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Ecological Compensation in Zhijiang City Based on Ecosystem Service Value and Ecological Risk

Xuexian Xu and Yuling Peng *

School of Civil Engineering and Architecture, Wuhan Institute of Technology, Wuhan 430074, China; 22004010039@stu.wit.edu.cn
* Correspondence: yulingpengwit@163.com

Abstract: Using Zhijiang City, Hubei Province as an example, this study constructed an ecological risk assessment model based on land use data from the three phases of 2000, 2010, and 2020. We then determined the ecological compensation priority sequence based on the ecosystem services value (ESV) and the economic status of the research area. The findings revealed that there was a significant spatial differentiation in ESV during the study period, with the ESV being higher south of the Yangtze River than north. Overall, in Zhijiang City, the ESV generally decreased over the course of the study period, with a decrease of CNY 812 million in 20 years. The loss of wetland and grassland was the greatest, and was most obvious between 2010 and 2020, whereas the loss of construction land was the lowest among the different types of landscapes. The ecological risk index of Zhijiang City showed a declining trend between 2000 and 2020. The extent of high-ecological risk areas shrank by 55.83 km^2, and their predominant landscape types were grassland and forest land. The low-ecological risk area expanded by 340.50 km^2 and was primarily distributed in construction land along the Yangtze River Basin. The ecological compensation priority sequence was divided into five levels in each town in Zhijiang City, with Gujiadian Town and Baiyang Town receiving the highest grades and being designated as priority compensation areas. The study intends to serve as a model for the construction of ecological cities, ecological environmental protection, and sustainable development in the Yangtze River Basin.

Keywords: ecosystem service value; landscape pattern; ecological risk; ecological compensation; Yangtze valley

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1. Introduction

The construction of an ecological civilization is the top priority of China's sustainable development strategy, and it is also a criterion that must be pursued in the process of human development [1]. Ecosystems are closely related to human society; on the one hand, ecosystems provide materials and ecological regulation in addition to giving landscapes cultural value for human society [2], while on the other hand, the pressures placed by human activities on the ecosystem have caused many ecological and environmental problems, which in turn have brought great troubles to daily life [3]. As such, realizing a harmonious coexistence between man and the natural ecological environment, improving the quality of the ecological environment, and maintaining ecological security patterns have become perennial themes [4].

The concept of ecosystem services can be traced back to the 1960s [5], and refers to the various benefits that human beings receive from the ecosystem [6]. Since the concept of ecosystem services was proposed, relevant research has been continuously carried out and deepened. Nature's services: Societal Dependence on Natural Ecosystems was published by Daily in 1997 [7]. Costanza et al. [8] classified and evaluated the global biosphere's ecosystem services in the same year. Both of these texts laid the foundation for the study of ecosystem service value evaluation. Domestic research began late, with scholars such as Ouyang et al. [9], Chen et al. [10], and Xie et al. [11] taking the lead. Since 2005, many scholars have begun to explore the links between ecosystem services and land use [12]. In 2007, Stanford University, the World Wide Fund for Nature, and the Nature Conservancy jointly developed the In VEST (Integrated Valuation of Environmental Services and Tradeoffs) model [13], which includes many modules such as the ocean, land, and freshwater. The model is suitable for multi-objective integrated ecosystem service value assessment. In 2015, Xie et al. [14] conducted a detailed exploration on the basis of Costanza's research, and supplemented and revised the equivalent factor method. This provided a specific reference method for the dynamic assessment of ecosystem service value [15], ecological compensation, and other applications [16]. For example, Zeng et al. [17] evaluated the value of ecosystem services in 16 jurisdictions of Beijing over a 10-year period based on the modified equivalent factor method, and analyzed the change law of the eco-economic coordination degree over this period. Deng et al. [18] constructed a dynamic equivalent scale of ecological service value. They also estimated the ecosystem service value, ecological compensation priority, and compensation quantity of 310 counties in the old revolutionary areas along the Long March. The equivalent factor method has the characteristics of simple operability and a lower data demand, and has become a common method for ESV evaluation in China. In addition, due to the spatial and temporal heterogeneity of ecosystem services, this method is suitable for the assessment of small-scale regions.

Ecological risk refers to the possibility of adverse effects in ecosystems and their components after external interference, and in relation to this, quantitative evaluation and in-depth research can guide the development of natural resource use and the construction of regional ecological civilizations. Ecological risk assessment research originated in the 1970s [19], and has gradually developed and matured. According to the general process of risk assessment, it can be seen that the ecological risk assessment procedures of different countries are essentially the same [20]. Generally, there are four steps [21]: (1) hazard identification; (2) exposure effect analysis; (3) exposure assessment; and (4) risk characterization [22]. As far as the research area is concerned, there are key ecological reserves such as watersheds [23], mining areas [24], wetlands [25], desert oases [26], etc. Relatively few studies have been carried out on the temporal and spatial evolution of ecological risks based on small- and medium-sized urban landscapes. The evaluation methods can be divided into risk source–risk receptor-based evaluation and landscape pattern-based evaluation. The latter has become a common paradigm for domestic scholars to study ecological risks. Landscape ecological risk assessment is derived from regional ecological risk assessment, and mirrors its research focus. At present, China has developed a theoretical evaluation framework that is of world-class standards [27], and numerous academics have conducted research on landscape ecological risk assessment [28].

Ecological compensation regulates the interaction between ecological construction and economic development by applying economic leverage, with the goal of maintaining and utilizing ecosystem services sustainably [29]. It can support the comprehensive improvement of the quality of regional ecological environments and regional ecological security pattern optimization. Ecological and economic factors serve as the fundamental components of ecological compensation research from a methodological standpoint. Since ecosystems are spatially variable in their geographic distribution at the ecological level, different regions' ecosystems supply varying kinds and sums of ecosystem services. Regional economic development varies depending on the economic degree, and economically underdeveloped places frequently suffer higher environmental harm [30] and require more assistance with ecological compensation. The input perspective and the output perspective can be used to derive a standard approach to estimating ecological compensation [31,32]. Most researchers use the value of ecosystem services to measure ecological benefits and then establish ecological compensation standards from the viewpoint of output [31,33]. Earlier studies typically used the total value of ecosystem services as the standard for ecological compensation [34]. However, since 2015, with the proposal of Xie et al. [35] to revise the total value of ecosystem services based on socioeconomic coefficients, which improved the credibility of the estimation of ecological compensation standards, this method has been used in more ecological compensation studies in China.

2. Materials and Methods

2.1. Study Area

Zhijiang City is located in the southeast of Yichang city, Hubei Province, which is a county-level city under the jurisdiction of Hubei Province. Its geographical position is around 111°25′–112°03′ E and 30°16′-30°40′ N. The city stands by the river and depends on the water. The Yangtze River flows through the region for 102 km, accounting for 1/10 of the coastline in Hubei Province. The Zhijiang City administrative region covers a total area of 1310 km^2, and the southeast plain accounts for about 41.2%. The terrain fluctuates slightly, and the average elevation is about 80 m. For a long time, due to rapid development and the use of land resources, environmental pollution in Zhijiang City has become increasingly problematic.

The deterioration of the natural environment in the Yangtze River Basin has seriously affected the landscape ecological security patterns of surrounding cities. As one of the seven node cities in the Yangtze River Basin, Yichang City is also the dividing line between the middle and upper reaches of the Yangtze River. Zhijiang City is the county containing the longest section of the Yangtze River, and its environmental quality is related to the ecological construction of cities in the middle and lower reaches of the Yangtze River. The geographical location and land use situation of Zhijiang City in 2020 are shown in Figure 1. In recent years, with the rapid development of the social economy and the rapid growth of the population, the spatial and temporal distribution patterns of land use in Zhijiang City have changed. As a result, the ecological environment of Zhijiang City is under severe threat, and the quality of the environment is growing worse year by year. Therefore, this paper uses small and medium-sized city in the Yangtze River Basin as the research object. Based on land use data from Zhijiang City in 2000, 2010, and 2020, the value of ecosystem services is assessed using the equivalent factor technique. This method of landscape pattern evaluation was used to explore the regulation of the spatial distribution of landscape ecological risks. Combined with economic data, the priority order of regional ecological compensation was calculated, and the priority area of ecological compensation in zhijiang city is defined. This has guiding significance for the construction of ecological cities, as well as ecological environmental protection and prevention, in the Yangtze River Basin.

2.2. Data Sources

The data used in this study include the following: (1) land use data, which were obtained from the 30 m global land cover data Globe Land30, referring to remote sensing data on land use in Zhijiang City in 2000, 2010, and 2020. With a spatial resolution of 30 m, the 30 m global land cover data include geographic distribution information and information on the distribution of landscape patterns. The land use type was classified into six categories based on the landscape type classification standard and the characteristics of land use status in the study area. There were six types of land considered in this study: cultivated land, forest land, grassland, water area, wetland, and construction land. (2) The socio-economic data were derived from the National Bureau of Statistics (http://www.stats.gov.cn/ (accessed on 17 July 2021)) and the Hubei Provincial Bureau of Statistics (http://tjj.hubei.gov.cn/ (accessed on 17 July 2021)). Additionally, they can also be obtained from the Yichang Statistical Yearbook for the years 2018, 2019, and 2020.

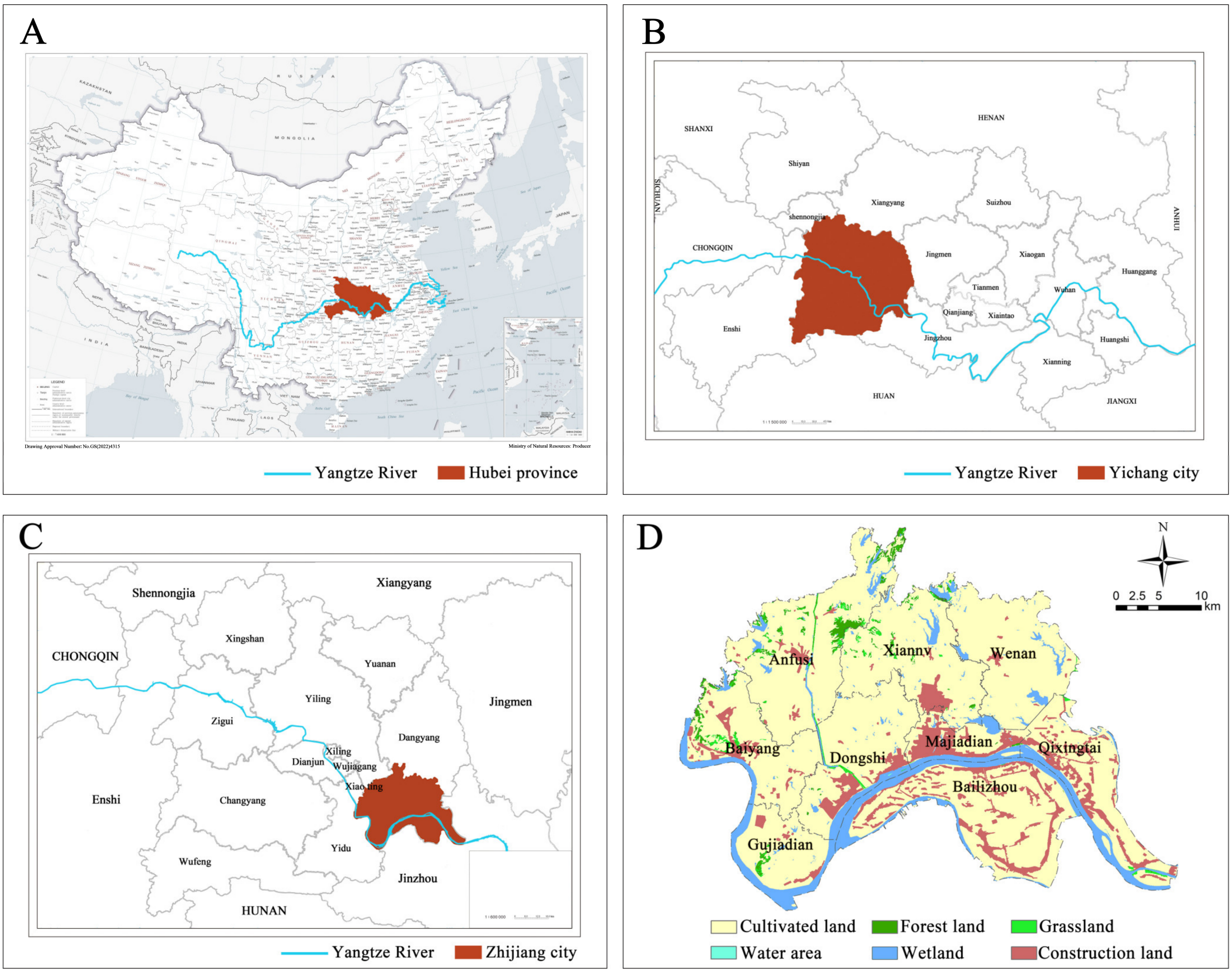

Figure 1. The study area: (**A**) the location of Hubei Province in China; (**B**) the location of Yichang City in Hubei Province; (**C**) the location of Zhijiang City in Yichang City; (**D**) land use in Zhijiang City in 2020.

2.3. Methodology

2.3.1. Estimation of Ecosystem Service Value

The evaluation of ESV in Zhijiang City requires not only qualitative analysis, but also quantitative measurement. In order to ensure the operability of the research process and the legitimacy of the research results, with reference to the advantages and disadvantages of various previous evaluation methods, this paper has adopted a market-oriented method to evaluate the ESV of Zhijiang City. According to Xie Gaodi's equivalent scale of land ecosystem service value per unit area in China [14,35], based on the analysis of land use in Zhijiang City, the ESV in this city was estimated by calculating its economic value.

According to the equivalent factor method of ecosystem service value, one standard unit of ecosystem service value is equal to 1/7 of the total economic value of grain production services per hectare of cultivated land [36], and its calculation formula is as follows:

$$M = \frac{1}{7} \times P \times Q \tag{1}$$

In Formula (1), M is the economic value of a unit equivalent factor (CNY/hm^2), P is the average grain price in the study area (CNY/kg), and Q is the average annual grain yield in the study area (kg/hm^2).

2.3.2. Landscape Pattern Index Analysis

The landscape pattern index is composed of the landscape pattern and landscape indices, which can quantitatively reflect the arrangement and combination of landscape elements in a spatial structure [37]. The landscape pattern index used in this study includes landscape loss degree, landscape fragility degree, landscape disturbance degree, landscape fragmentation degree, landscape separation degree, and landscape dominance degree.

The landscape loss index, which reflects the loss degree of the landscape when disturbed, is expressed by R_i.

$$R_i = F_i \times U_i \tag{2}$$

where F_i is the landscape vulnerability index, which reflects the ability of different landscapes to resist external interference. According to the previous research [38], the vulnerability of each of six landscape types, namely, cultivated land, forest land, grassland, water area, wetland, and construction land, was assigned a value of 4, 2, 3, 5, 6, and 1, respectively, and the vulnerability index of each landscape type is then obtained by normalization.

U_i is the landscape disturbance index, which refers to the degree of external disturbance imposed on the landscape.

$$U_i = \mathrm{a}C_i + \mathrm{b}N_i + \mathrm{c}D_i \tag{3}$$

where C_i is the landscape fragmentation index. The calculation formula is:

$$C_i = n_{\mathrm{i}}/A_i \tag{4}$$

N_i is the landscape separation index, which is used to reflect the dispersion degree between different patches in the landscape type:

$$N_i = \sqrt{n_i A}/2A_i \tag{5}$$

D_i is the landscape dominance index, which reflects the diversity degree of different landscapes. The higher the diversity, the lower the dominance:

$$D_i = \frac{Q_i + M_i}{4} + \frac{L_i}{2} \tag{6}$$

In the above formula, n_i is the number of patches; A_i is the patch area; Q_i is the percentage of grid number of the landscape type i; M_i is the percentage of the patch number of the landscape type I; and L_i is the percentage of patch area of the landscape type i. Following [39], in this study, a = 0.5, b = 0.3, and c = 0.2.

2.3.3. Spatial Autocorrelation

Spatial autocorrelation analysis can determine whether there is spatial dependence on an attribute value. It is divided into global spatial autocorrelation and local spatial autocorrelation, which are commonly expressed by Moran's I index [40]. In this paper, GeoDa and ArcGIS software were used to calculate Moran's I index and draw LISA cluster maps to study the spatial relationships amongst ecosystem service values.

The global spatial autocorrelation Moran's I is calculated as:

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} y_i y_j}{\sum_{i=1}^{n} y_i \left(\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \right)} \tag{7}$$

$$y_i = x_i - \overline{x},\ y_j = x_j - \overline{x} \tag{8}$$

The formula of local Moran's I is:

$$I_i = \frac{n y_i \sum_{j=1}^{n} w_{ij} y_j}{\sum_{i=1}^{n} y_i^2} \tag{9}$$

where n is the number of observation sites; W_{ij} is the spatial weight; $x_i(x_j)$ is the observed value of a spatial feature at locations $i(j)$; x is the mean of observed values at all the sites.

The value of Moran's I index ranges between −1 and 1. When the value is >0, the index presents a positive spatial correlation, and vice versa. A zero value indicates the existence of a random spatial pattern.

2.3.4. Construction of Ecological Risk Index

In this study, landscape fragmentation degree, separation degree, and dominance degree were used to calculate the landscape disturbance degree, and then an ecological risk assessment model was built in combination with the landscape fragility degree. With the help of ArcGIS and Fragstats software, referring to the research of Chen et al. [41], the evaluation unit was set as 2~5 times the average patch area of the landscape under study. Therefore, this paper selected a 900 × 900 grid as the evaluation unit to divide Zhijiang City, deriving a total of 1872 risk communities. The landscape loss index of each land use type is calculated using the Fragstats 4.2 software, and the ecological risk value of each grid is calculated in ArcGIS.

The calculation formula of the ecological risk index is:

$$ERI_{xi} = \sum_{i=1}^{n} \frac{S_{xi}}{S_x} R_i \tag{10}$$

In Formula (10), ERI_{xi} represents the ecological risk index of the x evaluation unit; n is the number of landscape types, and the value in this paper is 6; S_{xi} represents the area of Class i landscape in x risk community; S_x is the total landscape area of the x evaluation unit.

2.3.5. Calculation of Ecological Compensation Standard

The evaluation of ecosystem service value alone cannot define the urgency and compensation standard of ecological compensation, so the weighted sum of ecological risk service value and ecological risk was sampled to measure the differences in the urgency of ecological compensation between different regions. Referring to the method of "Ecological Compensation Priority Sequence (ECPS)" put forward by Wang et al. [42], the ecological compensation priority index was determined by comprehensively considering the regional level of economic development. The larger the index, the greater the priority that should be placed on the region in terms of compensation. The expression is as follows:

$$ECPS = \frac{aX + bY}{P_n} \tag{11}$$

In Formula (11), $ECPS$ is the priority of ecological compensation; X is the ecosystem value per unit area; Y is the ecological risk index per unit area; P_n is the GDP per unit area of region n; a and b are undetermined parameters. According to other relevant research [43], considering the actual situation of Zhijiang City, it is considered that ESV and ES are of equal importance in this paper; thus, it is assumed that $a = b = 0.5$. The greater the $ECPS$, the more urgent the demand for ecological compensation in this region, and vice versa.

3. Results

3.1. Spatiotemporal Characteristics of Ecosystem Service Value

3.1.1. The Time Change of Ecosystem Service Value

The dynamic degree of ecosystem service value is used to express the change speed of the ecosystem service value in a set period, and its calculation formula is as follows:

$$D = \frac{ESV_b + ESV_a}{ESV_a} \times 1/T \times 100\%$$

where: D is the dynamic degree of ecosystem service value; ESV_a and ESV_b are the service values of a certain type of ecosystem in the early and late stages; T is research period.

It can be seen from Table 1 that from 2000 to 2020, the ESV of wetlands and construction land changed greatly, with construction land increasing by 12.6% and wetlands decreasing by 4.9%. From 2000 to 2020, the negative ecological service value benefits generated by construction land in Zhijiang City showed an increasing trend year by year, indicating that this type eroded and occupied other ecological land types over a period of years. At the same time, the ecosystem service values of other land use types, apart from construction land, have been declining over the past 20 years, and the trend of changes in land use type is basically consistent with the changing trends of the total ecosystem service values of all kinds of land use.

Table 1. Ecosystem service value dynamics from 2000 to 2020.

Year	Statistical Type	Cultivated Land	Forest Land	Grassland	Water Area	Wetland	Construction Land	Total
2000	ESV (10^8 CNY)	14.82	1.00	0.57	39.92	0.31	−0.95	55.66
2010	ESV (10^8 CNY)	14.56	1.01	0.48	33.40	0.86	−1.99	48.31
2020	ESV (10^8 CNY)	13.84	0.95	0.42	35.69	0.01	−3.36	47.54
2000–2010	ESV dynamic degree	−0.18%	0.18%	−1.56%	−1.63%	17.83%	10.89%	−1.32%
2010–2020	ESV dynamic degree	−0.50%	−0.66%	−1.12%	0.69%	−9.92%	6.88%	−0.16%
2000–2020	ESV dynamic degree	−0.33%	−0.24%	−1.25%	−0.53%	−4.89%	12.63%	−0.73%

3.1.2. The Spatial Change of Ecosystem Service Value

We used ArcGIS software to superimpose and analyze the data regarding ESV and the Zhijiang City administrative unit, and then calculated the average ESV according to the area of each township and classified the data into five grades [44]: low-value area (CNY <2.5 million/km^2); medium-low-value area (CNY 2.5~3.5 million/km^2); medium-value area (CNY 3.5~4.5 million/km^2); medium-high-value area (CNY 4.5~5.5 million/km^2), and high-value area (CNY >5.5 million/km^2). The results are shown in Figure 2.

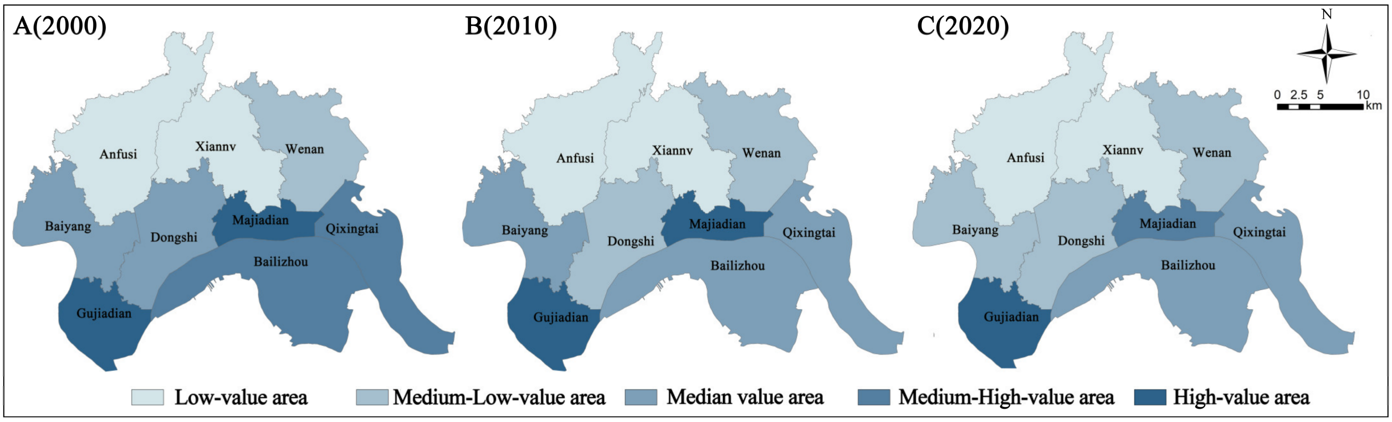

Figure 2. Per hectare ESV levels of nine towns in Zhijiang City: (**A**) 2000; (**B**) 2010; (**C**) 2020.

The spatial distribution pattern of the average ecosystem service value in the whole study area showed obvious regional characteristics, and the average ESV in the south along the Yangtze River was generally higher than that in the north, far away from the Yangtze River. The distribution of high-value areas is consistent with that of rivers and lakes, such as in the Gujiadian and Majiadian towns in the southern Yangtze River Basin. The medium-high-value areas are distributed in Bailizhou Town and Qixingtai Town along the Yangtze River in the south. Xiannv Town and Anfusi Town are in low-value areas among the nine towns (streets). The low-value areas and medium-low-value areas are mainly distributed in the central and northeast regions. On the whole, the average ecological service value of Zhijiang City is declining.

We used ArcGIS to compare the differences in ESV in the study area from 2000 to 2020, and determined the value changes in each period. These changes can be divided into increases and decreases, as shown in Figure 3. From 2000 to 2010, the value of ecosystem services in all regions showed a decreasing trend, mainly because after 2000, Zhijiang City vigorously advanced its economic construction, and its construction land area increased. From 2010 to 2020, the value of ecosystem services in some areas increased, and the number of increasing ESV areas reached five townships, exceeding the number of decreasing ESV areas. During the whole study period, aside from the value of ecosystem services in Anfusi Town, which increased, all areas showed reductions in ESV.

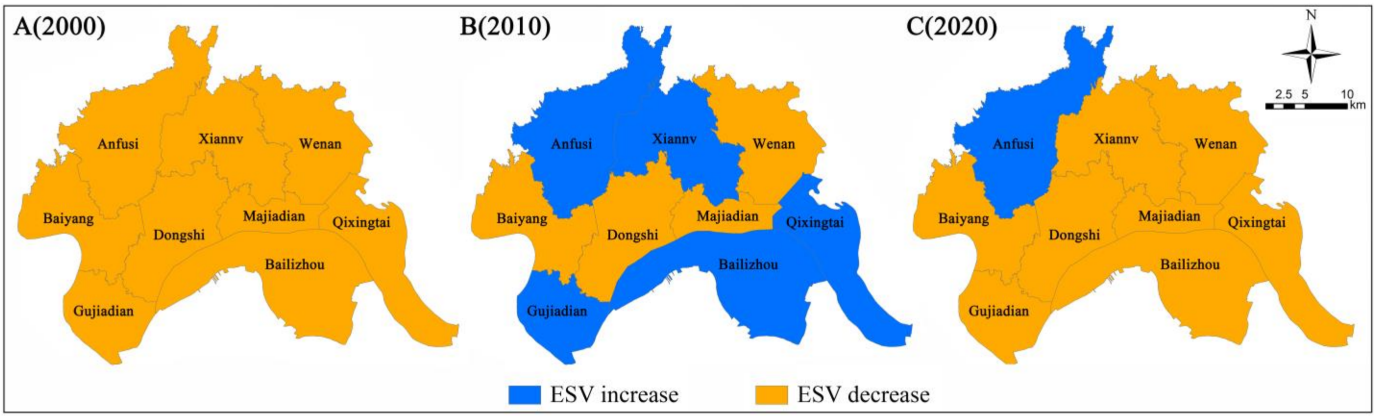

Figure 3. Distribution of and changes in ESV levels in the study area: (**A**) 2000; (**B**) 2010; (**C**) 2020.

3.2. Spatial Autocorrelation Analysis of Ecosystem Service Value

The vector data of 215 villages in Zhijiang City were intersected with the vector data of land use in 2000, 2010, and 2020 to derive the land use type and area of each village, which can then be used to calculate their ecosystem service values. Finally, these data were imported into the GeoDa software for spatial autocorrelation analysis.

According to the randomization results of 99,999 replacements, the Moran's I index of ecosystem service values in the study area in 2000, 2010, and 2020 were 0.217, 0.207, and 0.189, respectively. The z-values were 5.3039, 5.0608, and 4.6509, respectively, and the p-values were all 0.00001. Based on the z-value > 2.58 and p-value < 0.01, the confidence level was 99%, indicating high confidence in the results. The Moran's I indices of the three periods were all positive, indicating that the spatial distribution of ecosystem service values in the study area had a positive correlation. There were clusters of ecosystem service values, with correspondingly high ecosystem service values distributed around the high-value areas and relatively low ecosystem service values around the low-value areas, as well as a relatively balanced distribution. According to the change in the Moran's I index in the three periods, the global spatial autocorrelation of ecosystem service values showed a downward trend, indicating that the spatial aggregation trend of ESV in the study area gradually weakened from 2000 to 2020.

Global autocorrelation analysis can only judge whether the spatial distribution of elements is related, but cannot fully reflect the degree of spatial interconnection. Therefore, it is necessary to further study the spatial aggregation characteristics related to the accessibility of public cultural facilities using local autocorrelation (LISA). Through LISA cluster analysis, local spatial autocorrelation information concerning the accessibility of ecosystem service values in the study area can be obtained (Table 2). Over time, the number of low–low cluster villages decreased first and then increased, the number of high–high cluster villages gradually decreased, and the number of low–high cluster villages changed marginally. From a spatial distribution point of view, the areas with high ecosystem service values were mainly distributed along the Yangtze River Basin, namely, Guixihu Village in Baiyang Town; Qinglongshan Village, Renheyuan Village, and Xiongjiapeng Village in Gujiadian Town; Sanwangmiao Village and Yazikou Village in Qixingtai Town; Yanjiang Village, Bazhou Village, and Bao Yue Temple Village in Bailizhou Town; and Liangmeihuan Village and Ganlin Village in Dongshi Town. In 2020, the village in Majiadian Town, central Zhijiang City, changed from a high–high concentration area to an area with insignificant concentration, indicating that the spatial correlation of ecosystem service values in this area had weakened. The low–low concentration area of Anfusi Town gradually decreased to zero, indicating that the ecosystem service value of this area increased, which was consistent with the growth trend of the overall ecosystem service value of Anfusi Town. The low–low concentration areas in Bailizhou Town showed rapid growth, mainly because the area of construction land in these villages had been increasing year by year, resulting in a decrease in ecosystem service value.

Table 2. LISA cluster distribution of villages in the nine towns of Zhijiang City.

	Year	Anfusi Town	Baiyang Town	Bailizhou Town	Dongshi Town	Gudian Town	Madian street	Qixingtai Town	Wenan Town	Xiannv Town	Total
High–high	2000	0	1	3	3	3	4	1	0	0	15
	2010	0	1	2	3	3	3	1	0	0	13
	2020	0	1	3	3	3	0	2	0	0	12
Low–low	2000	6	1	1	4	2	0	0	4	3	21
	2010	3	0	4	3	0	0	0	1	2	13
	2020	0	0	9	5	0	1	0	1	5	21
Low–high	2000	0	1	1	1	3	1	2	0	0	9
	2010	0	1	2	1	3	0	2	0	0	9
	2020	0	1	1	1	3	0	2	0	0	8
High–low	2000	0	0	0	0	0	0	0	1	0	1
	2010	0	0	1	0	0	0	0	1	0	2
	2020	1	0	1	0	0	0	1	1	0	4

3.3. Changes of Landscape Pattern Index

Using Fragstats landscape index calculation software and the statistical function of Excel, a change table for the landscape pattern index of six land use types in Zhijiang City from 2000 to 2020 was obtained (see Table 3).

(1) With regard to quantity, among the six landscape types, the cultivated land patch type had the largest area and the smallest patch quantity; thus, the landscape fragmentation and separation degree were the smallest, and the dominance index was the highest. The small area of grassland, in spite of the largest number of patches assigned to this type, indicated that the spatial distribution of grassland was scattered, and so the calculated landscape fragmentation, separation, and loss were the highest. The landscape separation index, disturbance index, and loss index of wetland in 2020 were much higher than those for the other five landscape types. The main reason is that the wetland area decreased sharply in 2010–2020, leaving only 0.07 km^2 in 2020. The landscape loss index of construction land was the lowest, and the number of patches assigned to this type was small, indicating that the spatial distribution of construction land is concentrated, its landscape stability is the highest, and its anti-interference ability is strong.

(2) With regard to time, the landscape fragmentation index and separation index of cultivated land increased from 2000 to 2020, while the dominance index, disturbance index, and loss index first increased and then decreased around 2010, indicating that the spatial distribution of cultivated land tends to be discrete. The landscape fragmentation of water area and forest land gradually decreased, indicating that the landscape types gradually became concentrated in their regional distributions. The fragmentation indexes of wetlands, construction land, and grassland first decreased and then increased, indicating that the landscape patches gradually tended towards continuity from 2000 to 2010. However, after 2010, the landscapes of construction land, grassland, and wetlands were divided, and the fragmentation degree increased due to disorderly construction. The loss index of wetland

and grassland had increased obviously from 2010 to 2020, indicating that the ecological loss of grassland and wetland landscapes in Zhijiang City had become increasingly serious since 2010, and it should be paid more attention in future ecological protection strategies.

Table 3. Changes of landscape pattern index in Zhijiang City from 2000 to 2020.

	Year	Cultivated Land	Forest Land	Grassland	Water Area	Wetland	Construction Land
Landscape fragmentation degree	2000	0.0018	0.3633	0.6933	0.0340	0.0412	0.0141
	2010	0.0026	0.2912	0.6366	0.0340	0.0291	0.0093
	2020	0.0026	0.2829	0.6751	0.0235	0.3003	0.0111
Landscape separation degree	2000	0.0236	2.4067	3.6191	0.2959	2.1996	0.3480
	2010	0.0285	2.1372	3.7778	0.2959	1.1005	0.1954
	2020	0.0293	2.1801	4.1271	0.2382	39.3090	0.1646
Landscape dominance index	2000	0.6685	0.1267	0.1748	0.1961	0.0051	0.0508
	2010	0.6723	0.1130	0.1434	0.1961	0.0154	0.0929
	2020	0.6484	0.1028	0.1342	0.1845	0.0005	0.1530
Landscape disturbance Index	2000	0.1417	0.9290	1.4673	0.1450	0.6815	0.1216
	2010	0.1443	0.8093	1.4803	0.1450	0.3478	0.0818
	2020	0.1398	0.8160	1.6025	0.1201	11.9429	0.0855
Landscape vulnerability Index	2000	0.1905	0.0952	0.1429	0.2381	0.2857	0.0476
	2010	0.1905	0.0952	0.1429	0.2381	0.2857	0.0476
	2020	0.1905	0.0952	0.1429	0.2381	0.2857	0.0476
Landscape loss degree	2000	0.1643	0.2974	0.4578	0.1817	0.4413	0.0761
	2010	0.1658	0.2776	0.4599	0.1858	0.3152	0.0624
	2020	0.1632	0.2788	0.4785	0.1691	1.8472	0.0638

3.4. Ecological Risk Analysis

According to the formula, the ecological risk value of each grid unit was calculated, and then the ecological risk value was assigned to the center point of each grid via the element turning point. Finally, using the spatial analysis method of geostatistics, the spatial distribution map of ecological risk in the three phase of the study area was obtained via the Kriging interpolation method. According to the natural breakpoint method of the ArcGIS10.8 software and the characteristics of ecological risk data in the third phase, the ecological risk of Zhijiang City's landscape was divided into five grades: low-risk area (<0.12734), medium-low-risk area (0.12734~0.15166), medium-risk area (0.15166~0.16875), medium-high-risk area (0.16875~0.19044), and high-risk area (>0.19044). The results are shown in Figure 4.

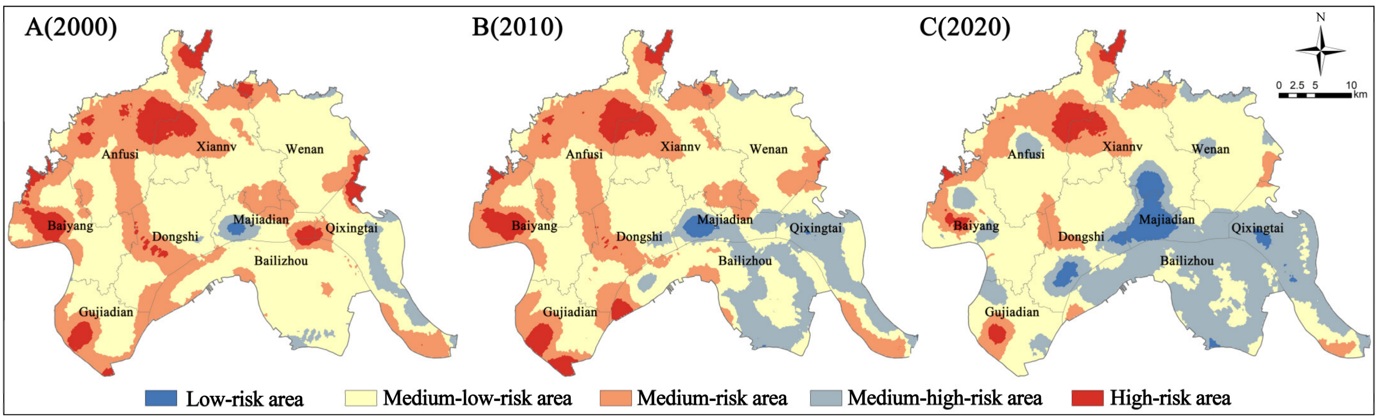

Figure 4. Distribution of ecological risk levels in Zhijiang City: (**A**) 2000; (**B**) 2010; (**C**) 2020.

In 2000, 2010, and 2020, the average ecological risk indexes of Zhijiang City were 0.1697, 0.1665, and 0.1577, respectively, showing a gradual downward trend. (1) In terms of the area ratio, the area of high-risk and medium-high-risk areas gradually decreased from 97.46 km^2 and 399.98 km^2 in 2000 to 41.63 km^2 and 194.95 km^2 in 2020, respectively. The low-risk and medium-low-risk areas were gradually increasing, with the medium-low-risk areas being the most obvious, and with the area ratio rising from 3.87% in 2000 to 28.64% in 2020. (2) In terms of spatial distribution, the high-risk areas and medium-high-risk areas were mainly distributed in grassland areas with significant landscape losses in the northwest and southwest, while low-risk areas and medium-low-risk areas were mainly distributed near construction land, with small landscape losses along the Yangtze River Valley in southeast China. (3) In terms of temporal and spatial changes, the medium-high-risk areas showed a decreasing trend in circles during the study period, the medium-low-risk areas continued to expand to both sides of the Yangtze River Basin, and the low-risk areas showed a distribution trend ranging from single-center to multi-center. (4) According to the division of administrative regions, the low-risk areas were mainly distributed in Shuangshouqiao Village in the west of Majiadian Town in 2000 and 2010, and by 2020, they had expanded from Shuangshouqiao Village to Zhache Village, Shejiaxi Village, Planned Village, Tengjiahe Village, Yandunbao Village, and Xiannv Village in the south of Xiannv Town, and Ganlinsi Village, Liangmeihuan Village, and Yaojiagang in the south of Dongshi Town.

3.5. Priority of Ecological Compensation

Using ArcGIS, the ecosystem service value index and the ecological risk score were weighted and superimposed, and the statistics represented the town area. The results and the average GDP of each town area were substituted into the formula, and the ecological compensation priority index of each town in the study area was obtained. In order to analyze the spatial distribution characteristics of ecological compensation priorities in the study area more intuitively, a grading chart (Figure 5) was drawn according to the natural best breaking point grading method which divided the different areas into five grades. The higher the grade, the higher the ecological compensation priority and the greater the urgency of ecological compensation.

The area with an ecological compensation priority of five was Gujiadian Town, and Baiyang Town had an ecological compensation priority of four. The values of ecosystem services in these two towns are high, and the protection of the ecological environment limits the economic development, which leads to the relatively low level of regional economic development, a low GDP, and a high ecological risk index. Therefore, ecological compensation should be given priority. Bailizhou Town has a low priority, mainly because its ESV is the highest, but its ecological risk is low and its economic development level is high. Ecological protection places little restriction on economic development here, so it does not require urgent ecological compensation. Majiadian Town has the lowest ESV and ecological risk, but its economic development is good, so its ecological compensation priority is the lowest.

Regarding the change in the ecological compensation priority of each township, although the overall ranking of each township did not change much, the priority of ecological compensation gradually increased with the passage of time. Xiannv Town and Anfusi Town changed the most, increasing from 0.76502 and 0.60072 in 2000 to 0.95627 and 0.75090 in 2020, respectively. According to the distribution results of the three phases, Gujiadian Town, Baiyang Town, Qixingtai Town, and Majiadian Town consistently took the fifth, fourth, third, and first places in terms of compensation. Wen'an Town, in the northeast, became the second-level compensation area after 2010, and returned to third place in 2020; Bailizhou Town was ranked first in 2000 and 2010, and reached second in 2020. The priority of ecological compensation in Ansi Town rose from second in 2000 to third in 2010. This shows that Gujiadian Town, in the south of Zhijiang City; Baiyang Town, in the west; and Xiannv Town, in the central northern part of the country should be offered ecological compensation first. The economies of Bailizhou Town and Anfusi Town developed rapidly after 2010, which caused damage to the ecological environment and increased the pressure on ecological protection. Therefore, ecological compensation should be paid actively. Majiadian Town's ESV and ecological risk index are low, and its contribution to ecological protection is relatively small, so the urgency of ecological compensation is the lowest in this area.

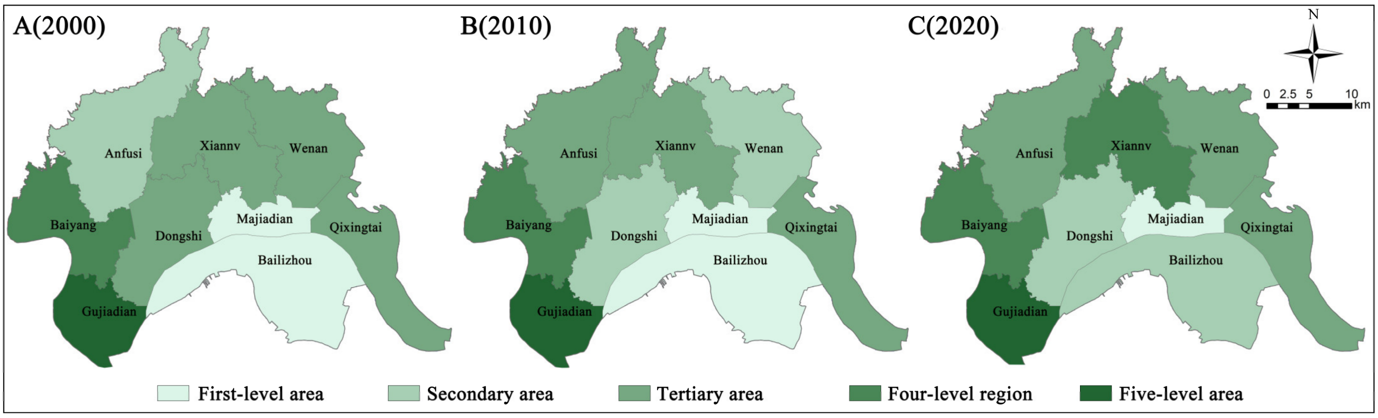

Figure 5. Classifying map of ecological compensation priority sequence of Zhijiang City. (**A**) 2000; (**B**) 2010; (**C**) 2020.

4. Discussion

The Yangtze River Basin, which spans the three major economic regions in the east, middle, and west of China, is the third largest river basin in the world, and is rich in natural resources. The Yangtze River Economic Belt, with a population and economic aggregate of more than 40% of the country, is an inland economic belt with global influence and a leading demonstration belt for the construction of ecological civilization. Therefore, the Yangtze River Basin has a very high ecological value and economic status [45]. Archiving the organic unity of economic development and ecological civilization construction is the primary prerequisite for the development of the Yangtze River Basin. Although the quality of the water-based ecological environment in the Yangtze River Basin has been greatly improved in recent years, the ecological environments in some cities are still poor [46]. Large amounts of urban industrial wastewater discharge, a concentration of the "three phosphorus" enterprises, and substantial regional chemical contamination are all characteristics of Yichang City [47]. Meanwhile, its ecological environmental quality has gradually deteriorated [48]. The most downstream portion of the Yangtze River Basin in Yichang City is Zhijiang City, which is situated in the southeast corner. Zhijiang City's performance, in terms of ecological safety monitoring, is a key protector of the ecological environment of the middle and lower reaches of the Yangtze River and nearby cities. According to the findings of this paper, Zhijiang City actively embraces Xi Jinping's concept of an ecological civilization, and has worked to advance the Yangtze River governance and protection project. As a result, Zhijiang City has shown gradual improvement in the overall quality of its ecological environment.

The spatiotemporal analysis of the ecological risks of various landscapes can help to monitor and identify potential risks, as well as to provide a decision-making basis for the scientific management of land resources and the sustainable development of the ecological environment [49]. At present, the ecological risk assessment method based on land use is one of the most widely used in the field of ecological risk assessment. The majority of the current research on the value of ecosystem services and ecological risks, both domestically and internationally, has been large-scale, at the global [50], national [51], provincial [52], municipal [53] and watershed levels [54]. Theoretical bases for measuring the value of ecosystem service functions and ecological risk in specific regions are lacking, and the research on ecological compensation mechanisms based on medium and small geospatial scales is still relatively scarce. According to this study, the spatiotemporal evolution characteristics of ecosystem service value in Zhijiang City are basically consistent with the temporal and spatial change trends of ecosystem service value in Yichang City [55].

In Zhijiang City, the value of ecosystem services is generally declining; however, there are several exceptions to this tendency. The negative ecosystem service value of construction land has rarely been taken into account in previous research on ecosystem service value equivalents [56], and this may have resulted in discrepancies in the total value of ecosystem services in Zhijiang City. On the other hand, the construction of a landscape ecological risk assessment model based on land use data has been consistent with the study of landscape ecological security in Yichang City [57], and the ecological risk index of Zhijiang City has been shown to be similar. Furthermore, the research findings of Chen et al. [57] have demonstrated that Zhijiang City's land use type is primarily agricultural, its landscape is highly fragile, and human activities have had a significant impact on it, all of which are compatible with the findings of this paper. The landscape ecological security level distribution map that they derived does, however, differ from that in this research due to distinctions between their classification of landscape ecological security levels in Yichang City and ours. In terms of ecological compensation priority measurement, the research that is currently available on ecological compensation standards analyzes the urgency of ecological compensation based only on the value of ecosystem services [58]. In this study, the ecological security level of the region was evaluated more deeply and comprehensively. The ecological risk index and the value of ecosystem services were superimposed, and by combining economic indicators, the priority of ecological compensation was jointly determined so as to enhance the process of identifying ecological compensation spaces.

4.1. Research Significance

According to the findings of this study, the value of ecosystem services in Zhijiang City shows clear spatial aggregation features. The value of ecosystem services is lowest in Anfusi Town and Xiannv Town in the northwest, while it is highest in Gujiadian Town and Majiadian Town in the southern regions of the Yangtze River Basin. When comparing land use types in high- and low-ESV areas, we discovered that high-ESV locations contain a disproportionately large share of the water area. When combined with the ESV equivalent scale, it can be seen that water area makes the highest contribution to ecosystem service value, and this is more than 10 times greater than the adverse ecological effects of construction land. In order to minimize the negative value of construction land, it is necessary to use the water area as an ecological reserve in future urban construction, and to strictly restrict its development and utilization. We must also make sure that established water areas are retained in the process of construction land expansion. On the whole, the ecological risk index of Zhijiang City declined throughout the study period. The low-ecological risk region was widely distributed across the southern construction land, with less vegetation cover, and its area increased over time at a significant rate. However, the spatial distributions of high-ecological risk areas, forest lands, and grasslands were obviously consistent. The areas of grassland and wetland in Zhijiang City were found to be very small, especially after 2010, when the wetland area decreased sharply and the proportion of high-ecological risk area decreased significantly. Zhijiang City's wetlands must be protected in future land use planning, since they are the most ecologically vulnerable and are exceptionally rich in species diversity. Their economic value can also be increased by developing wetland parks. Gujiadian Town is a uniquely green, ecological peninsula to the southwest of the Zhijiang River, with a forest coverage rate of 62%. Additionally, it is located upstream, in the Yangtze River Basin's Zhijiang sector, making its ecological security even more crucial. Gujiadian Town has the highest priority in terms of compensation, according to the results of the ecological compensation priority calculation we undertook. Even though Gujiadian Town has a high ecosystem service value, its economic development is still comparatively low. The establishment of an ecological product value realization mechanism is a key strategy for converting ecological benefits into economic benefits and resolving the conflict between ecosystem health and urban development. Meanwhile, the value of ecological products can be realized in six ways: ecological compensation, ecological agriculture industry development, ecological tourism industry development, carbon sink trading, green fund development, and ecological healthcare industry development.

The Yangtze River Basin has a vast territory, a complex geographical environment, uneven development foundations, and a unique ecological status. Environmental issues have developed and become significant in this region over time. In future ecological environmental protection and ecological risk control efforts in cities in the Yangtze River Basin, more attention must be paid to the impact of regional environmental changes and human factors on ecological risks. We must also actively pursue the establishment and enrichment of a value realization mechanism for ecological products; adopt unique, multi-adjustment solutions to satisfy the needs of the regional natural environment and the sustainable development of the social economy; and protect local ecosystems from interference and the effects of natural and societal factors. Therefore, this paper can serve as a scientific reference for reducing ecological risks and restoring habitats in cities along the Yangtze River Basin, as well as realizing high-quality urbanization of these areas.

4.2. Limitations

Although the impacts of external factors on an ecological environment can be partially reflected by an objective assessment of the ecological risk in the study area from the perspective of landscape ecology, there are still some limitations. First, the interpretation of remote sensing image data determines the outcomes of landscape ecological risk assessments. Land use classification errors are inevitable, so the use of high-precision land use data can improve the credibility of the results. Secondly, this paper only briefly explores the temporal and spatial evolution pattern of landscape ecological risk, and does not analyze the complex driving forces behind it. As a result, the drivers of ESV and the spatiotemporal changes of ecological risk should be taken into consideration in future research [59]. In future studies, more comprehensive and in-depth research can be carried out to address influencing factors. Furthermore, the ecological compensation priority of the study area was calculated on the basis of the value of ecosystem services and the ecological risk index alone, without taking into account the perception and willingness of various stakeholders [60]. How to use multi-source remote sensing and socio-economic data, combined with the responsibility and willingness of stakeholders in relation to building a more comprehensive ecological compensation system, will be an important area of focus for future regional landscape ecological security assessments and research.

5. Conclusions

The development of the natural environment in the Yangtze River Basin has seriously affected the landscape ecological security pattern of surrounding cities. From the perspective of the coupling relationship between the landscape pattern and ecological risk, this study constructed an ecological risk assessment model using a landscape pattern index to deeply explore the temporal and spatial evolution characteristics of ecological risk in Zhijiang City, and analyzed the ecological compensation combined with the ESV and economic data of Zhijiang City.

(1) From 2000 to 2020, the ESV of the study area showed obvious regional characteristics in terms of the spatial distribution, and the ESVs of towns along the Yangtze River valley in the south were generally higher than those in the north. High-ESV areas are mainly distributed in the south along the Yangtze River, while low-ESV areas are mainly distributed in the central and northeastern areas, where construction land is concentrated. Overall, the ESV of the entire study area has shown a downward trend.

(2) On the whole, the number and density of landscape patches in Zhijiang City decreased year by year from 2000 to 2020, indicating that the landscape pattern gradually tended towards singular integration. Among the six landscape types in the study area, cultivated land represents the largest landscape patch area, the highest landscape dominance index, and the lowest landscape loss index. From 2010 to 2020, wetland and grassland landscapes showed significant losses.

(3) From 2000 to 2020, the ecological risk degree of Zhijiang City decreased, and the global average ecological risk decreased from 0.1697 in 2000 to 0.1577 in 2020. The high-risk areas and medium-high-risk areas showed gradual reductions, and were mainly distributed in western Zhijiang City, represented by grassland and forest land areas. The low-risk areas and medium-low-risk areas showed gradual increases, concentrated in Majiadian Town along the Yangtze River in the southeast.
(4) We used ESV and the ecological risk index to comprehensively measure the ecological environment of the study area, and determined the priority of regional ecological compensation of each township using the ratio of GDP per unit area. The towns with the highest priority were Gujiadian Town and Baiyang Town, and the lowest priority was held by Majiadian Town. Generally speaking, the priority for ecological compensation of each township changed little during the study period.

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