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Coupling Analysis of Ecosystem Services Value and Economic Development in the Yangtze River Economic Belt: A Case Study in Hunan Province, China

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Abstract: Sound ecosystems are a precondition for the sustainable survival and development of human society. However, ecological deterioration caused by socioeconomic activities can result in increasing pressure on ecosystems. Exploration of the spatial interaction between ecosystem and economic development under the background of high-quality and green development is, therefore, necessary. In this study, we analyzed the spatial interaction between the ecosystem services value (ESV) and economic development with the economic and ecological coupling index method based on high-resolution remote-sensing land-use data and socioeconomic statistical data in Hunan Province from 2000 to 2018. The results revealed that the ESV provided by the ecosystems in Hunan Province decreased by US$1256.166 million from 2000 to 2018. The areas with high ESV per unit area were distributed in the mountainous areas, while the areas with low ESV per unit area were distributed in the major cities and their surroundings. The bivariate spatial autocorrelation analysis showed that the ESV had significant spatial dependence on the economic development. In addition, the coupling analysis documented that the relationship between the ESV and economic density was mostly in the low conflict and potential crisis states. These results provide important guidance for the coordinated development of the regional economy and ecosystem conservation.

Keywords: ecosystem services value; sensitivity analysis; economic development; bivariate spatial autocorrelation analysis; coupling analysis; Hunan province; China

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1. Introduction

Coordinating economic development and ecological conservation in fast-growing areas is an essential method of regional sustainable development [1,2]. The sustainable supply capacity of ecosystem services is affected by socioeconomic activities, often resulting in the severe degradation of ecosystem functions in the process of regional economic development [3,4]. To promote a coordinated relationship between economic development and ecological conservation, it is necessary to analyze the spatial interaction between ecosystem services and regional economic development [5,6].

However, few previous studies have explored the coupling degree between ecosystem services and economic development. Facing the increasingly severe global issues of population explosion, food scarcity, resource exhaustion, and ecological degradation, clarifying the relationship between ecological conservation and economic development has attracted increasing attention [7,8]. In this situation, it is important to analyze the relationship between ecosystem services and economic development for a better understanding of the impact of socioeconomic activities on ecosystem services. This has excellent policy implications for the adjustment of land-use structures and the improvement of land allocation efficiency and ecosystem protection. It also is a realistic choice to realize the coordination and optimization of regional economic development and ecological conservation.

The monetary evaluation method of ecosystem services value (ESV) has greatly promoted the evaluation of ecosystem services globally [9]. An increasing number of studies have attempted to evaluate the ESV at different scales, including the global scale, national scale, and regional scale with the monetary evaluation method of ESV [9,10]. The evaluation methods, theories, and concept connotations of ESV have been greatly enriched and expanded [9,11–13]. For example, Xie et al. [14] revised the classification and equivalent table of ESV proposed by Costanza et al. [9] based on the actual situation of ecosystems combined with expert knowledge in China.

In addition, the evaluation method and equivalent table of ESV have been further revised based on the existing studies and combined with factors, such as the biomass and consumption level [15–17]. A series of models have been proposed, such as InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) [18], ARIES (Artificial Intelligence for Ecosystem Services) [19], MIMES (Multi-Scale Integrated Models of Ecosystem Services) [19], SolVES (Social Values for Ecosystem Services) [20], EcoAIM (Ecosystem Services Asset, Inventory, and Management) [21], and ESValue (Valuing Ecosystem Services) [22,23], to explore ecosystem services evaluation from different aspects. InVEST, ARIES, and MINMES models can be applied to the global scale, river basin, or landscape scale through simplification of the algorithm mostly focusing on ecological data, with strong generalization [22]. The SolVES model has a high applicability under the condition that the original survey data are available or the value transformation results are acceptable, while the EcoAIM and ESValue models are poor in generalization and are mainly applicable to the value assessment of ecosystem services in specific regions [24].

At present, a considerable number of studies on ecosystem services are emerging with great progress and rich achievements in the evaluation, tradeoff, influencing factors, supply, demand, balance, flow, classification, formation, and impact mechanism aspects of ecosystem services, and the relationship with human social welfare, as well as interrelations and interactions between different ecosystem services, which, in recent years, have been the hot topics and frontier issues in ecosystem services research [25–31].

Previous studies have proved that ESV can partly reflect the process of interaction, interrelationships, and collaborative evolution between land use and ecosystem as well as the close interaction between land use and economic development [32–34]. As a bridge and link of coupling natural and social process, ecosystem services provide new theoretical support for the study of the coupling of human and natural systems [32]. The relationship between economic and ecological systems is complicated [3,35].

For example, economic development can improve the ecosystem services capacity through the scale effect, optimization of the industrial structure, and improvement of the population quality and management level. In addition, economic development can also cause the degradation of ecosystem services (e.g., biodiversity decline, ecosystem degradation, soil erosion, and desertification) through population growth, resource consumption, and construction land expansion [36].

A good ecosystem can provide the necessary material conditions, such as water and fresh air to support the sustainable development of socioeconomic activities. However, a weak ecosystem would lead to the decline of living environment quality, the decrease of regional investment environment competitiveness, the low supporting capacity of ecological elements, and the frequent occurrence of disaster events, thus, slowing down or restraining economic development [5,6,8,37]. Specifically, supplying services can provide the necessities of life, regulating services can purify the environment and prevent water and soil loss, cultural services can increase residents' sense of belonging and happiness, and supporting services can provide biological habitats, increase biodiversity, support the biogeochemical cycle, pollination, and energy transmission [38].

If the pressure of socioeconomic development on the ecosystem exceeds the maximum bearing capacity of the ecosystem, this could cause the collapse of the natural ecosystem and threaten the survival of human society [39]. Therefore, how to quantitatively evaluate the pressure of economic development on an ecosystem, how to reduce the pressure, and how to coordinate the economic and ecological benefits are important issues in sustainable development. Previous studies have made efforts to explore the relationship between economic development and ecosystem services, but most of the existing studies were limited to one-way research of a single factor and lacked analysis of the coupling degree of ESV and regional economic development, particularly the spatial differentiation rules of their coupling and coordination characteristics.

The Kuznets inverted U-curve is commonly used to describe the relationship between economic growth and environmental protection, which suggests that economic development, especially in the early stages, was often involuntarily at the expense of natural resources [40]. How can we free regional development of the "resource curse" and realize ecological value-addition and economic growth? The mutual growth of ESV and the gross domestic product (GDP) is the goal and direction of current socioeconomic development.

Although previous studies have made continuous ESV measurement progress, few studies have directly reflected the spatiotemporal evolution pattern of ESV by drawing a dynamic map of the ESV for a specific region and analyzed the spatial interaction relationship between the ESV and regional economic development [2]. Identifying the relationship between ESV and regional economic development not only can reveal this interaction but can also provide a differentiated basis and reference for local ecological protection decision-making and economic development planning.

From the perspective of coupling analysis, this study chose Hunan Province, an important province in the Yangtze River Economic Belt and the Rise of Central China strategies, as a study case to analyze the coupling relationship between ESV and regional economic development. Geographically, Hunan Province is located in the transition zone between the eastern coastal region and central and western China, with the regional advantages of the junction of the Yangtze River Economic Belt and the Coastal Open Economic Belt.

In the process of rapid economic development and urbanization, the contradiction between the natural ecosystem and the socioeconomic system is increasingly severe. Therefore, it is necessary to explore the coordinated development level and spatial differences between ecosystem services and regional economic development. The research on the interaction mechanism and evolution rule of ESV and economic development can provide scientific references for the rational allocation of land resources. To this end, this study set four research objectives as follows:

(1) to evaluate the spatiotemporal characteristics of ESV in Hunan Province from 2000 to 2018;
(2) to explore the spatiotemporal characteristics of the ESV sensitivity in Hunan province from 2000 to 2018;
(3) to measure the bivariate spatial autocorrelation relationship between the ESV and economic development level in Hunan Province from 2000 to 2018; and
(4) to analyze the spatiotemporal evolution characteristics of the coupling relationship between the ESV and economic development of Hunan Province from 2000 to 2018.

2. Materials and Methods

2.1. Study Area

Hunan Province is located in the middle reaches of the Yangtze River Economic Belt (108°47′–114°13′E, 24°39–30°08′N) (Figure 1), the administrative area is 211,739.605 km^2. The terrain of Hunan Province belongs to the transition zone from Yunnan-Guizhou Plateau to Jiangnan Hills and from Nanling Mountains to Jianghan Plain. Hunan Province is surrounded by mountains in the east, west, and south, and gradually inclines to the middle and northeastern. Hunan Province is in the continental subtropical monsoon humid climate, characterized by cold and dry winters, hot and rainy summers, rainy springs with changeable temperature, and dry autumns with a sudden temperature drop.

The gross domestic product (GDP) of Hunan Province increased from RMB 355.149 billion in 2000 to RMB 3642.578 billion in 2018, accounting for 3.682% in 2000 and 4.046% in 2018 of the national GDP. The GDP per capita increased from RMB 5425 in 2000 to RMB 52,949 in 2018, which were both lower than the national averages (RMB 7942 in 2000 and RMB 64,644 in 2018, respectively). The population urbanization rate increased from 29.75% in 2000 to 56.02% in 2018, which were also both lower than the national urbanization rates (36.22% in 2000 and 59.58% in 2018, respectively).

From 2000 to 2018, the proportion of added value of the primary industry, secondary industry, and tertiary industry of Hunan Province changed from 22.101:36.412:41.487 to 8.465:39.679:51.855, with a significant increase in the proportion of added value of the secondary industry and the tertiary industry. With the implementation of the "Rise of Central China" strategy, the "Two-Oriented Society" comprehensive supporting reform experimental area, and other policies, the socioeconomic development of Hunan Province has increased significantly. The rapid development of the socioeconomic activities intensified the land use activities and increased the risk of ecosystem functions being damaged and weakened.

Under the comprehensive influence of topographic and geomorphic conditions, the spatial pattern of Hunan's economy was significantly different. The relatively developed areas, such as the Changsha–Zhuzhou–Xiangtan urban agglomerations, presented a rapid economic development, while the less developed areas, such as the western part of Hunan province, had a relatively low economic growth rate [41,42]. Therefore, it is of great practical significance to analyze the spatiotemporal coupling relationships between the ESV and economic development in Hunan Province.

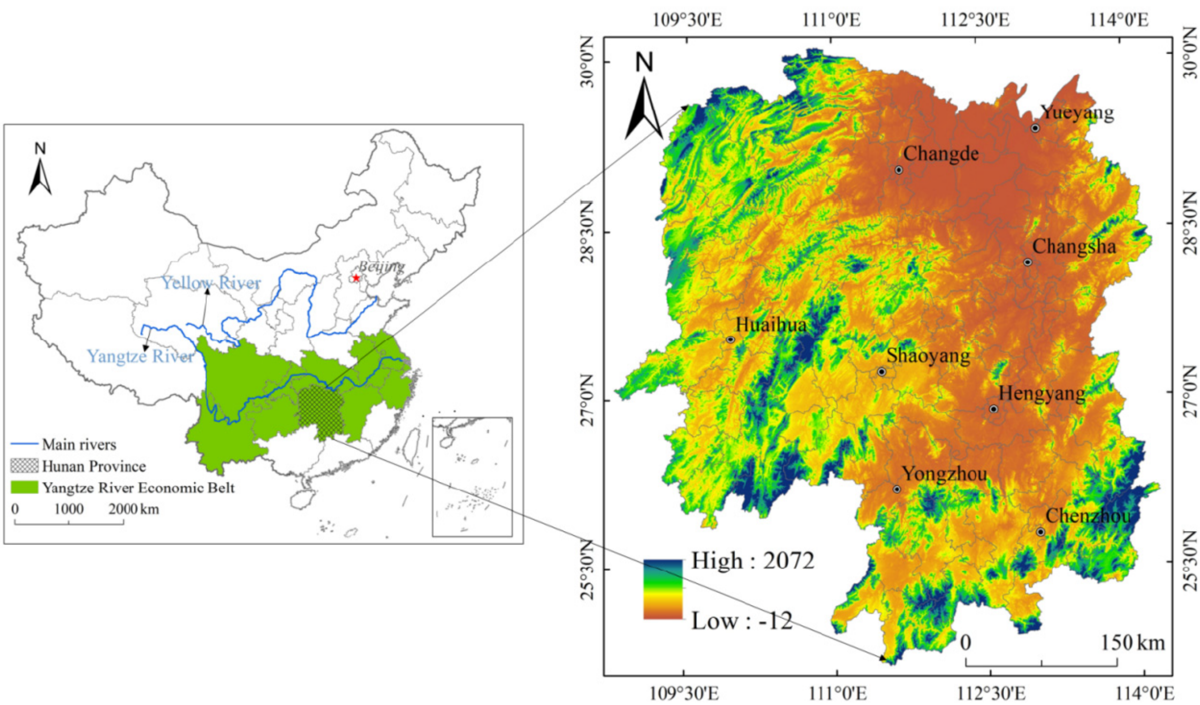

Figure 1. Location of the study area.

2.2. Data Sources and Preprocessing

The 30 × 30 m spatial resolution land use remote sensing monitoring data in 2000, 2005, 2010, 2015, and 2018 used in this study were downloaded from the Data Center for Resources and Environmental Sciences of the Chinese Academy of Sciences (http://www.resdc.cn/DataList.aspx, accessed on 14 April 2021) [43–45]. The land use data were reclassified into seven categories using ArcGIS10.3, including cultivated land, construction land, water area, wetland, unused land, forestland, and grassland (Figure 2). GDP is a vital indicator to reflect the level of economic development.

The total GDP growth reflects the comprehensive strength of regional development. Both the GDP statistics and the data of grain yield per unit area of 2000, 2005, 2010, 2015, and 2018 in this study were obtained from the *Hunan Statistical Yearbooks* of the corresponding years. The data of grain price came from the *China Yearbook of Agricultural Price Survey 2016*.

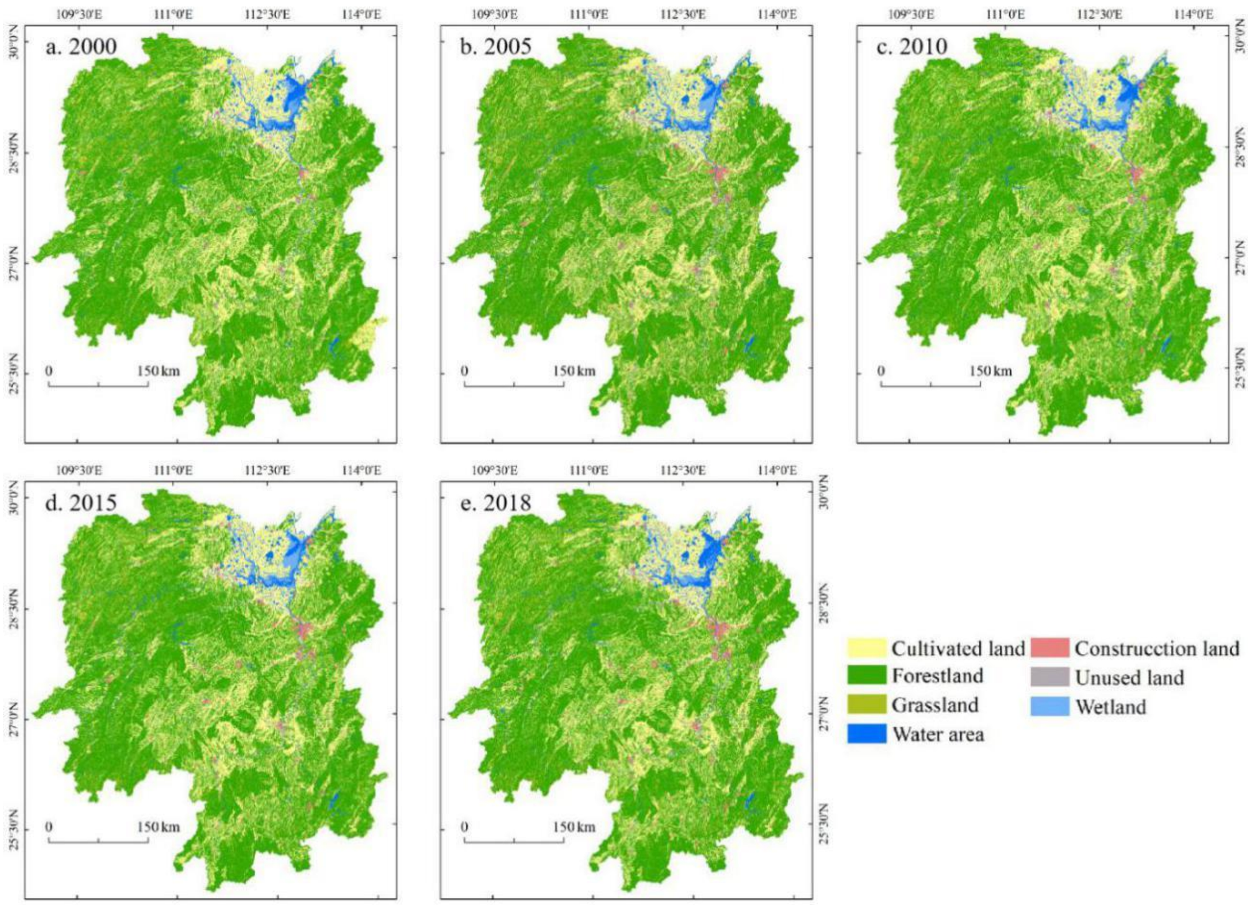

Figure 2. Spatial pattern of land use in Hunan Province from 2000 to 2018.

2.3. Methods

To explore the coupling relationship between the ecosystem services value and economic development in Hunan Province from 2000 to 2018. This study first analyzed the land-use and land-cover change characteristics and measured the ESV using the land-use and -cover change data in Hunan Province from 2000 to 2018 [14,46–49]. Then, the spatial pattern of the sensitivity coefficients of different land use types in Hunan Province in 2018 was determined to verify the feasibility of the evaluation results [50–52]. The spatial interactions between the ESV and economic development were measured by bivariate spatial autocorrelation models [53,54]. The coupling pattern of the ecosystem services value and economic development in Hunan Province from 2000 to 2018 was ultimately analyzed with the economic and ecological coupling index method [1,55]. The framework of this study is presented in Figure 3.

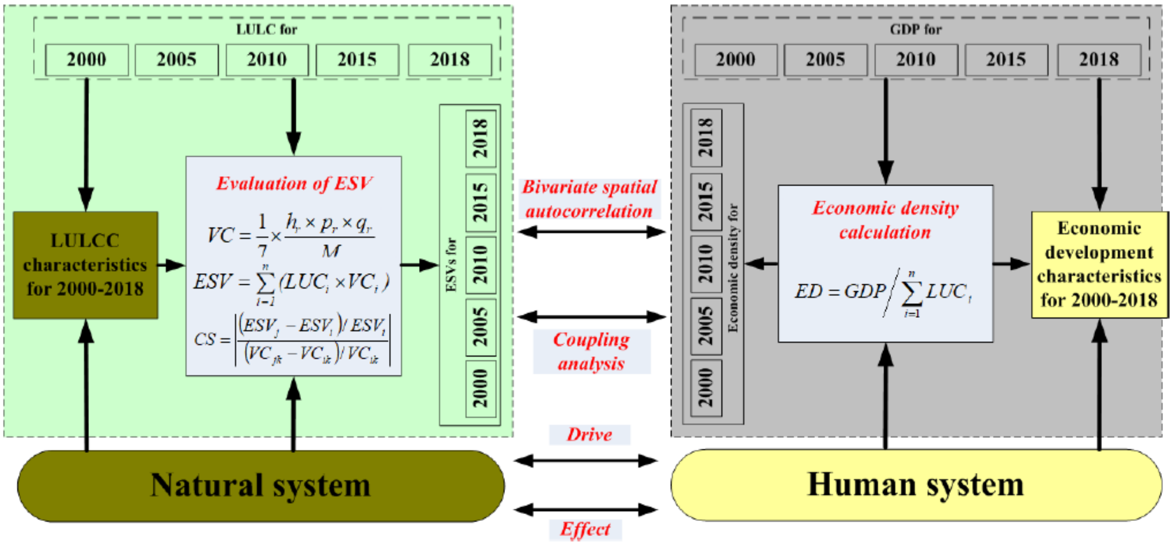

Figure 3. Framework of this study.

2.3.1. Measurement of the Ecosystem Services Value

Xie et al. [14,47] conducted questionnaire surveys on 200 and 500 ecological experts in 2002 and 2007, respectively. They revised the ecosystem services classification and equivalent table according to China's specific situation based on the study of Costanza et al. [9]. Specifically, the equivalent factor of ESV was defined as 1/7 of the cultivated land's annual grain economic value. Through field research and investigation, they determined that rice was the main grain crop in Hunan Province.

Therefore, the economic value of the ESV equivalent factor in Hunan Province was examined by the rice yield per unit area and rice price. From 2000 to 2018, the rice yield per unit area of Hunan Province was 6293.146 kg/hm^2, and the average price of rice was RMB 2.02/kg. We can calculate that the equivalent value per unit area of ESV in Hunan Province was RMB 1816.022/(hm^2·a).

Construction land was generally considered not to provide ESV in previous studies; however, some studies considered that construction land also provided ESV (e.g., entertainment culture or soil conservation functions). Referring to previous studies, this study considered that construction land provided ESV [46,48,49]. The equivalent value per unit area of ESV and values per unit area of ESV in Hunan Province are, respectively, shown in Tables 1 and 2. The specific equations are as follows:

$$VC = \frac{1}{7} \times \frac{h_r \times p_r \times q_r}{M} \quad (1)$$

$$ESV = \sum_{i=1}^{n} (LUC_i \times VC_i) \quad (2)$$

$$AESV = \frac{\sum_{i=1}^{n} (LUC_i \times VC_i)}{\sum_{i=1}^{n} LUC_i} \quad (3)$$

where ESV represents the ecosystem services value (RMB), LUC_i represents the area of land use type i (hm^2), VC_i is the ESV equivalent coefficient of land use type i (RMB/(hm^2·a)), and n is the number of regional land use types. h_r, p_r, and q_r are, respectively, the sown area of rice, the average price of rice, and the per unit area yield of rice. M is the sown area of rice. $AESV$ represents the average ecosystem services value, which is calculated by dividing the ESV by the administrative area.

Table 1. Equivalent value per unit area of ecosystem services in Hunan Province.

Categories	Sub-Categories	Forestland	Grassland	Cultivated Land	Wetland	Water Area	Unused Land	Construction Land
Supplying services	Food production	0.33	0.43	1	0.36	0.53	0.02	0.01
	Raw material	2.98	0.36	0.39	0.24	0.35	0.04	0
Regulating services	Gas regulation	4.32	1.5	0.72	2.41	0.51	0.06	−2.42
	Climate regulation	4.07	1.56	0.97	13.55	2.06	0.13	0
	Hydrological regulation	4.09	1.52	0.77	13.44	18.77	0.07	−7.51
	Waste treatment	1.72	1.32	1.39	14.4	14.85	0.26	−2.46
Supporting services	Soil formation and retention	4.02	2.24	1.47	1.99	0.41	0.17	0.02
	Biodiversity protection	4.51	1.87	1.02	3.69	3.43	0.4	0.34
Cultural services	Recreation and culture	2.08	0.87	0.17	4.69	4.44	0.24	0.01
Total equivalent value		28.12	11.67	7.9	54.77	45.35	1.39	−12.01

Notes: Equivalent value in this study were sourced from Xie et al., 2008 and Ye et al., 2018.

Table 2. Ecosystem services value (ESV) per unit area after correction in Hunan Province. [dollars/(hm^2·a)].

Categories	Sub-Categories	Forestland	Grassland	Cultivated Land	Wetland	Water Area	Unused Land	Construction Land
Supplying services	Food production	96.218	125.376	291.571	104.966	154.533	5.831	2.916
	Raw material	868.882	104.966	113.713	69.977	102.050	11.663	0.000
Regulating services	Gas regulation	1259.588	437.357	209.931	702.687	148.701	17.494	−705.602
	Climate regulation	1186.695	454.851	282.824	3950.790	600.637	37.904	0.000
	Hydrological regulation	1192.526	443.188	224.510	3918.717	5472.791	20.410	−2189.700
	Waste treatment	501.502	384.874	405.284	4198.625	4329.832	75.809	−717.265
Supporting services	Soil formation and retention	1172.116	653.119	428.610	580.227	119.544	49.567	5.831
	Biodiversity protection	1314.986	545.238	297.403	1075.898	1000.089	116.628	99.134
Cultural services	Recreation and culture	606.468	253.667	49.567	1367.469	1294.576	69.977	2.916
Total ESV		8198.982	3402.636	2303.413	15,969.355	13,222.754	405.284	−3501.770

Notes: 100 dollars could be exchanged for RMB 622.84 in 2015.

2.3.2. Sensitivity Analysis

Sensitivity analysis was used to verify the elasticity between the "total ESV" and "equivalent value coefficient (*VC*)" of various land use types, which was an indispensable part of the ESV estimation [50,51]. If the elasticity was less than 1, this meant that ESV lacks elasticity to *VC*, and the evaluation result was reliable. If the elasticity was greater than 1, this meant that ESV was elastic to *VC*.

In this study, the concept of elasticity in economics was adopted to verify the sensitivity of the total ESV to the local *VC* of various land-use types [52]. The dependence of ESV on *VC* factors was determined by adjusting up and down 50% of the seven land-use types' equivalent factors. The specific calculation equation is as follows:

$$CS = \left| \frac{\left(ESV_j - ESV_i\right)/ESV_i}{\left(VC_{jk} - VC_{ik}\right)/VC_{ik}} \right| \tag{4}$$

where CS is the sensitivity coefficient. ESV_i and ESV_j represent the ecosystem services value before and after adjustment, respectively. VC_{ik} and VC_{jk} represent the equivalent value factor of the kth land-use type before and after adjustment, respectively.

2.3.3. Spatial Autocorrelation Test

The bivariate Moran's *I*, including the global bivariate spatial autocorrelation and local bivariate spatial autocorrelation was used to analyze the spatial agglomeration and spatial dispersion pattern between the ESV and economic development in this study [54]. The global spatial autocorrelation was used to detect the spatial autocorrelation of the economic development and ESV in the whole region.

The local bivariate spatial autocorrelation was used to detect the spatial autocorrelation of different units. The global Moran's *I* index ranges from −1 to 1. A negative Moran's *I* value represents a negative correlation between the economic development and ESV, and a positive Moran's *I* value represents a positive correlation between the economic development and ESV. If Moran's *I* approaches zero, this indicates that the discrete distribution exists between economic development and ESV. Permutation tests (9999) were used in this study for the statistical significance assessment [53].

2.3.4. Coupling Analysis

To study the coupling relationship between the ESV and economic development, we introduced a coupling index to describe the coupling relationship between the economic development and ESV and to reflect the coupling degree between the ESV and economic development caused by land use [1,55]. The specific calculation equations are as follows:

$$CEE = \frac{ESV_{pr}}{GDP_{pr}} \tag{5}$$

$$ESV_{pr} = \frac{ESV_{pj} - ESV_{pi}}{ESV_{pi}} \tag{6}$$

$$GDP_{pr} = \frac{GDP_{pj} - GDP_{pi}}{GDP_{pi}} \tag{7}$$

where *CEE* represents the coupling index between ESV and economic development. ESV_{pr} represents the change rate of ESV, GDP_{pr} is the change rate of GDP in the corresponding units, and *pi* and *pj* are the beginning and end year of the study period, respectively.

With reference to a previous study [1], the *CEE* was classified with 0.2 as a unit, and divided into 12 classes, including worsening relationship (−∞,−1.0], high conflict (−1.0, −0.8], relatively higher conflict (−0.8, −0.6], moderate conflict (−0.6, −0.4], relatively lower conflict (−0.4, −0.2], low conflict (−0.2, 0], potential crisis (0, 0.2], low coordination (0.2, 0.4], relatively low coordination (0.4, 0.6], medium coordination (0.6, 0.8], higher coordination (0.8, 1.0], and coordination relationship (1.0, ∞).

3. Results

3.1. Land-Use Change in Hunan Province from 2000 to 2018

The spatial pattern of land use showed that land use in Hunan Province changed significantly during the study period. Forestland and cultivated land were the dominant land use types in Hunan Province (>90%). Among them, forestland was the primary land use type in Hunan Province, accounting for more than 61% of the coverage, followed by cultivated land. The proportions of cultivated land were 29.324%, 29.152%, 28.358%, 28.184%, and 27.927% in 2000, 2005, 2010, 2015, and 2018, respectively.

We found that the cultivated land exhibited a continuous decreasing trend, and grassland only accounted for a small proportion (Figure 4). During the study period, the proportion of grassland and wetland area decreased continuously, while the water area increased. The proportions of construction land were 1.346%, 1.510%, 2.004%, 2.299%, and 2.720% in the years of 2000, 2005, 2010, 2015, and 2018, respectively, showing a continuous increasing trend.

The land-use transition between cultivated land and forestland was the most frequent. A large amount of cultivated land was occupied by construction land, which was evidently higher than the supplementary cultivated land.

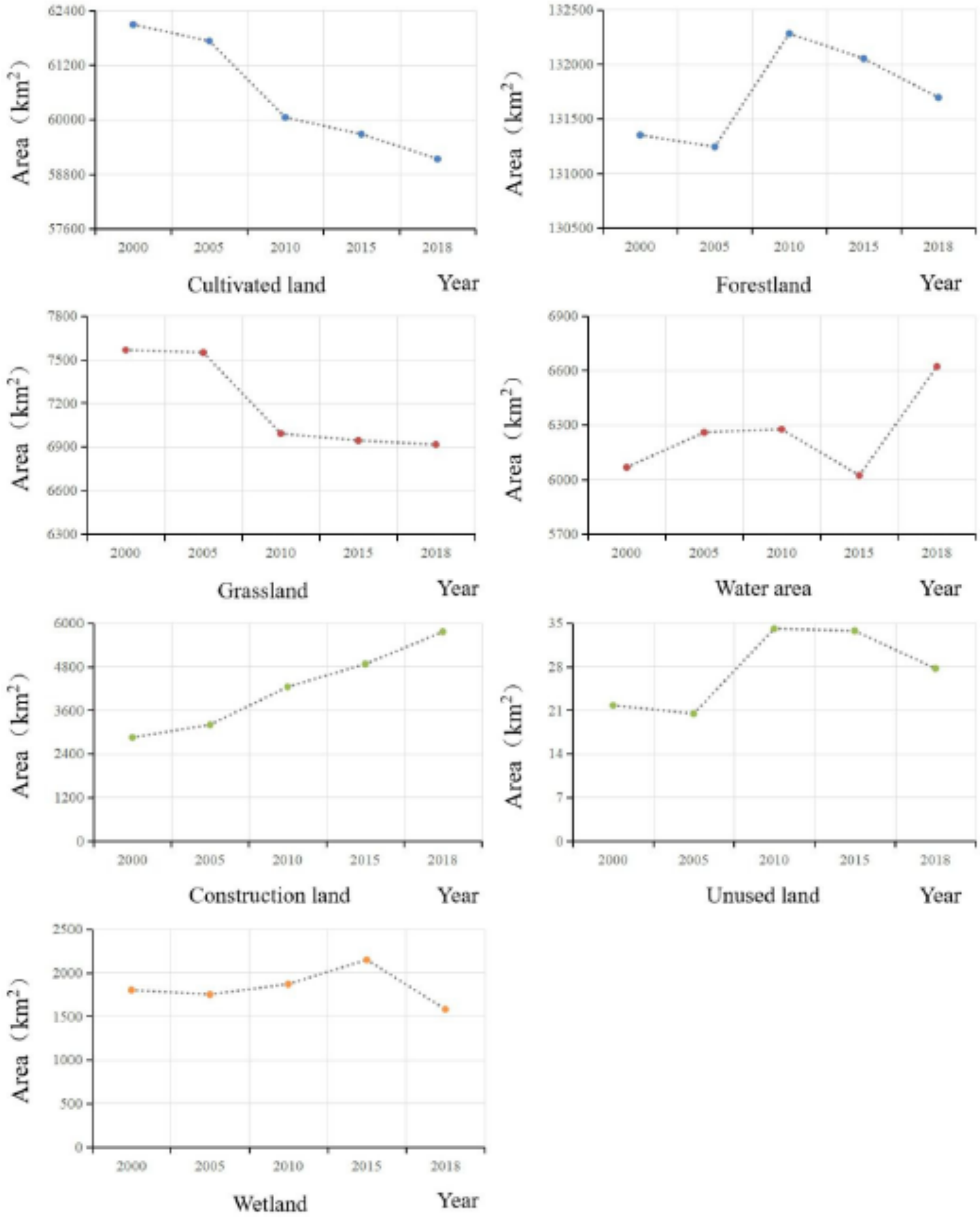

Figure 4. Land-use change of Hunan Province from 2000 to 2018.

3.2. Spatial Pattern of Ecosystem Services Value in Hunan Province from 2000 to 2018

In 2000, 2005, 2010, 2015, and 2018, the ESVs provided by ecosystems in Hunan Province were US$134,470.470 million, US$134,344.862 million, US$134,466.623 million, US$134,065.505 million, and US$133,214.304 million, respectively (Table 3). We found that the ESV in Hunan Province documented a fluctuant variation tendency of decreasing first from 2000 to 2005 (US$125.61 million), increasing later from 2005 to 2010 (US$121.76 million), and then decreasing again from 2010 to 2018 (US$401.12 million during 2010–2015 and US$851.20 million during 2015–2018), respectively.

Among them, the ESV provided by forestland was the highest (>80%), followed by cultivated land (>10%). During the study period, the ESV provided by unused land was relatively low (close to 0.001%). The ESVs provided by construction land were negative, which were −US$997.838 million, −US$1119.530 million, −US$1485.664 million, −US$1704.457 million, and −US$2016.604 million in 2000, 2005, 2010, 2015, and 2018, respectively.

In the sub-categories of ecosystem services, the proportions of hydrological regulation function and biodiversity maintenance function were higher than other sub-categories of ecosystem services (>15%), followed by gas regulation, climate regulation, and soil conservation function (approximately 13%) (Table 4). The food production function was the lowest (approximately 2.4%) among all sub-categories of ecosystem services types. During the study period, the food production function and hydrological regulation function showed a significant decreasing trend.

Other types of sub-categories of ecosystem services, including raw material production, gas regulation, climate regulation, soil conservation, and biodiversity conservation showed a downward trend from 2000 to 2005, a significant increase from 2005 to 2010, and a continuous decrease from 2010 to 2018, respectively. In 2000, 2005, 2010, 2015, and 2018, the average ESVs in Hunan Province were 6350.598 US$/hm^2, 6344.666 US$/hm^2, 6350.544 US$/hm^2, 6331.600 US$/hm^2, and 6291.759 US$/hm^2, respectively, documenting an overall decreasing trend but with significant fluctuations.

In terms of the spatial distribution, we found that the areas with a high average ESV in Hunan Province were located in Wuyi Mountain and Xuefeng Mountain in the west, Luoxiao Mountain in the east, and Wuling Mountains in the south. The areas with low average ESV were located in major cities and their surrounding areas (e.g., Changsha, Shaoyang, and Hengyang) (Figure S1). In addition, the ESV around Changsha–Zhuzhou–Xiangtan urban agglomerations, major cities, and their surrounding areas declined sharply (Figure 5).

Table 3. Ecosystem services values of different land-use types from 2000 to 2018 (US$ million).

Land-Use Types	2000	2005	2010	2015	2018
Cultivated land	14,302.183	14,218.600	13,831.071	13,746.060	13,619.970
Forestland	107,694.389	107,604.525	108,457.975	108,267.962	107,976.455
Grassland	2573.791	2568.106	2378.621	2362.218	2352.787
Water area	8020.218	8275.951	8297.624	7961.308	8754.782
Construction land	−997.838	−1119.530	−1485.664	−1704.457	−2016.604
Unused land	0.883	0.828	1.382	1.368	1.123
Wetland	2876.845	2796.383	2985.614	3431.047	2525.791
In Total	134,470.470	134,344.862	134,466.623	134,065.505	133,214.304

Notes: 100 dollars could be exchanged for RMB 622.84 in 2015.

Table 4. Ecosystem services value of different categories of ecosystem services from 2000 to 2018. (US$ million).

Categories	Sub-Categories	2000	2005	2010	2015	2018
Supplying services	Food production	3282.561	3273.278	3229.067	3214.651	3198.501
	Raw material	12,272.832	12,260.626	12,327.106	12,301.623	12,266.365
Regulating services	Gas regulation	18,194.868	18,147.526	18,153.783	18,086.467	17,935.162
	Climate regulation	18,763.614	18,731.290	18,829.755	18,884.543	18,637.670
	Hydrological regulation	20,794.721	20,782.766	20,670.932	20,466.164	20,321.318
	Waste treatment	12,573.262	12,590.065	12,534.607	12,468.338	12,385.091
Supporting services	Soil formation and retention	18,729.979	18,700.073	18,721.350	18,688.725	18,596.551
	Biodiversity protection	20,360.423	20,351.658	20,433.053	20,399.736	20,342.982
Cultural services	Recreation and culture	9498.210	9507.580	9566.970	9555.258	9530.664
	Total ESV	134,470.470	134,344.862	134,466.623	134,065.505	133,214.304

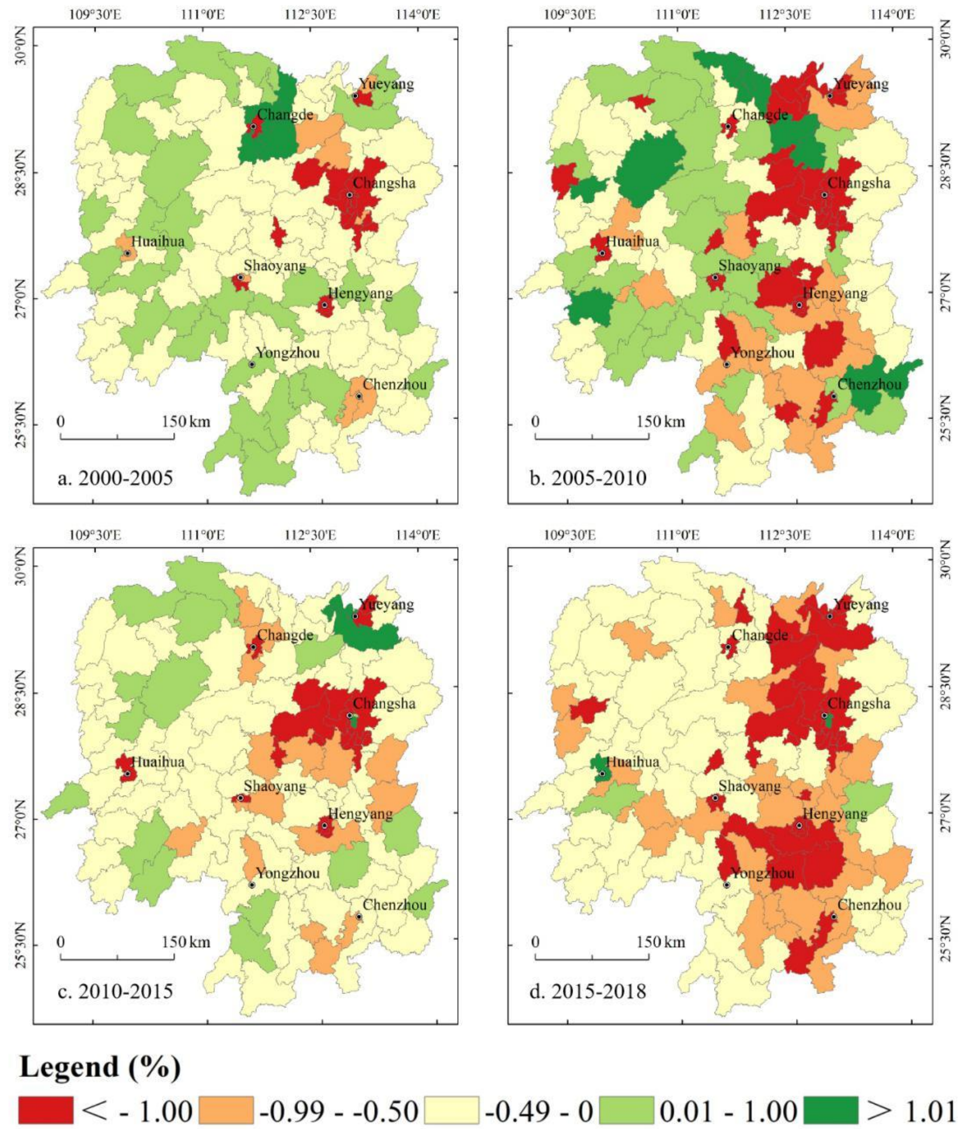

Figure 5. Spatial pattern of the change rate of ecosystem services value in Hunan Province from 2000 to 2018 (%).

3.3. Sensitivity Analysis of Ecosystem Services Value in Hunan Province from 2000 to 2018

According to Equation (3), the sensitivity index was calculated by adjusting 50% of ESV equivalent coefficient up and down, respectively (Table 5). The sensitivity indexes of ESV to *VC* for various land use types were less than 1, and the order from high to low was forestland, cultivated land, water area, wetland, grassland, construction land, and unused land. Among them, the sensitivity index of forestland ranged from 0.227 to 0.228, indicating that when the *VC* of forestland increased by 1%, the ESV would increase by 0.227–0.228%. This showed that ESV in the study area lacked the elasticity to *VC*, and the study results were credible.

To further analyze the spatial distribution characteristics of the sensitivity index of ESV to *VC* of different land types, we mapped the sensitivity indexes of seven land types from 2000 to 2018. The spatial distribution pattern of the sensitivity index of ESV to *VC* of different land-use types were similar in different years, and we only listed the maps in 2018 (Figure 6). The spatial distribution showed that the sensitivity index of cultivated land in the plains areas was higher than those in mountainous areas (Figure 6a).

Table 5. Sensitivity coefficient resulting from adjustment of the equivalent value coefficient.

Land-Use Types	2000	2005	2010	2015	2018
Cultivated land	0.027	0.026	0.026	0.026	0.026
Forestland	0.227	0.227	0.227	0.228	0.228
Grassland	0.005	0.005	0.004	0.004	0.004
Water area	0.015	0.015	0.015	0.015	0.016
Construction land	0.002	0.002	0.003	0.003	0.004
Unused land	0.000	0.000	0.000	0.000	0.000
Wetland	0.005	0.005	0.006	0.006	0.005

This is mainly because the plains areas were rich in cultivated land, and the change of cultivated land *VC* had a greater impact on the ESV. The sensitivity indexes of grassland and forestland in the surrounding mountainous areas were relatively higher (Figure 6b,c). The sensitivity indexes of water area and wetland around Dongting Lake in the northern region of Hunan Province were significantly higher than in other regions (Figure 6d,g).

Similar areas with high sensitivity indexes in construction land were mainly distributed in the Changsha–Zhuzhou–Xiangtan urban agglomerations and the surrounding areas of major cities (Figure 6f). It was of great significance to analyze the sensitivity indexes of different land use types in different county units for regional ecological protection measures and land-use planning, as well as providing more scientific guidance for optimizing the land use structure, and the coordinated development of ecology and economy in Hunan Province.

3.4. Spatial Pattern of Economic Density in Hunan Province from 2000 to 2018

The economic density of Hunan Province increased from 269,264 US$/km^2 in 2000 to 2,761,702 US$/km^2 in 2018, about 10 times that of 2000. The economic development of Hunan Province was very rapid during the study period. As opposed to the spatial distribution of the average ESV, the areas with high economic density in Hunan Province were mainly distributed in Changsha–Zhuzhou–Xiangtan urban agglomerations, major cities, and their surrounding areas (e.g., Changsha, Changde, Yueyang, Shaoyang, Hengyang, Huaihua, and Chenzhou) (Figure S2).

In the surrounding mountainous areas, especially for Wuyi Mountain and Xuefeng Mountain in the western region, the economic density in these areas were particularly low. We found that the economic imbalance in Hunan Province was significant. For example, the economic density of Yongshun County located in the Xiangxi Tujia and Miao Autonomous Prefecture was 292 US$/km^2 in 2018, while that of Furong District in Changsha City was 502,722 US$/km^2. Moreover, the economic density in Changsha–Zhuzhou–Xiangtan urban agglomerations, major cities, and their surrounding areas increased evidently (Figure 7).

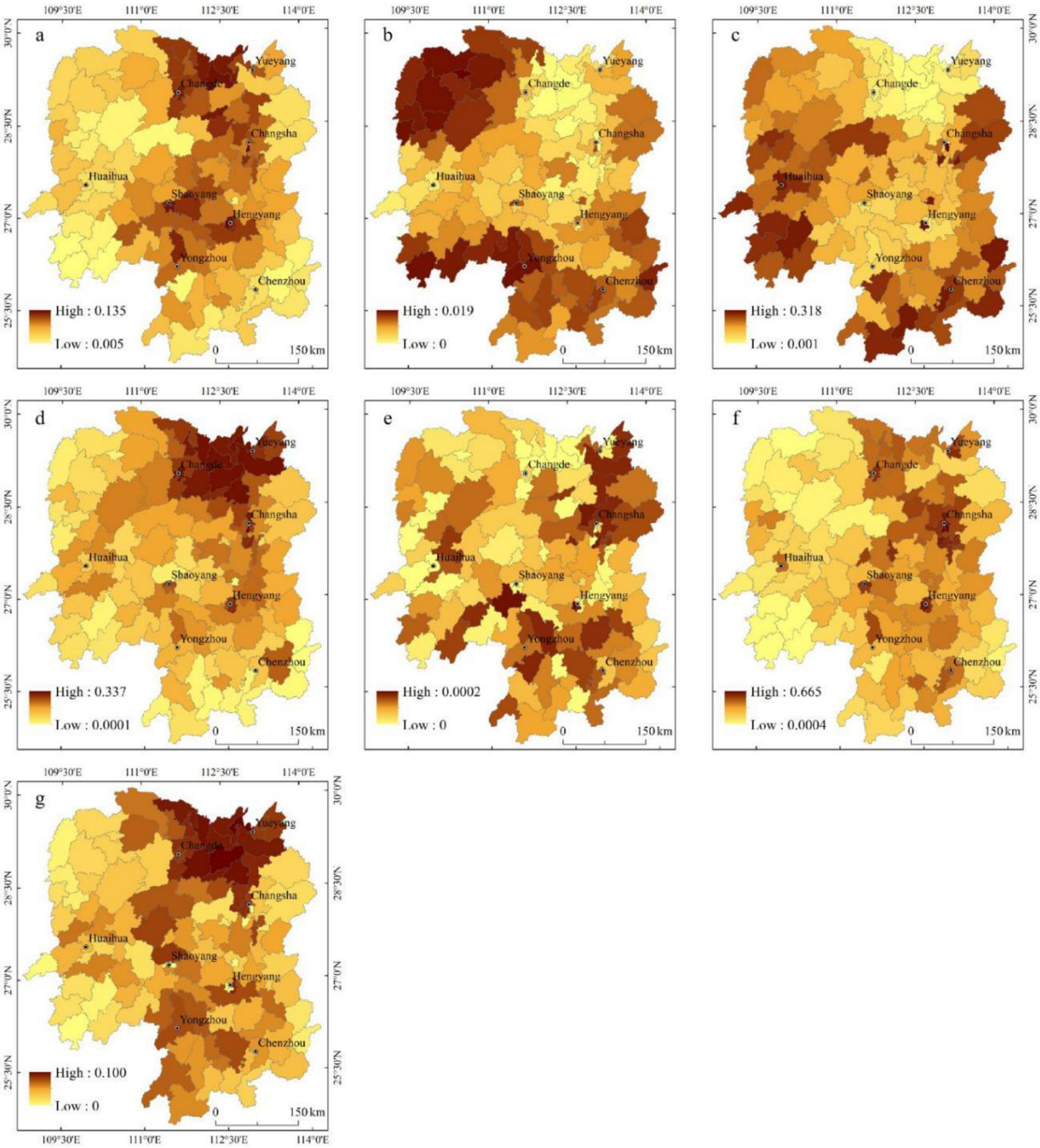

Figure 6. Spatial pattern of sensitivity coefficients of different land-use types in Hunan Province in 2018. Notes: (**a**) the spatial pattern of the sensitivity coefficient of cultivated land; (**b**) the spatial pattern of the sensitivity coefficient of grassland; (**c**) the spatial pattern of the sensitivity coefficient of forestland; (**d**) the spatial pattern of the sensitivity coefficient of water area; (**e**) the spatial pattern of the sensitivity coefficient of unused land; (**f**) the spatial pattern of the sensitivity coefficient of construction land; and (**g**) the spatial pattern of the sensitivity coefficient of the wetland.

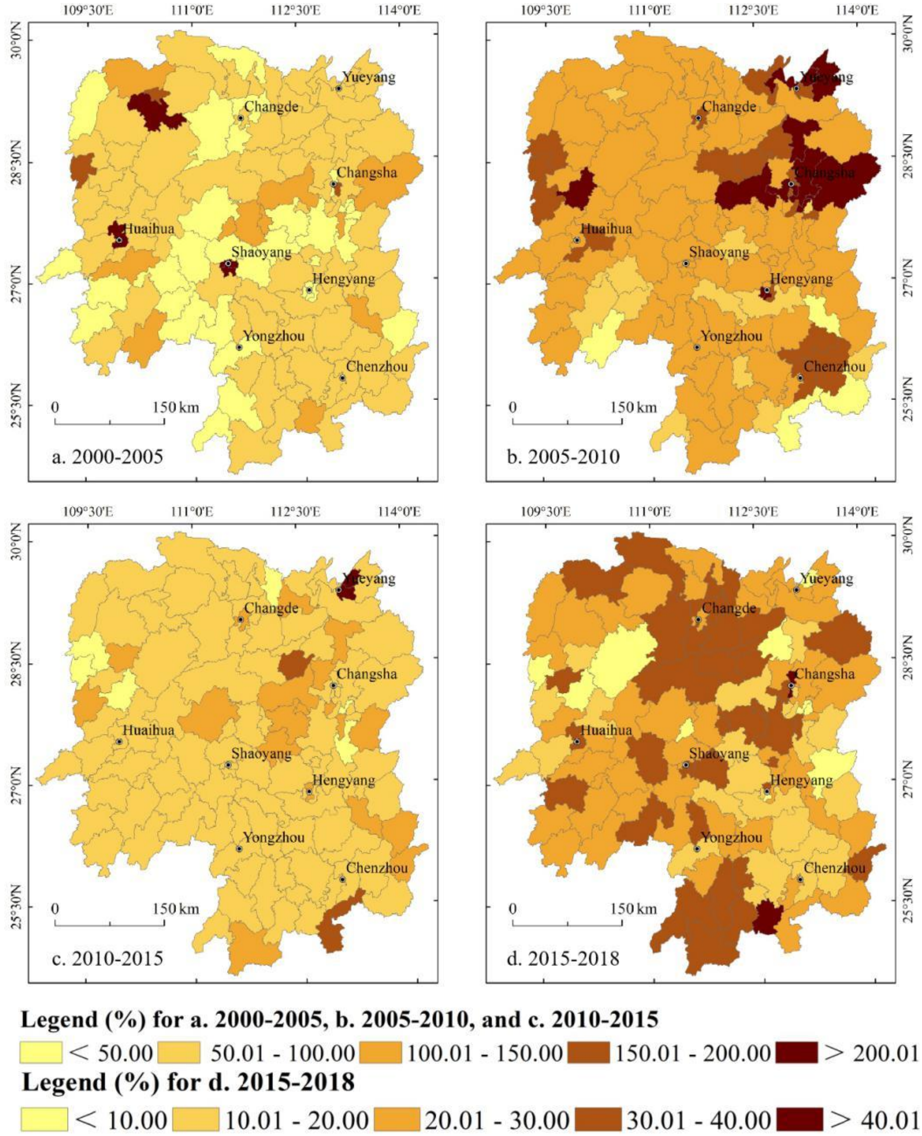

Figure 7. Spatial pattern of the change rate of economic density in Hunan Province from 2000 to 2018 (%).

3.5. Spatial Autocorrelation between Ecosystem Services Value and Economic Development in Hunan Province from 2000 to 2018

The results of the global bivariate spatial autocorrelation showed that the global Moran' *I* index values between the average ESV and economic density in Hunan Province in 2000, 2005, 2010, 2015, and 2018 were −0.371, −0.343, −0.419, −0.413, and −0.421, respectively ($p < 0.001$). We found that there was a significant negative correlation between the average ESV and economic density in Hunan Province during the study period, indicating that economic development would lead to the deterioration of ecosystem services. In terms of the local bivariate spatial autocorrelation, we further found a spatial aggregation trend between the average ESV and economic density in Hunan Province.

The spatial pattern of local indicators of spatial association (LISA) cluster maps between the average ESV and economic density in Hunan Province from 2000 to 2018 showed significant similarities (Figure 8). Specifically, the high-low type (areas with high average ESV and low economic density) were mainly distributed in most areas in the west and a few areas in the south of Hunan Province. The low-high type (areas with low average ESV and high economic density) were mainly distributed in Changsha (e.g., Kaifu District, Furong District, Changsha County, Yuhua District, Tianxin District, and Yuelu District).

The Wugang City in Shaoyang City was a low-low type (areas with low average ESV and low economic density) during the study period.

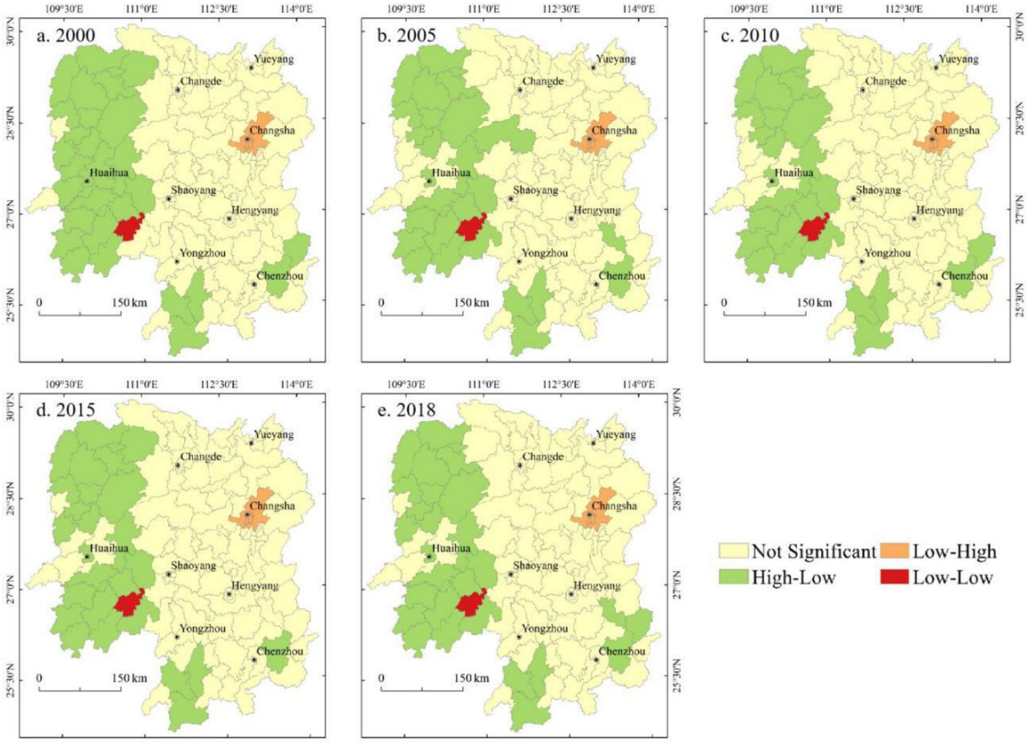

Figure 8. Local indicators of spatial association (LISA) cluster maps between average ecosystem services value and economic density in Hunan Province from 2000 to 2018.

3.6. Coupling Analysis of Ecosystem Services Value and Economic Development in Hunan Province from 2000 to 2018

During 2000–2005, 2005–2010, 2010–2015, and 2015–2018, the coupling index values between the average ESV and economic development were −0.001, 0.001, −0.004, and −0.023, respectively. The average ESV and economic development were in a potential crisis state only during 2005–2010, while they were in a low conflict state during 2000–2005, 2010–2015, and 2015–2018. This showed that the relationship between the average ESV and economic development of Hunan Province was in an overall uncoordinated state, and the ESV in Hunan Province needed to be further improved.

Figure 9 shows the coupling index's spatial pattern between the average ESV and economic development in Hunan Province from 2000 to 2018. We found that the coupling index between the average ESV and economic development from 2000 to 2018 basically ranged from −0.2 to 0.2, that is to say, the coupling index values between the average ESV and economic development were in the low conflict ($-0.2 < CEE < 0$) and potential crisis state ($0 < CEE \leq 0.2$). Most of the county units were in the low-conflict state, which indicated that economic development had a negative impact on the ecosystem services.

There was an uncoupled relationship between ecosystem services and economic development. The number of units in the potential crisis was relatively small and distributed discretely. Specifically, 69.672%, 70.492%, 83.607%, and 83.607% of the county units were in the low conflict state and 27.049%, 27.049%, 14.754%, and 3.279% of county units were in the potential crisis state, during 2000–2005, 2005–2010, 2010–2015, and 2015–2018, respectively (Table 6). In addition, we found that three counties were in the coordinated relationship state, and three counties were in the worsening relationship state from 2015 to 2018.

Table 6. Statistics of the coupling relationships between the economic development and ESV in Hunan Province from 2000 to 2018.

Types	Worsening Relationship	High Conflict	Relatively Higher Conflict	Moderate Conflict	Relatively Lower Conflict	Low Conflict	Potential Crisis	Low Coordination	Relatively Low Coordination	Medium Coordination	Higher Coordination	Coordination Relationship
2000–2005	0	1	1	1	1	85	33	0	0	0	0	0
2005–2010	1	0	0	1	0	86	33	0	0	0	0	1
2010–2015	0	0	0	0	1	102	18	0	0	1	0	0
2015–2018	3	0	0	1	8	102	4	1	0	0	0	3

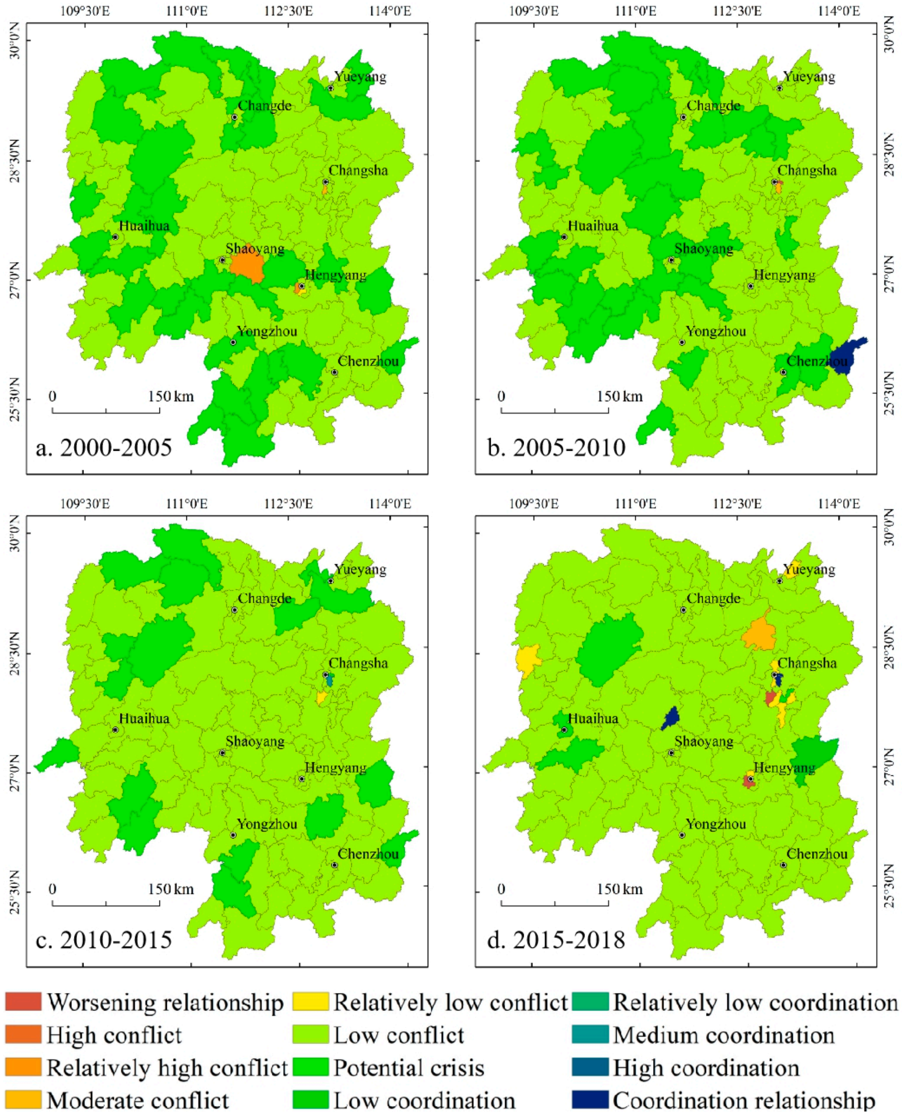

Figure 9. Spatial pattern of the ecological and economic coordination index in Hunan Province from 2000 to 2018.

4. Discussion

4.1. Interpretation of Findings

From 2000 to 2018, the GDP in Hunan Province increased by US$527.813 billion, while the ESV decreased by US$1256.166 million, and the coupling index between average ESV and economic development was −0.001. This indicated that the ecosystem protection and economic development were generally decoupled during the study period and that sufficient attention had not been paid to the impact of rational land use on the ecosystem services during the regional economic development.

The amount of ESV provided by forestland, cultivated land, and water area accounted for more than 96% of the total supply of ESV in Hunan Province, among which the supply capacity of ecosystem services by forestland, cultivated land, and water areas accounted for more than 80%, 10%, and 5% of the total ESV, respectively. This showed that the policies of returning cultivated land to forestland, damaging forestland to reclaim land, reclaiming land from lakes, and returning cultivated land to lakes and wetlands had an important impact on the changes of ESV in Hunan Province.

The ESV provided by construction land was negative. The increasing demand of urbanization for construction land had a negative impact on the ecosystem supply capacity. The adjustment of industrial structure promoted rational land use and improved the marketoriented utilization efficiency of the ESV as much as possible. Optimizing the industrial structure and protecting the local ecosystems were the important links of sustainable eco-economic development of land use. The results of bivariate spatial autocorrelation showed that there was a significantly negative correlation between the ESV and economic development, indicating that economic development would lead to the deterioration of the ESV.

The coupling analysis between the ESV and economic development showed that the relationship between ecosystem services and economic density in Hunan Province was mainly in the low conflict state and potential crisis state. This demonstrated that the ecological protection and economic development of Hunan Province were in an overall uncoordinated state and that the regional ESV must be further improved. It is necessary to allocate land resources and strengthen sustainable land use rationally.

The ESV in Hunan Province was found to be US$140,821.078 million in 2010 by Liu et al. (2015) [56], US$281,829.080 million in 2010 by Xiong et al. (2018) [57], and US$134,466.623 million in 2010 in this study. The findings of Liu et al. (2015) [56] were close to the present study. By comparing the evaluation results of ESV of Liu et al. (2015) [56], we found that the ESV of Hunan Province increased from 1995 to 2000, while exhibiting a trend of continuous decline from 2000 to 2010, with an overall decrease of US$592.447 million. Xiong et al. (2018) found that the ESV decreased during 1990–2000 and 2005–2015, while the ESV increased during 2000–2005 [57].

These studies all found that the ESV in Hunan Province fluctuated and decreased; however, the turning points were different. This was mainly due to differences in the equivalent value per unit area of ecosystem services and land use classification system used in these studies. Liu et al. (2015) [56] employed the equivalent value table proposed by Costanza et al. (1997, 2014) [9,46], while Xiong et al. (2018) [57] employed the equivalent value table proposed by Xie et al., (2003) with a regional correction factor (1.95 in Hunan province) [47].

Comparing the other two studies, the land-use classification in this study extracted wetland from water area, because the wetland in Hunan province occupies a considerable proportion. According to previous studies, it was found that the ecosystem services supply capacity of wetland was the highest than those of other ecosystems [9,14], and wetland fluctuations undoubtedly affect the assessment results. In addition, data sources and data accuracy would also lead to differences in evaluation results. For example, the land use data in Xiong et al. (2018) is interpreted using Landsat ETM and Landsat TM image, while land-use data of Liu et al. (2015) is Landsat TM image interpretation products provided by the Ministry of Ecology and Environment of the People's Republic of China [56,57]. The land-use data in this study are from the Data Center for Resources and Environmental Sciences of Chinese Academy of Sciences (http://www.resdc.cn/DataList.aspx, accessed on 14 April 2021) [43–45].

In this study, the ESV was evaluated from the equivalent value table proposed by Xie et al. (2008) and Ye et al. (2018) [14,48]. We considered that construction land provided a negative ESV [48]. Although many studies believed that the ecosystem services provided by construction land are of no value [57], some studies believed that construction land can provide certain ecosystem services (e.g., recreation, tourism, culture, and rest, carbon storage) [49,58].

In addition, some studies suggested that the ecosystem disservices brought by construction land exceeded the positive ecosystem services [48,59]. Ecosystem services are always positive, only ecosystem disservices can have negative values. In this study, considering the rapid decline in ESV due to the transition from a natural ecosystem to a semi-artificial ecosystem and artificial ecosystem in rapid urbanization and the dominant role of negative ecosystem services, we propose that ecosystem services provide negative ecosystem services.

4.2. Coupling Relationship between Ecosystem Services Value and Economic Development

According to the coupling index between the average ESV and economic development, the low conflict and potential crisis were the main relationships between them, and the low conflict state was the dominant relationship, indicating that the growth rate of ESV lagged behind the economic growth. By comparison with the findings of Chen et al. (2018) [1], in the West Dongting Lake region (the northern part of Hunan Province) from 2000 to 2011, most areas were in the low conflict state, and a small number of areas were in the state of potential crisis, which is consistent with the findings of this study.

Wang et al. (2011) [55] found that about 88% of the units in the Yangtze River Delta region were in the low conflict state and potential crisis state during 1991–2001, which were also dominated by the low conflict type. In the following period from 2001 to 2008, the average ESV and economic development relationship in the Yangtze River Delta region changed from a centralized and preliminary deterioration trend to a decentralized deterioration and coordination state [55]. In terms of quantity, there were many counties in the low conflict state in Hunan Province, indicating that the coordination between economic development and ESV was not high.

As far as the development stage was concerned, Hunan Province presented three forms in the coordinated development transformation (e.g., maintaining the low conflict state, transforming from the potential crisis state to the low conflict state, and transforming from the low conflict state to the potential crisis state). That is to say, most of the units were in the low conflict state during the study period, documenting that, in the process of economic development, the regional economic development and ESV were mostly in the uncoordinated state.

A possible explanation for the transformation from the low conflict state to the potential crisis state is that the counties with relatively rich forest resources took the path of circular industry development in the development process, realized the benign interaction between ecosystem protection and economic development, and gradually turned to the coordinated development of ecosystem protection and economic development.

This indicated that, in the process of regional economic development, attention should be paid to the coordination between rational land use and economic development and to continuously improving the supply capacity of ecosystem services. A possible explanation for the transforming from the potential crisis state to the low conflict state is that the rapid urbanization area occupied a large amount of cultivated land for construction, while the local government did not pay attention to the rational allocation of land-use structure as economic growth, thereby, reducing the ESV.

4.3. Integrating Ecosystem Services into Land Use Decisions

Important evidence has been provided regarding how economic development leads to significant ecosystem degradation through land use changes [60]. As the ESV declined in Hunan Province, the relationship between development and protection should be handled well in the process of regional land development and utilization. Land-use planning is not only a basic means to realize macro-control through the rational allocation of land resources but also an important way to ensure land ecological security.

Worldwide observations recognized that ecosystem services could be used as tools to enhance urban planning and decision making; however, integrating ecosystem services into practical urban management and policy guidance has seldom been considered in practice [3,61]. Additionally, the assessment of ecosystem services plays an important role in spatial planning at the national level, governing the environment, and making land use decisions; however, little attention has been paid to ecological protection, and some mismatches still exist between ecosystem services and their practical applicability and operationalization [62].

How to construct a bridge between research and decision making has been widely discussed [11,12,63,64]. However, related issues, such as ecosystem supply and demand, ecosystem trade-offs, and ecosystem flow, are still not well understood; therefore, it is difficult to apply the concepts of ecosystem services in practice. Estimating the change in ecosystem services caused by urbanization has been an important entry point for green development, as well as an important breakthrough for dealing with the continuous deterioration of the ecosystem. The study of ecosystem services is of great significance for the accounting of the total social costs of economic development and ecological compensation.

To alleviate the ecological problems caused by rapid economic development, the Chinese government has undertaken a series of efforts [18]. Most notable is a regulation clearly stating that an environmental impact assessment is the premise of all other planning (e.g., land-use planning and transportation infrastructure planning). The concept of main functional zone planning emphasizes that future population distributions, economic layouts, land use, and urbanization patterns should be planned based on regional resources and the environmental carrying capacity, development intensity, and development potential.

An evaluation of resources and environmental carrying capacity, along with an assessment of the land suitable for development, forms the basis for national land planning. For example, ecosystem services—including biodiversity, water conservation, soil conservation, wind protection, and sand fixation—were integrated into China's current national land planning policies. However, further discussion and study is required regarding how to strengthen the role of ecosystem services in national spatial planning [65].

4.4. Policy Implications

Increasingly serious conflict between humans and the land system drives economic developments adapting to the carrying capacity of the ecological environment. With sustained and rapid economic growth, the socio-economic development was greatly out of balance with the resource endowment and environmental carrying capacity. Hunan Province is an important part of the Yangtze River Economic Belt strategy. The Yangtze River ecological restoration should be placed in a prominent position, and the economic development should be adapted to the resource environmental carrying capacity under the premise of protection.

To achieve this overwhelming goal, we must adhere to the principle of "ecological priority and green development". In this situation, Hunan Province must coordinate ecological protection and economic development, accelerate economic restructuring, promote industrial transformation and upgrading, guide the rationalization of the spatial layout of industrial functions, and promote green development and high-quality development.

Possible efforts can be taken from the following aspects. First, the local government must change from emphasizing economic growth over environmental protection to paying equal attention to environmental protection and economic growth and take strengthening ecological protection as an important means to adjust economic structure, change the mode of economic growth, and strive for development in environmental protection [65].

Second, the government should change the development path of solving environmental problems from mainly using administrative methods to comprehensively using laws, economy, technology, and necessary administrative means, consciously follow economic and natural laws, improve the level of environmental protection, and make room for new development.

Third, the public needs to establish a resource-saving and environmentally friendly concept of circular economic development and promote the transformation of resource utilization from the linear mode of "resource–product–waste" to the circular mode of "resource–product–waste–renewable resource" to achieve sustainable socioeconomic development with as little resource consumption and environmental costs as possible.

Compared with the traditional economy, a circular economy is a kind of economic development pattern that is harmonious with the environment [66]. Fourth, the layout of spatial land development, spatial land carrying capacity, environmental policy, development stage, and other factors should be fully considered to make reasonable plans and to actively improve the mechanism of organization coordination, benefits compensation, and performance evaluation.

Additionally, the spatial distribution of urban space, agricultural space, and ecological space should be reasonably planned, and the red line for ecological protection, permanent basic farmland protection, and urban development should be set to explore the means of space governance and land-use control [66]. For example, the government should strengthen the planning of the green space system, improve the value of urban ecosystem services, and build multiple green space ecosystems, including parks, nurseries, and shelterbelts, as well as water conservation forests in the suburbs, ring city forests, and large areas of lawns, to reduce the impact of urban expansion on ecosystem services.

4.5. Limitations and Future Directions

In this study, the spatiotemporal patterns of the ESV in Hunan Province from 2000 to 2018 were calculated with the benefit transfer method using grain prices and grain output per unit area; however, the spatial distribution of ecosystem services in Hunan Province was not localized with elements, such as the biomass, consumer prices index accumulation coefficient, and marginal value coefficient, which can be further added in future research [16,67]. In addition, we only studied the spatial relationship and coupling characteristics between the ESV and economic density and did not analyze the spatial interaction between ESV and other socio-economic or natural factors. In future research, we can use a spatial regression model to further to explore the relationship between ESV and other driving factors.

5. Conclusions

Based on the benefit transfer method, this study measured the spatiotemporal characteristics of the ESV in Hunan Province from 2000 to 2018. The spatial interactions and coupling relationship between the ESV and economic development in Hunan Province were measured using the bivariate spatial autocorrelation and coupling index between the ESV and economic development. The results showed that the cultivated land and grassland area in Hunan Province continued to decrease, while the construction land continued to increase from 2000 to 2018.

From 2000 to 2018, the ESV provided by the ecosystem in Hunan Province decreased by US$1256.166 million. The ESV provided by the forestland was the highest (higher than 80%). The hydrological regulation function and biodiversity maintenance function accounted for a higher proportion (higher than 15%) in the sub-categories of ecosystem services types. The sensitivity indexes of ESV to *VC* were less than l, which showed that the evaluation results of ESV in Hunan Province were credible. The spatial distribution pattern of economic density and average ESV showed the opposite pattern characteristics.

The results of the bivariate spatial autocorrelation analysis documented that economic development could cause a decline of ESV, and high average ESV and low economic density was the dominant relationship. In addition, the analysis of the coupling relationship between the ESV and economic density showed that the relationships between the ESV and economic density in Hunan Province were mainly in the low-conflict state and potential crisis state. Therefore, it is necessary to pay increased attention to the coordination of economic development and ecological protection in future land use planning and socioeconomic development.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/rs13081552/s1, Figure S1. Spatial pattern of the average ecosystem services value in Hunan Province from 2000 to 2018 (US$/hm^2). Figure S2. Spatial pattern of gross domestic product (GDP) per unit area in Hunan Province from 2000 to 2018 (US$/km^2).

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