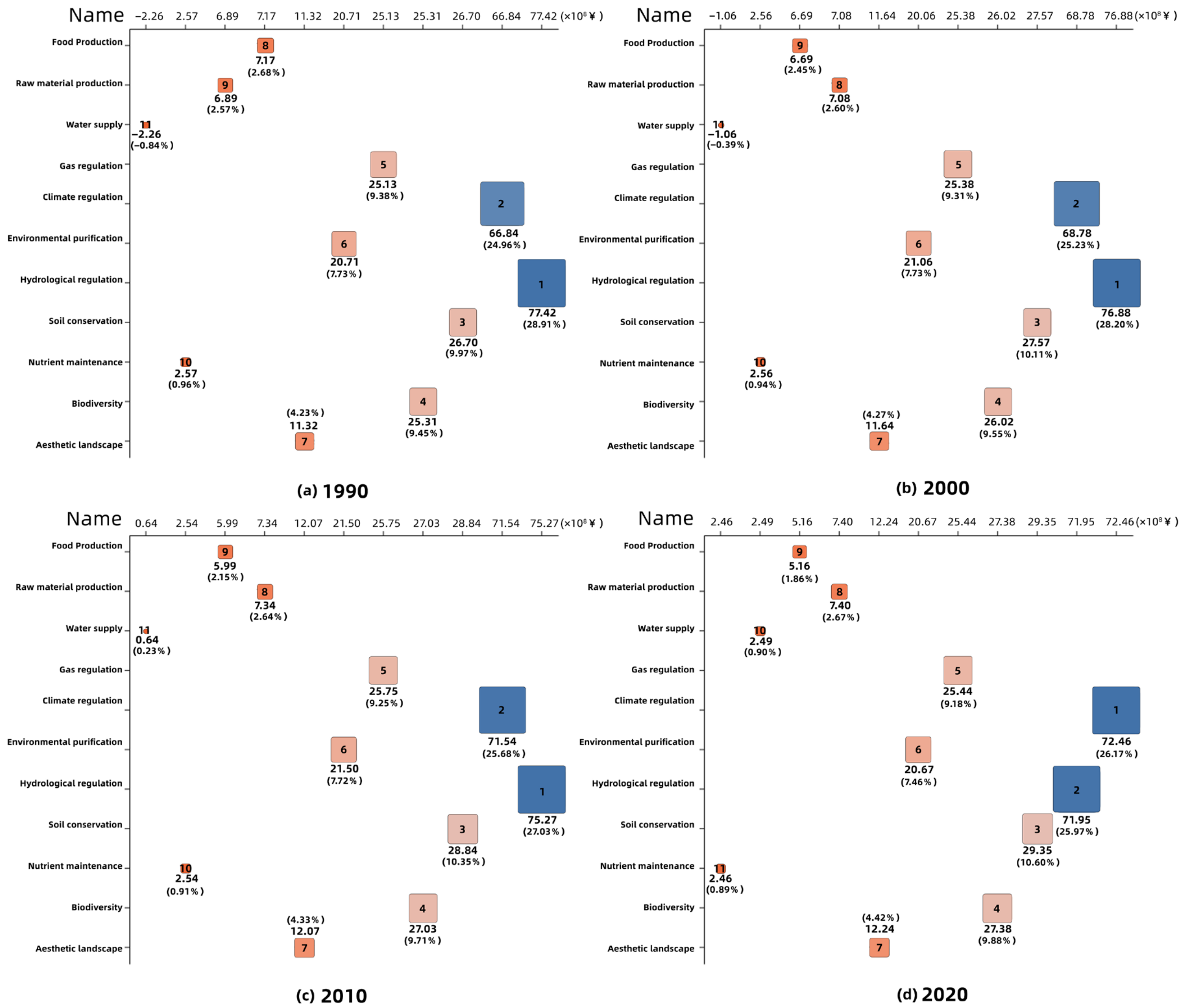

Figure 3. Value components of individual ecosystem service functions in 1990 (**a**), 2000 (**b**), 2010 (**c**), and 2020 (**d**) in the Li River Basin, Guilin, China. The vertical axis represents the names of individual ecosystem service functions, while the horizontal axis represents the value of individual ecosystem services during the study period. The main content includes the ranking and percentage of each individual ecosystem service function, with the total percentage summing up to 100.

4.3. Vertical Spatial Variations in Ecosystem Service Value Based on DEM

4.3.1. Slope Differences in Ecosystem Service Value Changes

From 1990 to 2020, the ecosystem service value per unit area of all slope sections in the Li River Basin showed a trend of increasing with slope, with significant increases in the 3–8° and 8–15° slope sections and slower increases in the 15–25° and >25° slope sections (Table 5). The unit area value of the 0–3° slope section from different time periods showed a tendency to decrease first, then rise, and then fall, with a net overall decrease of 9.84 yuan/hm^2, while both the 3–8° and 8–15° slope sections showed a tendency to first increase and then decrease, with a net increase of 2775.29 yuan/hm^2 and 2331.45 yuan/hm^2, respectively. The per-unit area value in the 15–25° and >25° slope sections continued to increase, from 50,253.78 yuan/hm^2 and 50,981.57 yuan/hm^2 in 1990 to 51,959.98 yuan/hm^2 and 52,600.07 yuan/hm^2 in 2020, respectively, with a net increase of 1706.20 yuan/hm^2 and 1618.50 yuan/hm^2. In terms of the composition of the total ecosystem service value, the 15–25° slope section was the highest in the four study periods of 81.39 × 10^8 yuan, 82.79 × 10^8 yuan, 83.92 × 10^8 yuan, and 84.17 × 10^8 yuan, accounting for 30.39%, 30.37%, 30.13%, and 30.38%, respectively. With a steady growth trend, its overall increase was the largest, at 2.78 × 10^8 yuan. The ecosystem service value was also high in the 8–15° slope section, representing more than 20% of the total, with a tendency to first rise and then fall, increasing by 2.64 × 10^8 yuan. The 3–8° slope section had the lowest total value of ecosystem services, but the overall increase was greater at 2.28 × 10^8 yuan. The 0–3° slope section had a fluctuating trend of decreasing and then increasing and then decreasing, from 48.43 × 10^8 yuan in 1990 down to 48.41 × 10^8 yuan in 2020, which was a slight decrease of 0.02 × 10^8 yuan.

Table 5. Value of ecosystem services by slope section in the Li River Basin from 1990 to 2020.

Slope	Value per Unit Area (yuan/hm^2)				Total Value (10^8 yuan/year)			
	1990	2000	2010	2020	1990	2000	2010	2020
0–3°	36,620.53	36,333.69	36,900.49	36,610.69	48.43	48.05	48.79	48.41
3–8°	43,526.96	45,300.31	47,646.76	46,302.25	35.91	37.37	39.31	38.19
8–15°	47,885.09	49,291.86	50,660.71	50,216.54	54.08	55.67	57.27	56.72
15–25°	50,253.78	51,125.42	51,839.59	51,959.98	81.39	82.79	83.92	84.17
>25°	50,981.57	51,722.41	52,289.25	52,600.07	48.01	48.69	49.23	49.53

4.3.2. Altitude Differences in Ecosystem Service Value Changes

Between 1990 and 2000, the ecosystem service value per-unit area of all elevational zones in the Li River Basin showed a tendency to increase and then decrease with the increase of elevation, with a significant increase in the 200–500 m altitude zone, a slow increase in the 500–800 m and 800–1200 m altitude zones, and a small decrease in the altitude zone of the >1200 m altitude zone. The ecosystem service value per unit area of each altitude zone showed a fluctuating tendency to increase, then decline, and then increase, with the height increasing from 2010 to 2020 (Table 6). During the study period, areas with higher elevations had a higher ecosystem service value per unit area, which was consistent with the distribution of landscape types within different elevational areas, with construction land and agricultural land in the Li River Basin mainly distributed in the lower elevation zones, and forestland and grassland in the higher elevation areas. Starting from different time periods, the value per unit area in the 0–200 m altitude zone showed a tendency to increase and then decrease, with an overall net increase of 533.56 yuan/hm^2. In the 200–500 m altitude zone, the value per unit area continued to rise, from 48,957.53 yuan/hm^2 in 1990 to 52,010.42 yuan/hm^2 in 2020, which was a net increase of 3052.89 yuan/hm^2. The altitude of 500–800 m, 800–1200 m, and >1200 m tended to decrease first and then increase. In terms of the composition of the total ecosystem service value, the 200–500 m altitude zone had the highest ecosystem service value over the four study periods, with 126.15 × 10^8 yuan, 129.89 × 10^8 yuan, 133.53 × 10^8 yuan, and 134.02 × 10^8 yuan accounting for 47.10%, 47.65%, 47.94%, and 48.38%, respectively. It showed a continuous increasing trend, with a net increase value of 7.87 × 10^8 yuan. Similarly, the 0–200 m altitude zone had a high ecosystem service value, showing a tendency to first increase and then decrease, with a net increase of 0.91 × 10^8 yuan. The 500–800 m, 800–1200 m, and >1200 m altitude zones all showed fluctuating changes of first decreasing and then increasing in the ecosystem service values, with an overall small increase.

Table 6. Value of ecosystem services by altitude zone in the Li River Basin from 1990 to 2020.

Altitude	Value per Unit Area (yuan/hm^2)				Total Value (10^8 yuan/year)			
	1990	2000	2010	2020	1990	2000	2010	2020
0–200 m	35,891.85	36,637.88	37,866.37	36,425.41	61.26	62.54	64.63	62.17
200–500 m	48,957.53	50,408.67	51,824.01	52,010.42	126.15	129.89	133.53	134.02
500–800 m	51,640.34	51,499.59	51,481.27	51,937.11	49.37	49.24	49.22	49.65
800–1200 m	51,960.01	51,747.49	52,002.98	52,079.06	23.27	23.18	23.29	23.33
>1200 m	51,559.69	51,540.95	52,107.74	52,132.26	7.76	7.75	7.84	7.843

4.4. Spatial Variation in the Ecosystem Service Value Level Based on Grid Cells

Based on the area of each landscape type in the Li River Basin, a 2 km × 2 km grid was used to sample the equidistant system, resulting in 1603 grids, and the ecosystem service value index for each grid was calculated by applying Equation (4). In order to visually represent the spatial distribution characteristics of ESV in the Li River Basin at different times, referring to the relevant reviews (Ma Jun et al. 2014), the standard deviation grading method was used to classify the ecosystem service value index of different grids, from low to high: low ESV zone (ESVI $\leq$ 1.20×10^4 yuan/hm^2), lower ESV zone (1.20×10^4 yuan/hm^2 < ESVI $\leq 1.90 \times 10^4$ yuan/hm^2), medium ESV zone (1.90×10^4 yuan/hm^2 < ESVI $\leq 2.60 \times 10^4$ yuan/hm^2), high ESV zone (2.60×10^4 yuan/hm^2 < ESVI $\leq 3.30 \times 10^4$ yuan/hm^2), higher ESV zone (3.30×10^4 yuan/hm^2 $\leq$ ESVI), and so on, thus generating a spatial change map of ecosystem service values in the Li River Basin (Figure 4). Figure 4 shows that the ESV classes in the Li River Basin from 1990 to 2020 changed to some degree, with significant spatial differences, but that the general pattern remained fundamentally stable, showing a characteristic distribution of low in the middle and high on all sides. During the study period, the areas with a high ecosystem service value were concentrated in the north and east of the Li River Basin, where a large number of natural ecological reserves and waters were distributed. Areas with a high ecosystem service value continued to expand, with the area remaining stable in the north and experiencing the most significant increase in the east. The area with the low ecosystem service values was primarily located in the center of the Li River Basin, the tourism economic belt of Xing'an County, Lingchuan County, Guilin City, and Yangshuo County, primarily in the central townships of the Li River Basin. From 1990 to 2000, the distribution was sporadic and scattered, and after 2000, the distribution gradually changed from discrete to concentrated and contiguous. The areas of lower and intermediate ecosystem service values were mostly located in the flat terrain of the Li River valley, with the former being dispersed and not changing much and the latter contracting significantly in extent between 1990 and 2010, namely shifting over time more toward higher or high ecosystem service value areas.

When examining the different time periods (Figure 5 and Table 7), from 1990 to 2000, we see that the regional ecosystem service level of 82.18% of the area remained the same, primarily in the northern and southeastern portions of the Li River Basin; 10.20% of the area increased, mostly in the flat central and southern regions; and 7.62% of the area declined, mostly in Guilin City and its surrounding towns and Yangshuo County. From 2000 to 2010, the regional ecosystem service level of 82.28% of areas remained stable, and their distribution was similar to that of the previous period; 10.96% of areas increased, mainly in the northern part of Guilin city and the southern part of the Li River Basin; and 6.76% of areas decreased, mainly in Guilin city and the key central towns in the Li River Basin, which were more concentrated in patches compared to the previous period. From 2010 to 2020, the regional ecosystem service levels of 88.68% of areas remained unchanged, with a similar and extended distribution as the previous two phases; 4.11% of areas increased, mainly in the northeastern part of the Li River Basin and along the Li River system; and 7.21% of areas decreased, with most being concentrated around Xing'an County, Lingchuan County, Guilin City, and Yangshuo County. From the whole study period, the regional ecosystem service level of 81.71% of areas remained unchanged and was distributed in the natural ecological reserves in the north and east; 10.97% of areas increased, mainly in the flat areas in the northeastern part of the Li River Basin and the middle and lower reaches of the Li River; and 7.32% of areas declined, mostly concentrated in the Guilin City and the southern central towns.

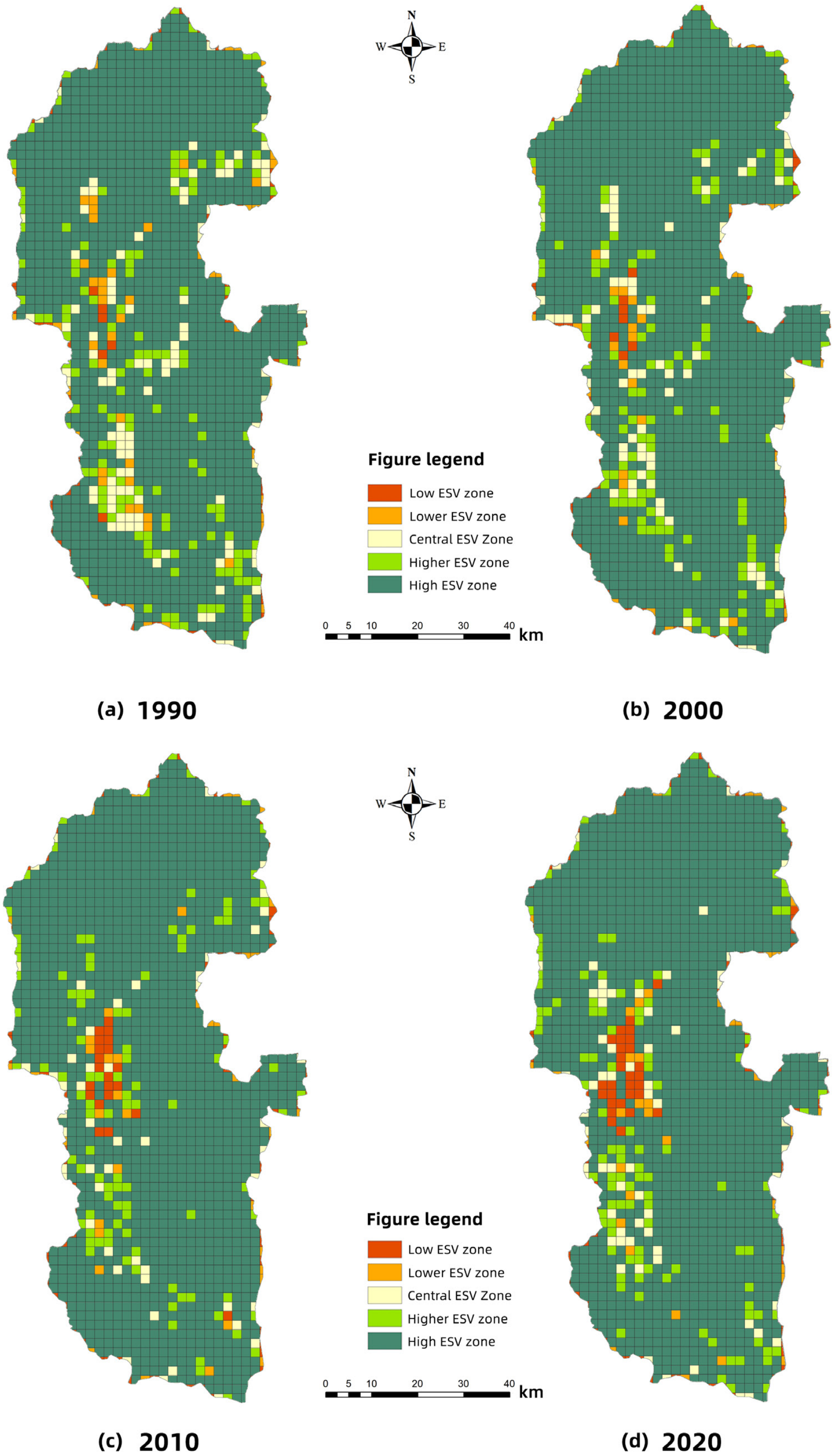

Figure 4. Distribution of ecosystem service values based on grid cells in 1990 (**a**), 2000 (**b**), 2010 (**c**), and 2020 (**d**) in the Li River Basin, Guilin, China.

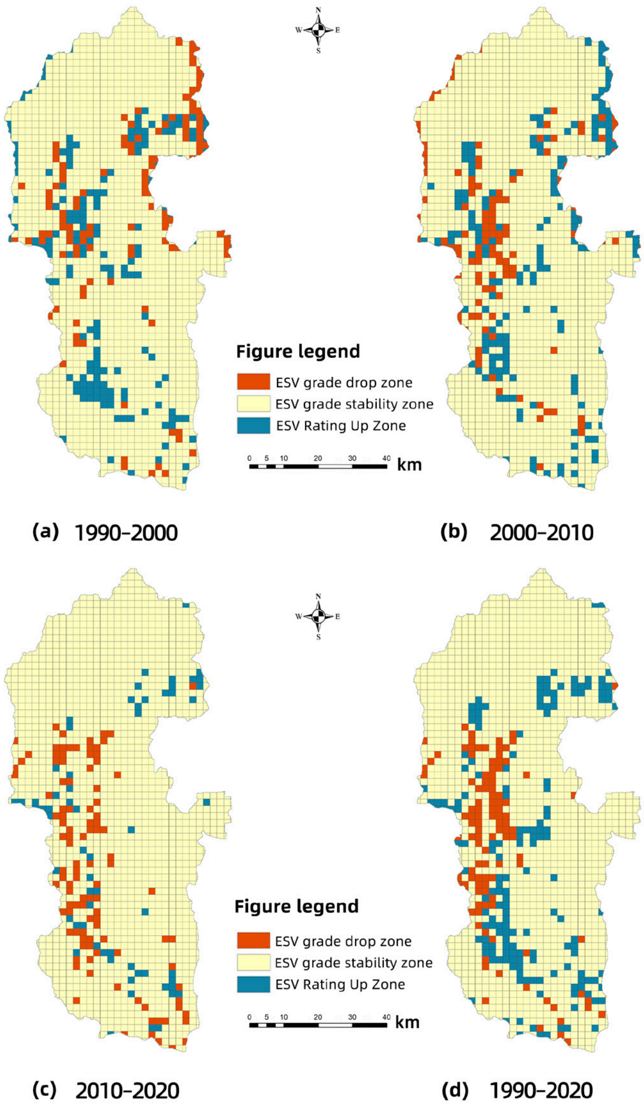

Figure 5. Changes in ESV classes in the Li River Basin, Guilin, China: 1990–2000 (**a**), 2000–2010 (**b**), 2010–2020 (**c**), and 1990–2020 (**d**), based on grid cells.

Table 7. Area statistics of gradation change in the Li River Basin over the years.

Types	1990–2000		2000–2010		2010–2020		1990–2020	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Grade Drop Zone	445.06	7.62	394.70	6.76	421.16	7.21	427.52	7.32
Grade Stability Zone	4797.64	82.18	4803.53	82.28	5177.02	88.68	4770.46	81.71
Grade Up Zone	595.23	10.20	639.70	10.96	239.75	4.11	639.95	10.97
Total	5837.93	100	5837.93	100	5837.93	100	5837.93	100

4.5. To Analyze the Spatial Autocorrelation of Ecosystem Service Value

4.5.1. Spatial Autocorrelation Analysis on a Global Scale

A global spatial autocorrelation analysis of the Li River Basin Ecosystem Service Value Index was conducted using GeoDa1.20 to interpret the spatial convergence of ecosystem service values in the study area; in 1990, 2000, 2010, and 2020, the global Moran's I value of Li River Basin Ecosystem Service Value Index was 0.422, 0.411, 0.422, and 0.437, respectively (Figure 6). For all four time periods, the global Moran's I value was greater than 0, with a significance level below 0.05. The values showed a decreasing trend followed by an increasing trend, resulting in a slight increase of 0.015 over the entire study period. The spatial distribution of ecosystem service values showed a significant positive correlation, with neighboring grid cells exhibiting a high degree of spatial similarity and aggregate distribution.

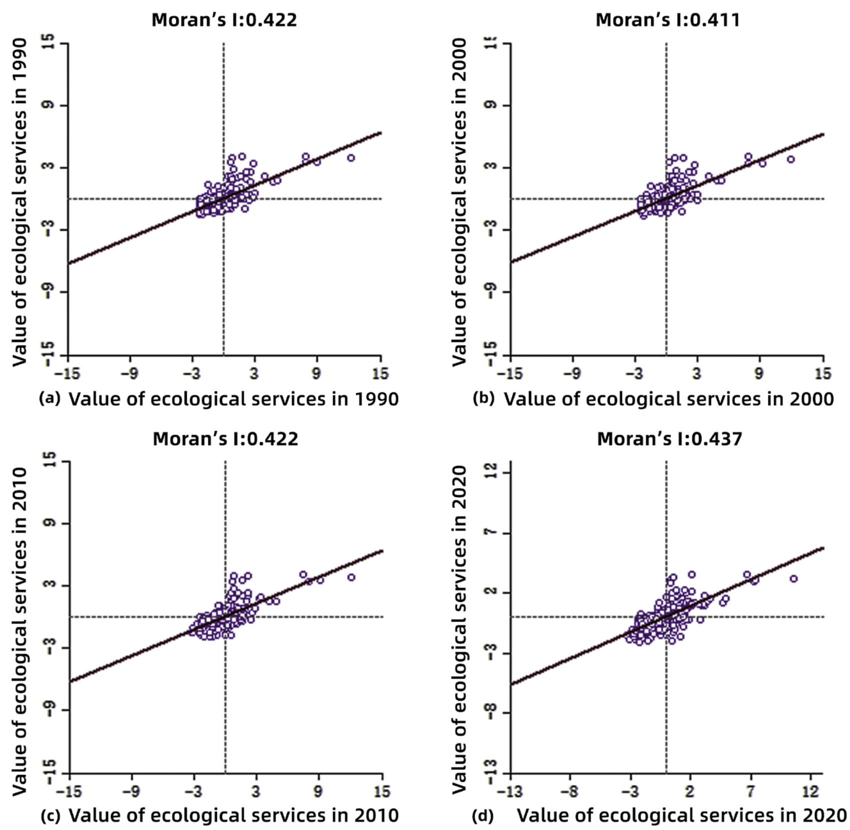

Figure 6. Moran's I scatter plots of the value of ecosystem services in 1990 (**a**), 2000 (**b**), 2010 (**c**), and 2020 (**d**) in the Li River basin, Guilin, China.

4.5.2. Analysis of Local Spatial Autocorrelations

The local spatial autocorrelation analysis reflects the local indexes of the whole region and visualizes the aggregation locations of ecosystem service values in grid space, as well as their regional correlation degree. Equation (6) was used to derive the LISA results of the local spatial autocorrelation of the ecosystem service value in the Li River Basin for 1990, 2000, 2010, and 2020 (Figure 7).

From 1990 to 2020, the distribution of high-value and low-value clusters in the Li River basin was basically the same; that is, the ecosystem service value was higher in the north and parts of the east and southeast, and it was lower in the middle gentle slope. The high ecosystem service value clustering area was located in the north and to a lesser extent in the east and southeast of the Li River Basin, mainly due to the presence of natural mountains and forests in the north and east of the study area, including the Cat Mountain National Nature Reserve, the Qing Shi Tan Water Source Conservation Forest Reserve, the Hai Yang Shan Water Source Conservation Forest Reserve, and many other ecological protection sites. This area had a high ecosystem service value, a good vegetation condition, a low population density, and little interference from human activities, whereas the clustering area showed a shrinking trend, indicating that the aggregation degree of the grid in the region was weakening. The areas of low clustering were concentrated in the central and western parts of the study area, as well as a small number of fringe regions, which had the most significant clustering changes over the entire study period, primarily due to the fact that the low-value areas were located on the tourist economic belt of Xing'an County, Lingchuan County, Guilin City, and Yangshuo County. These areas were all densely populated and urbanized, characterized by rapid urbanization, a well-developed tourist industry, and intense human activities.

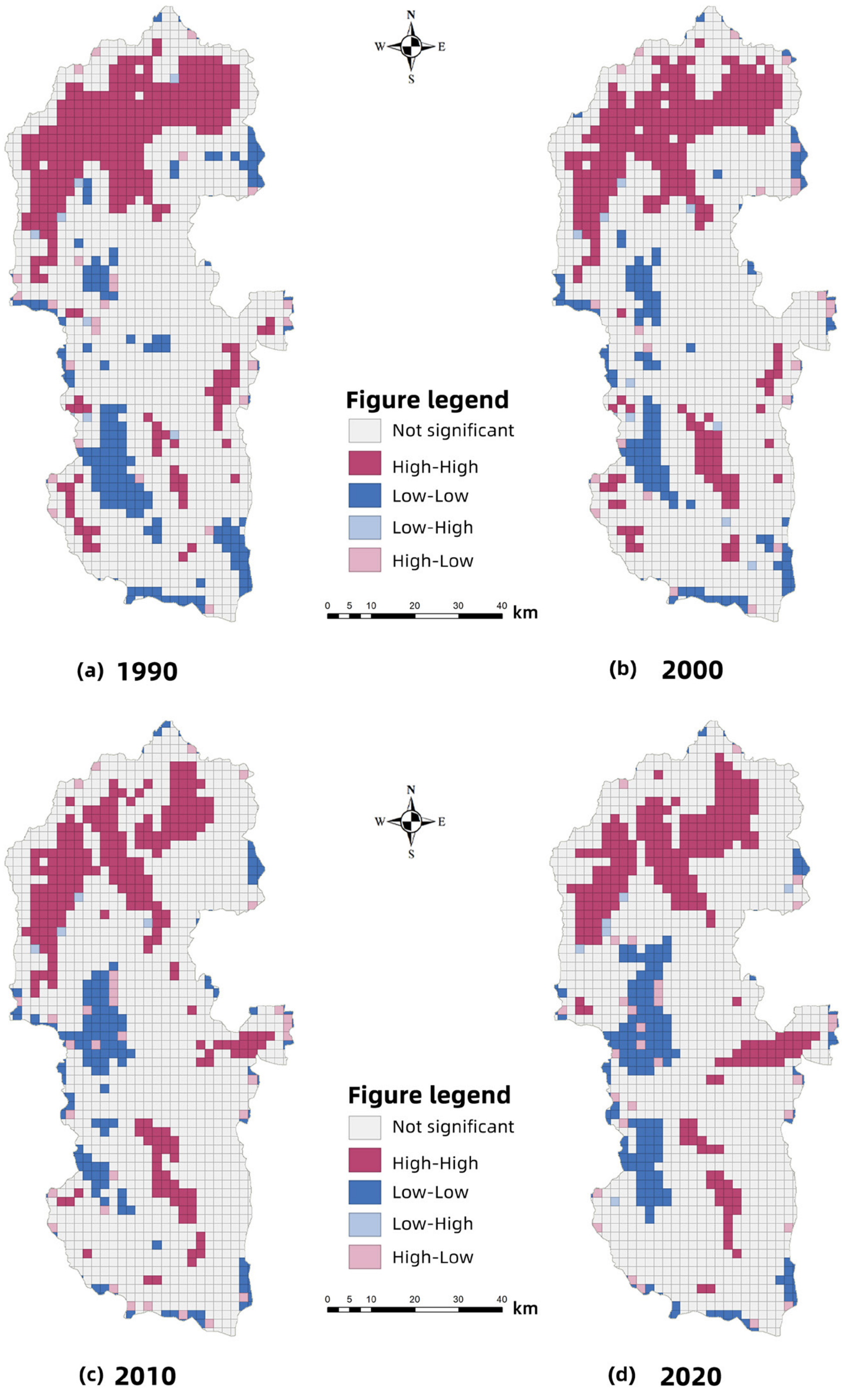

Figure 7. Local spatial autocorrelation of ecosystem service values in 1990 (**a**), 2000 (**b**), 2010 (**c**), and 2020 (**d**) in the Li River Basin, Guilin, China.

5. Discussion

5.1. Effects of Landscape Type Change on the Ecosystem Service Value in the Li River Basin

The Li River Basin is a major water conservation area in the Pearl River Basin and a major ecological barrier in Southern China. The landscape structure was relatively stable over the last 30 years, while the area of landscape types underwent considerable changes. Due to the implementation of a series of measures such as afforestation, the returning of farmland to forests, and the planting of fruit trees, forest land has continued to increase over a large area. Additionally, research conducted by Min Wang et al. [45] indicated that these measures have greatly promoted regional control of rocky desertification. The continued decline in farmland was attributed to the restructuring of economic crop cultivation and the conversion of farmland to built-up land. The rapid expansion of construction land was influenced by the accelerated expansion of tourist towns with the building of new rural areas and tourist service facilities, and this is consistent with the research findings of Haoran Wang et al. [46]. The water area first decreased and then increased. The decrease resulted from the expansion of cities and the reclamation of water to create land in the early stages, while the small increase in the later phase was due to the continuous introduction of associated conservation policies and the improvement of people's awareness of Li River protection. The decline in grassland was primarily caused by reforestation of wastelands and field cultivation in the early period, while after 2010, the implementation of afforestation policies resulted in some grasslands being converted to forestlands. Therefore, the landscape was mainly being transformed to forestland and construction land.

Changes in each landscape type directly led to synergistic changes in the ecosystem service value and the value of individual functions [32]. The continued increase of forestland value during the study period was the main factor increasing the total ecosystem service value in the Li River Basin, while the rapid increase of the built-up land area and the decrease in the area of cultivated land, water bodies, and grassland led to a decrease of the ecosystem service values. Together, these two factors contributed to a slight increase in the ecosystem service value throughout the study period. Based on the above changes, it was concluded that policy measures to manage ecological protection had a positive impact on increasing the ecosystem service value in the study area. Nonetheless, a focus on the rapid loss of the ecosystem service values in some regions was necessary; R.S. de Groot and colleagues also hold similar views [17]. Between 1990 and 2020, there were little changes in the contributions of each individual service value, with regulating services being significantly higher than other types of services. Hydrological and climate regulation were firmly in the top two, both accounting for over 50% of the total. However, they showed opposite trends, with hydrologic regulation continuing to decline and climate regulation continuing to rise both at the largest amount, which was driven primarily by the rapid increase of construction land with the negative hydrologic regulation effects and the growth of forestland with high climate regulation functions. The researchers Shi et al. confirmed a significant negative correlation between built-up land and regulating services [40]. The largest increase and decrease in water supply and food production, respectively, were mainly due to the significant reduction of arable land area since the continued conversion of arable land with higher negative water supply effects and higher food production value coefficients to other land types.

5.2. Characteristic of the Composite Spatial Pattern of Ecosystem Service Values within the Li River Basin

From the vertical space, the ecosystem service value per unit area increased with the slope, mainly because forestland with a high ecosystem service value was concentrated in areas with high slopes and stable ecosystems, while construction land and agricultural land were mainly in the area with a gentle slope and intensive human activities [11]. In areas with low slopes (0–15°), a late decline in the ecosystem service value per unit area was primarily associated with the continued increase in tourism development and town-building activities after 2010. Except for the slope segment of 0–3°, the ecological service value increased in all other slope segments, primarily due to the conversion of low-slope areas such as cropland and water bodies to built-up land. The conversion of marginal farmland to forest and the planting of trees and fruits mainly occurred in higher slope areas. Similar results were also found by Ranran Liu et al. [6]. The ecosystem service value per unit area in all elevation zones fluctuated and increased with height, mainly because construction land and arable land were concentrated in the lower elevation zones, while the higher elevation zones were mainly distributed with a large area of forests and grasslands with high value coefficients [4]. The ecosystem service values increased in all elevation zones, with the largest increase in the 200–500 m range and a small increase in other elevation zones. It was mainly because the adjustment of planting structures such as the return of farmland to forest and fruit trees planting mainly occurred in the 200–500 m elevation range, while forest conservation measures took place in the above 500 m elevation range with good growth conditions and more stable ecosystems. This is similar to the findings of Kelin Wang et al. [10].

In terms of horizontal grid space, the overall spatial variation in ecosystem service values in the Li River Basin from 1990 to 2020 was characterized by low values in the middle and high values in the surrounding areas, with the high value areas clustering from the north and east towards the center and the low value areas gradually extending from the center to the surroundings in time order. The high ecosystem service value areas were mainly located in the northern and eastern parts of the Li River Basin, where forests grew in abundance with healthy forest ecosystems, little interference from human activities, and large areas of natural ecological reserves and water, such as Cat Mountain National Nature Reserve, Hai Yang Shan Water Source Conservation Forest Reserve, Qing Shi Tan Reservoir, etc. A study by Shiyou Chen, Xuechao Wang, and others has shown that forests and aquatic ecosystems are crucial for maintaining the stability of regional ecosystem services' value [9,13]. In contrast, the low-value zones of ecosystem services were mainly concentrated in the central townships within the Li River Valley. These areas experienced active urban construction and tourism development, resulting in a rapid expansion of construction land and large-scale concentrated development. The study demonstrated an overall upward trend in the ecological service level of the Li River Basin during the study period, with most regions maintaining their service level. The increase in service level was mainly concentrated in the flat areas of the Li River Valley, where a significant amount of farmland was converted into forestland due to the development of rural tourism and large-scale cultivation of fruit trees. This point was validated in the research conducted by Zhigang Zou and others [47]. Conversely, the decrease in service level occurred primarily in areas with frequent tourism-development activities, such as Guilin city, Yangshuo County, Xing'an County, and the vicinity of major scenic spots. These areas underwent rapid urbanization, and the developed tourism industry led to extensive land conversion into construction land.

By contrasting with previous research [2,6], we can gain a more comprehensive understanding of the importance of ecosystem services in the region and the extent of human impact, providing a scientific basis for future ecological conservation and sustainable development.

5.3. Analyses of Research Assessment Methods

Current studies of regional ecosystem service values typically take land-use types and administrative areas as the basic units of assessment [21,22], and most perform simple quantitative change and horizontal benchmarking based on estimating the ecosystem service value in different areas, making it difficult to reveal spatial differences in ecosystem service value in depth. This study introduced the grid-based method to the study of ecosystem service values [41,42], built the ecosystem service value index to achieve the spatialization of the ecosystem service values evaluation, and combined spatial autocorrelation analysis with DEM data for composite analysis. It revealed the spatial distribution pattern of ecosystem service value in the Li River Basin in the past 30 years from horizontal and vertical dimensions, which provided usable data support for the management of regional ecosystems. Given the complex topographical conditions of the Li River Basin and the low resolution of the remotely sensed imagery, there were only six categories of landscape types, namely forestland, farmland, construction land, water, grassland, and bare land, which could potentially lead to some errors in the measurement results. Therefore, the high-accuracy remote-sensing data should be used to refine landscape types in the future.

5.4. Specific Recommendations

(1) Strengthen the protection and restoration of forest ecosystems: Planners and decision-makers should conduct a scientific assessment of the biodiversity and ecosystem services value in the Li River Basin. They should establish additional nature reserves in key areas, avoiding human interference, and continue to promote forest conservation and restoration projects. Measures such as afforestation, land conversion from agriculture to forests, and forest regeneration should be implemented to increase forest area and maintain the sustainability of forest ecosystem services.

(2) Enhance the function of ecosystem regulation services. Planners and decision-makers should consider regulation services as a critical indicator for ecosystem management and planning decisions in the Li River Basin. They should strengthen the protection and restoration of wetlands, forests, and water bodies; optimize water resource allocation; implement soil and water conservation measures; and undertake targeted water pollution control. This will improve the basin's capacity for climate regulation, hydrological regulation, and disaster prevention.

(3) Pay attention to spatial differences in ecosystem services. Planners and decision-makers should establish corresponding management goals, measures, and policies based on the ecosystem service requirements and characteristics of different regions to achieve optimal ecosystem service benefits. Additionally, enhanced communication and cooperation between different regions should be promoted, establishing cross-regional ecological conservation organizations. They can jointly develop regional development plans, coordinate resource utilization, share ecosystem services, and achieve sustainable regional development.

(4) Deepen the management decisions regarding ecosystem services: Planners and decision-makers should thoroughly consider the distribution characteristics and ecological functional requirements of ecosystems, formulate long-term ecosystem management and planning measures, and establish a comprehensive ecosystem service assessment system. Regular ecosystem service assessments should be conducted to monitor changes in ecosystem services. Multiple ecosystem service values should be considered to ensure the comprehensive development of regional ecosystem services.

6. Conclusions

This study focused on investigating the spatiotemporal changes of ecosystem services in the Li River Basin over the past 30 years. By using a modified equivalent factor table and remote-sensing imagery data from 1990 to 2020, the study conducted an in-depth analysis of the spatiotemporal variations of ecosystem services resulting from landscape changes from different dimensions. The research results prominently demonstrate that landscape changes have had a significant impact on the composition and functionality of ecosystems, leading to changes in the types and intensities of ecosystem services. Forest land has consistently been the dominant landscape type in the Li River Basin, with its area continuously increasing during the study period. Conversely, the areas of farmland, water bodies, and grassland have decreased, while the areas of built-up land and bare land have increased. The overall value of ecosystem services showed an initial increase followed by a decrease, with a net increase of 9.20×10^8 yuan. Forest land was the primary contributor to the increase in ecosystem service value. Among specific ecosystem services, climate regulation and hydrological regulation consistently ranked in the top two positions, accounting for over 50% of the total value. Notably, regulation services were significantly superior to other service types in the Li River Basin. Regarding vertical spatial variations, the value of ecosystem services per unit area increased with increasing slope and elevation. The highest value was observed in areas with slopes of 15–25° and elevations of 200–500 m. The Li River Basin, as a whole, exhibited a relatively high level of ecosystem service value, which continued to increase. However, there were significant spatial differences that were characterized by a distribution pattern of lower value in the central region and higher value in the surrounding areas. High-value areas were mainly located in the northern and eastern parts of the Li River Basin, while low-value areas were concentrated in the central zone, particularly in the tourism–economic belt formed by Xing'an County, Lingchuan County, Guilin City, and Yangshuo County. Overall, the ecosystem service pattern in the Li River Basin was relatively stable, with different temporal periods exhibiting distinct spatial clustering characteristics. Based on the study's findings, we should strengthen forest ecosystem protection and enhance ecosystem-regulating services. Additionally, we should consider spatial variation in ecosystem services and improve management decisions accordingly. The study on spatial and temporal changes of ecosystem services based on landscape evolution can provide the basis for ecosystem management and planning decisions in the study area, which is of great significance for the realization of regional sustainable development.

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