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Coupling Relationship between Ecosystem Service Value and Socioeconomic Development in the Qinba Mountains, China

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Abstract: The degree of coordination between ecosystem services and the level of socioeconomic development has essential implications for regional sustainability. The coordinated development of ecology and economy is a major theoretical and practical problem for the Qinba Mountains, which is once one of the 14 contiguous destitute areas in China. Based on the land use and cover change (LUCC) data interpreted by medium-resolution remote sensing images, this study adopted the modified equivalent factor method to calculate ecosystem service value (ESV) and its temporal and spatial variation in the Qinba Mountains. A comprehensive index system was constructed to measure the socioeconomic development level and to reveal the coupling relationship between the ESV and socioeconomic development. The results show that: (1) for 2000–2015, the ESV in these areas was increasing, the proportion of forest ESV was the largest, and it increased significantly. (2) The level of socioeconomic development was constantly improving, and the differences within the region were gradually emerging. (3) Except for the Hantai District, which has been in a highly uncoordinated state, the degree of coordination between ESV and socioeconomic development has improved year by year, and most counties were in a state of medium coordination, or above. The results contribute to a scientific basis for decision making regarding ecological environmental protection and green economic development in the Qinba Mountains, and have positive significance for promoting the construction of ecological civilization and sustainable development in the study area.

Keywords: ecosystem service value (ESV); socioeconomic development; coupling coordination degree; entropy weight method; Qinba Mountains

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1. Introduction

The ecological environment is the basis of human dependence. With the rapid population growth, food shortages, resource depletion and other global problems, ecosystem function degradation, environmental quality decline, and other phenomena emerge endlessly, and many negative economic development benefits are highlighted [1,2]. Coordinating the balance between economic development and ecological environmental protection, improving ecosystem services, has become the only way to construct ecological civilization and the sustainable development [2–4]. Ecosystem services are the benefits that humans obtain directly or indirectly from an ecosystem [5]. As a bridge between natural and socioeconomic processes, ecosystem services provide a new theoretical basis for studying the coupling of human and natural systems [1,6,7].

There have been several explorations and practices conducted on the impact of socioeconomic activities on ecosystem services at home and abroad. International research on ESV and socioeconomic development stems from the rise in "ecological economics," focusing on the complex interaction between the economy and the environment, as well as the characteristics of spatial relationships [8–10]. Grossman et al. (1991) proposed the environmental Kuznets curve (EKC) [11], which became an important tool to analyze the direct relationship between regional economic development and the environment [12]. With the EKC model, Cristina et al. (2016) [13] analyzed the research status of the economic value of ecosystem services in Spain and clarified the importance of economic assessment in the study of ESV. Constanza et al. (1997) [14] proposed the evaluation method of ESV, which made the principle and method of ESV estimation clearer in the scientific sense. This method, which is more intuitive, easy to use, and requires less data, is widely applied to ecological and economic problems at the global and regional scales [15,16]. In addition, there are other methods to study the relationship between environmental quality and economic development. Destek et al. (2018) [17] used the ecological footprint to characterize the ecological environment and studied the relationship between the ecological environment and economic development in European countries. Medeiros et al. (2020) [18] analyzed the trade-off between economic and environmental factors through multi-objective programming to further optimize land use in the Midwest of Brazil.

Related research in China is relatively late. After Xie et al. (2008, 2015) [19,20] improved the calculation and evaluation methods of ESV based on Constanza's research [14], considerable exploration and empirical work on coupling and coordination between ecology and economics has been conducted by scholars from various disciplines, including geography, ecology, and forest management [21]. The research areas involve administrative regions [22] and river basins [23,24], as well as economic belts and urban agglomerations [25–27], etc. The main concerns are the environment and the economy [28], ESV of forest and tourism economy [29], urbanization and ecosystem services [30,31], etc. For example, Sun et al. (2015) [32] explored the relationship between economic growth and ESV in the Beijing-Tianjin-Hebei region, conducting an in-depth analysis on the degree of coupling and coordination between the two and the economic benefits of the ecosystem. With the help of Xie et al.'s research results (2008, 2015) [19,20], Zhu et al. (2022) [33] revised and obtained the equivalent factor table of ESV in the Guanzhong region, and used the coupling degree model to explore the coupling relationship between ESV and economic development in this region. Chen et al. (2018) [34] measured the construction of ecological civilization by coupling the three subsystem indicators of ecological environment-economy-society. Feng et al. (2022) [35] analyzed the degree of coupling and coordination between different relocated population density and ESV variables. Wang et al. (2022) [26] calculated the ESV and tourism urbanization degree of the Chang-Zhu-Tan urban agglomeration, and analyzed the coordination relationship between them. Combined with multiple perspectives, these studies illustrate the relationship between ecological protection and economic development at different scales [36,37].

In summary, scholars at home and abroad have fundamentally the same cognition direction regarding ESV. Most methods of calculating the ESV on a regional scale use equivalent factor tables or value substitution. The research on the coupling relationship between changes in ESV and socioeconomic development mainly focuses on economically active areas, such as administrative regions, economic belts, and urban agglomerations. Relatively little attention has been paid to the contiguous destitute areas. Socioeconomic indicator systems are mostly confined to economic indicators, and there is a lack of comprehensive indicators that reflect people's living standards, social security, and socioeconomic scale and structure. Therefore, this study took the Qinba Mountains, one of 14 contiguous destitute areas in China, as the research object, and then revised the "Chinese land ecosystem services value equivalent factor table," discussing the temporal and spatial characteristics of its ESV changes, combined with the comprehensive level of socioeconomic development. The objectives of this study are: (1) to evaluate the comprehensive status of ESV and socioeconomic development in contiguous destitute areas, (2) to reveal the spatial and temporal heterogeneity of the coupling relationship between the ESV and socioeconomic development, and (3) to explore the interaction mechanism and the dynamic relationship of coupling and coordination between the ESV and socioeconomic development. This study can provide a reference for the development of ecological compensation policy and the in-depth study of green development in contiguous destitute areas.

2. Materials and Methods

2.1. Overview of the Study Area

The contiguous destitute areas in the Qinba Mountains cover six provinces in Sichuan, Hubei, Shaanxi, Henan, Chongqing, and Gansu. This paper takes the Southern Shaanxi section of the Qinba Mountains, which is composed of the cities of Ankang, Hanzhong, and Shangluo in Shaanxi Province, as the research object. There are 28 counties in total (Figure 1), with a total area of 70,234.93 km^2. In 2020, the population of the study area was 7,746,100, and the GDP was CNY 0.34 trillion (China yuan). The north side of the area is made up of the Qinling Mountains, the south side is the Bashan Mountains, and the middle part is the Hanjiang River, presenting the feature description that, “There is a river in the middle of two mountains.” The terrain is dominated by hilly and mountainous areas at a medium altitude; in terms of climate, the north subtropical humid climate and the warm temperate humid climate are dominant, with cold winters and hot summers, and the four seasons are distinct [38]. The average annual temperature is 12–18 °C, and the annual rainfall is 700–1400 mm. The complex and diverse landforms and climatic environments have nurtured the abundant animal and plant resources in the Qinling Mountains, which is a key area for the protection of rare and endangered animals and plants in the country and the world, including the Qinling, Daba, and Minshan-Hengduan biodiversity priority areas. It is also an essential water source conservation area for China’s South-to-North Water Diversion Project, playing an important strategic role in this endeavor.

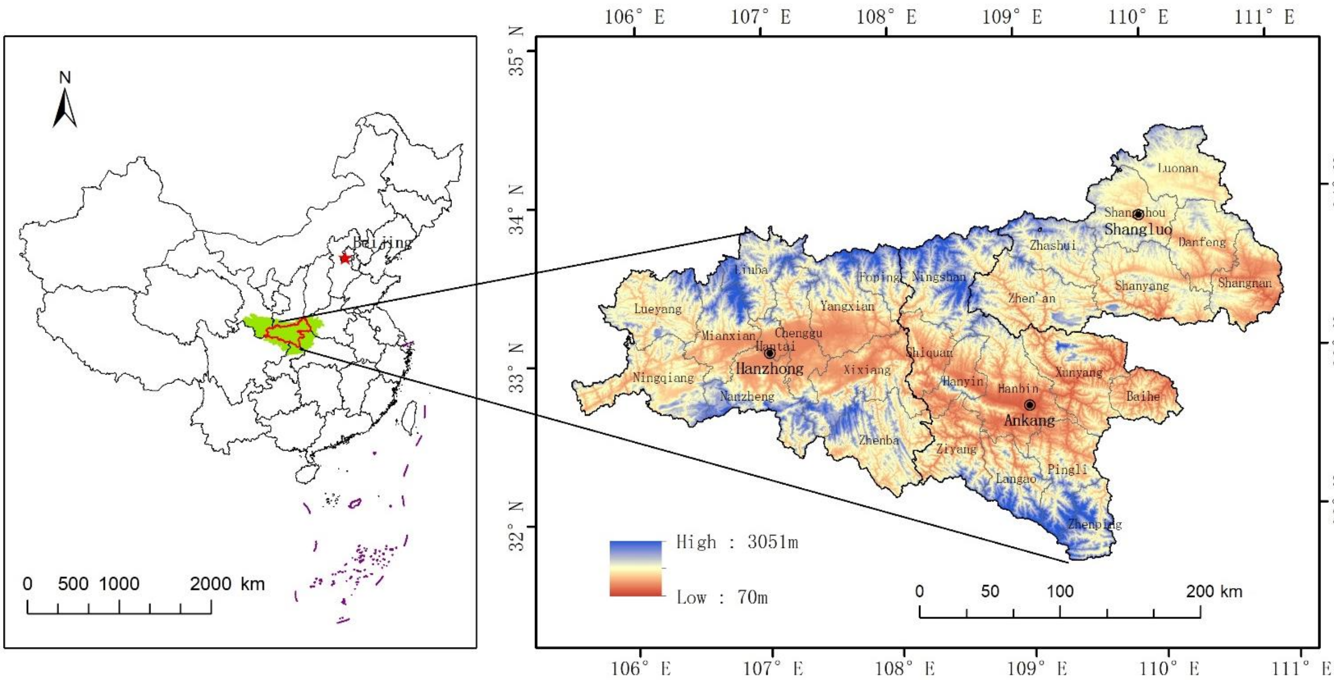

Figure 1. Overview of the study area.

2.2. Methods

This study is mainly divided into three steps. First of all, the ESV of different land use types in the Qinba Mountains from 2000 to 2015 was evaluated. Secondly, the socioeconomic development level of different counties was estimated. Finally, the analysis of their coupling coordination degree was conducted from 2000 to 2015 using the coupling and coordination model. The framework of this study is presented in Figure 2.

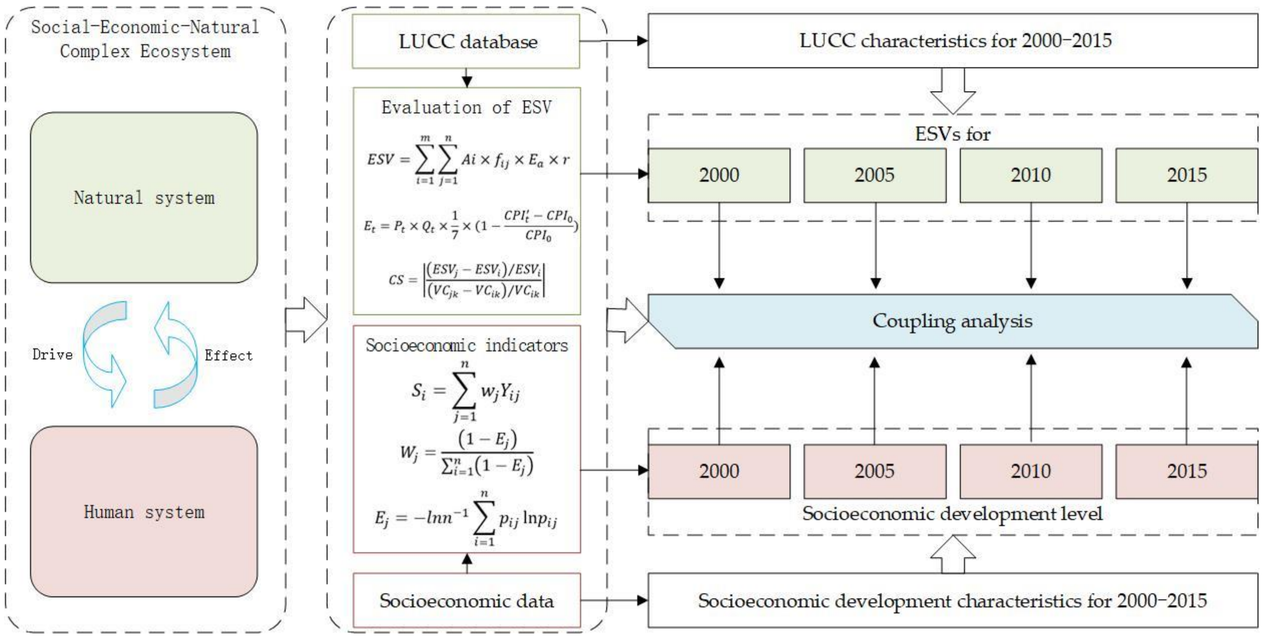

Figure 2. Framework of this study.

2.2.1. Calculation of ESV

(1) Calculation model of ESV

Xie et al. (2008) [19] formulated a table of equivalent factors of ESV per unit area of different terrestrial ecosystems in China (Table 1). Then, this established method was developed and optimized again by Xie et al. (2015) [20]. The formula used to calculate ESV was:

$$ESV = \sum_{i=1}^{m} \sum_{j=1}^{n} Ai \times f_{ij} \times E_a \times r \quad (1)$$

where ESV is the total value of ecosystem services (yuan); Ai is the area of type i land ecosystem; f_{ij} is the equivalent value per unit area of the j type ecosystem service of the i land ecosystem; E_a is the ecological ESV coefficient of the food production per unit area of the regional farmland ecosystem; and r is the equivalent factor correction coefficient.

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

Categories	Sub-Categories	Farmland	Forest	Grassland	Water Area	Unused Land	Construction Land
Supplying services	Food production	1	0.33	0.43	0.53	0.02	0
	Raw material	0.39	2.98	0.36	0.35	0.04	0
Regulating services	Gas regulation	0.72	4.32	1.5	0.51	0.06	0
	Climate regulation	0.97	4.07	1.56	2.06	0.13	0
	Hydrological regulation	0.77	4.09	1.53	18.77	0.07	0
	Waste treatment	1.39	1.72	1.32	14.85	0.26	0
Supporting services	Soil formation and retention	1.47	4.02	2.24	0.41	0.17	0
	Biodiversity protection	1.02	4.51	1.87	3.43	0.40	0
Cultural services	Recreation and culture	0.17	2.08	0.87	4.44	0.24	0

(2) Equivalent correction coefficient r

Due to the differences between ecosystems in different regions, relevant amendments should be made when calculating specific regions. According to the biomass factor table of farmland ecosystems in different provinces of China, developed by Xie et al. (2005) [39], the regional correction of China's ESV was expressed in the table, and the correction coefficient of Shaanxi Province was 0.51. According to the relevant data from the Shaanxi Regional Statistical Yearbook, the average grain yield of the Qinba Mountains in southern Shaanxi from 2000 to 2015 was 3227.33 kg/hm^2, which was 0.936 times that of the average grain yield of 3446.47 kg/hm^2 in Shaanxi Province during the same period. Therefore, the farmland ESV coefficient was revised to 0.477 of the national average.

(3) ESV of a standard equivalent E_t

Xie et al. (2008) [19] put the value of one equivalent factor as 1/7 of the national average grain yield market price. Many studies directly used the average value of food price over a certain year or several years to explore the evolution of ESV. However, there will be corresponding changes in different periods due to different natural, social and cultural conditions. The results obtained by calculating only the average value are quite different from the actual situation. For eliminating the impact of inflation, we introduced the consumer price index (CPI) accumulation coefficient to modify and develop the method for evaluating the value equivalent factor in unit area [40,41]. The formula for E_t is as follows:

$$CPI'_t = CPI_0 \times \frac{CPI_1}{100} \times \frac{CPI_2}{100} \ldots \frac{CPI_t}{100} (t = 0, 1, 2, \ldots, \text{n}) \tag{2}$$

$$E_t = P_t \times Q_t \times \frac{1}{7} \times \left(1 - \frac{CPI'_t - CPI_0}{CPI_0}\right) \tag{3}$$

where CPI'_t is the CPI accumulation coefficient; CPI_t is the CPI in the t year (this study takes the CPI in 2000 as the benchmark, that is $CPI_0 = 100$); E_t is the economic value of a standard unit of ESV equivalent factor in the study area and the unit is yuan·hm^{-2}; P_t is the unit price of grain in the t year, the unit is yuan·kg^{-1}; and Q_t is the grain output per unit area, and the unit is kg·hm^{-2}. The calculation result is shown in the following table (Table 2).

Table 2. Equivalent value table of ecological services per unit area.

Years	National Grain Price/(yuan·kg^{-1})	Unit Grain Yield/(kg·hm^{-2})	Unit Output/(yuan·hm^{-2})	Unit Equivalent Factor/(yuan)	CPI Accumulation Coefficient	Corrected Unit Equivalent Value/(yuan)
2000	0.967	5133	4964	709	100	339
2005	1.347	5897	7943	1135	107	505
2010	2.076	6353	13,189	1884	124	688
2015	2.326	7011	16,307	2329	142	646

(3) The method of Sensitivity test

To test whether the ESV is sensitive to the ESV coefficient and whether the evaluation results are credible, this study introduces the coefficient of sensitivity (CS) in economics [42]. Through the adjustment method of increasing or decreasing the equivalent coefficient, we compare the changes before and after the ESV, and judge the dependence of the total ESV on the change of the equivalent coefficient. The equation is as follows:

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

where CS is the coefficient sensitivity of a value, and a CS greater than 1 indicates that the ESV is elastic to the ESV coefficient, showing low reliability; a CS less than 1 indicates that the former is not elastic to the equivalence coefficient, and the result can be considered reliable. ESV_j and VC_{jk} represent the adjusted total value and equivalent coefficient of ecosystem services, respectively. The former unit is yuan and the latter unit is yuan/hm^2. In the same way ESV_i and VC_{ik}, respectively, represent the total value and equivalent coefficient of ecosystem services before adjustment. k represents different land use types.

2.2.2. Calculation of Socioeconomic Development Level of the Qinba Mountains

This study refers to the previous findings [27,33], combined with the availability of data, to weigh the level of the indicators of socioeconomic development, and finally chooses GDP per capita and local fiscal revenue per capita to reflect the scale of socioeconomic development; the proportion of the tertiary industry and the industrial added value indicators per capita reflect regional economic structure; the per capita net income of rural residents and the number of beds in health institutions per 1000 people reflect social security; the urbanization rate and total per capita social consumer goods reflect people's living standards. The weight of each index is determined by the entropy weight method [43]; then, the socioeconomic development level score of each district and county in the Qinba Mountains is calculated. The calculation process is as follows:

(1) Data standardization processing. Since the index data obtained from statistical yearbooks or local websites is not uniform in nature, dimension, order of magnitude, etc., we cannot directly use data indicators for in-depth analysis. Therefore, the range method is used to standardize the indicators.

(2) Calculate the entropy weight. The calculation formula of information entropy is as follows:

$$E_j = -lnn^{-1} \sum_{i=1}^{n} p_{ij} \ln p_{ij} \quad (5)$$

where $p_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}}$ and at the same time, the condition of $p_{ij} = 0$ is satisfied, $p_{ij} ln p_{ij} = 0$, and the range of entropy value should be satisfied that $e_{ij} \in [0, 1]$.

The weight of each indicator is as follows:

$$W_j = \frac{(1 - E_j)}{\sum_{i=1}^{n} (1 - E_j)} \quad (6)$$

where Y_{ij} is the index value after standardization using the range method, x_{ij} is the original index value, minx_{ij} is the minimum value of each index, maxx_{ij} is the maximum value of each index, n is the number of statistical indicators, E_j the information entropy of the jth index, and W_j is the weight of the jth indicator. The calculation results of the weights of each indicator are as follows (Table 3):

Table 3. Evaluation index system and weight of socioeconomic development level.

Index	Weights
GDP per capita (yuan)	0.105
Local fiscal revenue per capita (yuan)	0.112
Proportion of the tertiary industry (%)	0.058
Industrial added value per capita (yuan)	0.106
Urbanization rate (%)	0.301
Total per capita social consumer goods (yuan)	0.091
Number of beds in health care institutions per 1000 people (sheets)	0.129
Per capita net income of rural residents (yuan)	0.097

(3) Calculate the comprehensive index score. After using the entropy weight method to objectively determine the index weight, the socioeconomic development level of each

district and county in the Qinba mountains are calculated according to the index weight. Calculated as follows:

$$S_i = \sum_{j=1}^{n} w_j Y_{ij} \quad (7)$$

2.2.3. Coupling and Coordination Model

(1) Calculate the coordination index. The coupling degree is used to reflect the degree of interdependence between systems or elements [33]. The coordination index is an indicator to measure the degree of interdependence between the two. In this study, the coupling coordination index is used to measure the coupling coordination between ecology and socioeconomic development level in the Qinba Mountains. The equation is as follows:

$$D = \sqrt{C \cdot T} \quad (8)$$

$$C = 2 \cdot \sqrt{(U_1 \cdot U_2)/(U_1 + U_2)^2} \quad (9)$$

$$T = a \cdot U_1 + b \cdot U_2 \quad (10)$$

where D is the coordination index, $D \in [0, 1]$. The closer D is to 1, the more coordinated the two systems or elements are; and the closer D is to 0, the lower the degree of coordination between them is. C is the coupling degree, $C \in [0, 1]$. The closer C is to 1, the better the coupling state between the two systems or elements, and the closer to 0, the worse the coupling state between the two; T is the comprehensive coordination index of the two systems or elements, U_1 is the standardized ecosystem services, and U_2 is the score of socioeconomic development level; a and b are the undetermined coefficient, with $a + b = 1$. Since the relationship between socioeconomic development and ecological protection is mutually restrictive and interrelated, we use a value of 0.5 for both a and b, in line with previous studies [31].

(2) Divide the types of coupling coordination. In order to more intuitively explain the coupling development status between ESV and socioeconomic development, the coupling coordination degree is divided into five levels by using the equal spacing method, combined with the actual situation of the study area, and referring to the existing research [33] (Table 4).

Table 4. Types and levels of development of coupling and coordination between ESV and socioeconomic development.

Coupling Coordination Degree (D)	Coordination Level
0 ≤ D ≤ 0.2	Highly uncoordinated
0.2 < D ≤ 0.4	Basically uncoordinated
0.4 < D ≤ 0.6	Lowly coordinated
0.6 < D ≤ 0.8	Mediumly coordinated
0.8 < D ≤ 1	Highly coordinated

2.3. Data Sources

The data used in the study include food production data, land use data, and economic indicators. The land use and cover change (LUCC) data, which can meet user mapping accuracy demands at a scale of 1:100,000, is provided by the Data Center for Resources and Environmental Science, Chinese Academy of Sciences (RESDC) (http://www.resdc.cn, accessed on 18 November 2016). Based on the consistent use of the same methods, this database has been updated every 5 years using the Landsat TM/ETM (1990–2010) and Landsat 8 (2015) remote sensing images, with a spatial resolution of 30 m and the comprehensive evaluation accuracy of more than 93%. The data of Shaanxi Province in 2000, 2005, 2010, and 2015 were downloaded, including data for farmland, forest, grassland, water area, construction land, and unused land (Figure 2) [44,45]. The urbanization rate is replaced by the proportion of construction land in county land use. The data on grain prices and other economic indicators are derived from the China Yearbook of Agricultural Price Survey (2005, 2010, 2016) and the Shaanxi Regional Statistical Yearbook (2000–2016).

3. Results and Analysis

3.1. Evalution Analysis of ESV

3.1.1. Changes in Ecosystem Types

Table 5 shows the structure of land use types in the Qinba Mountains for 2000–2015. The grassland area made up the largest proportion in the study area, accounting for 41.23% in 2015, followed by forest land and farmland, accounting for 31.85% and 25.63%, respectively. For 2000–2015, the change in all kinds of the land area was relatively obvious. The grassland area reduced significantly, decreasing by 395.00 km^2, followed by farmland, decreasing by 58.52 km^2. The forest area increased significantly by 230.09 km^2. The proportion of construction land area increased continuously, from 0.53% in 2000 to 0.77% in 2015, with a total increase of 167.60 km^2. Due to the protection of water conservation areas by the South-to-North Water Transfers Strategy, the water area increased year by year. Overall, the area of all types changed greatly during 2000–2010, but the change was small during 2010–2015.

Table 5. Changes in land use types in the Qinba Mountains from 2000 to 2015.

Land-Use Types	**Percentage of Land Use Types (%)**				**Change in Land Area (km^2)**			
	2000	**2005**	**2010**	**2015**	**2000–2005**	**2005–2010**	**2010–2015**	**2000–2015**
Farmland	25.72	25.39	25.70	25.63	−231.14	219.60	−46.98	−58.52
Forest	31.52	31.60	31.87	31.85	58.63	184.55	−13.09	230.09
Grassland	41.80	41.97	41.23	41.23	120.29	−514.95	−0.34	−395.00
Water area	0.42	0.43	0.48	0.49	5.89	33.77	3.29	42.96
Unused land	0.01	0.01	0.02	0.03	0.02	6.26	6.60	12.88
Construction Land	0.53	0.60	0.70	0.77	46.32	70.77	50.51	167.60

Figure 3 shows the spatial distribution of ecosystems in the Qinba Mountains for 2000–2015. Grassland, as the main component, was mainly distributed in the middle and low mountains, while the forest land was distributed in the middle and high mountains, and the farmland was mainly distributed in the river valley areas. The change in the ecosystem was mainly distributed on both sides of the Hanjiang River and the Danjiang River, mainly in the low mountain and hilly areas. Due to the rapid development of urbanization (e.g., the urbanization rate of Hantai District increased from 6.20% in 2000 to 12.37% in 2015.), the ecosystems types in the flat top basins where the Hantai, Hanbin, and Shangzhou districts are located, were undergoing positive changes. Land for urban construction and rural development expanded by 167.60 km^2 over the past 16 years, occupying a large amount of arable land. Secondly, the implementation of ecological restoration policies, such as the Grain for Green project and the South-to-North Water Transfers from 2002 to 2008, has ensured the stability of the water conservation function in this area. The forest area increased gradually, with an additional area of 230.09 km^2 from 2000 to 2015, while grassland area gradually decreased, with a total decrease of 395.00 km^2 in this period.

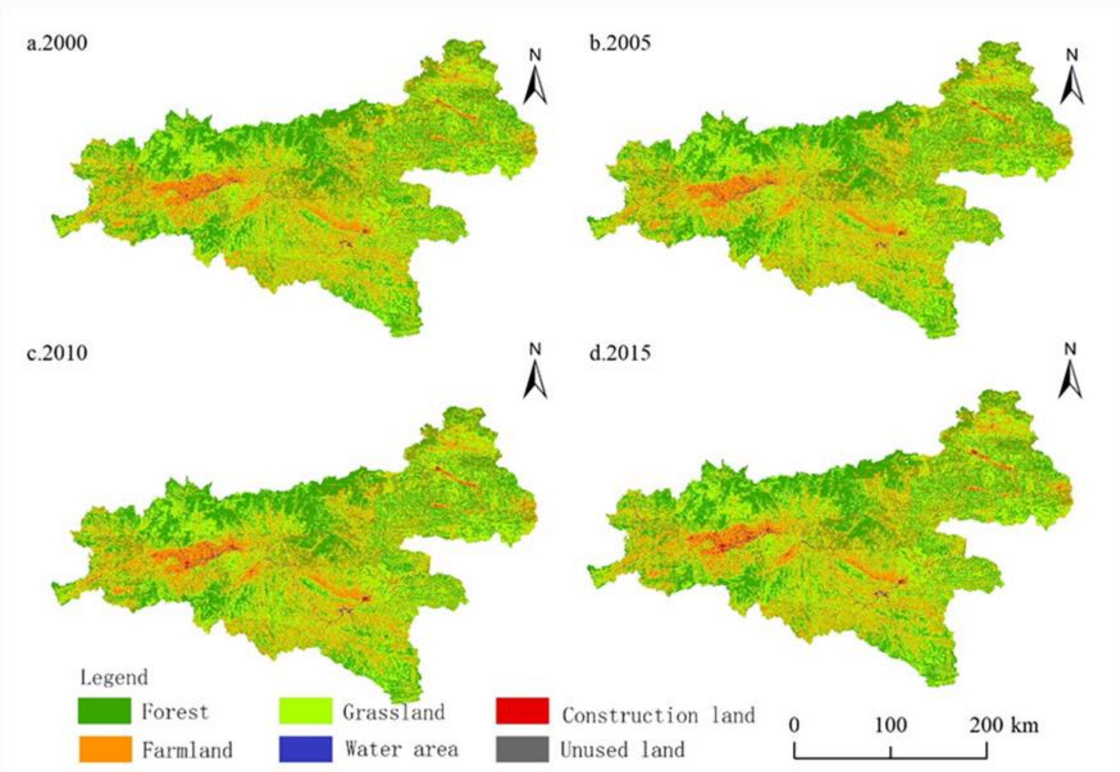

Figure 3. Spatial pattern of ecosystems in the Qinba Mountains in (**a**) 2000, (**b**) 2005, (**c**) 2010, and (**d**) 2015.

3.1.2. Temporal Changes in ESV

The ESV of the Qinba Mountains generally showed an upward trend, with a total increase of CNY 34.623 billion for 2000–2015. In 2000–2005 and 2005–2010, the value of ecosystem services increased evenly. The total ESV decreased slightly by CNY 4.777 billion from 2010 to 2015. During this period, the ESV increased in farmland, forest, grassland, water area, and unused land. Forest ESV increased the most, reaching CNY 19.514 billion, followed by grassland and farmland, with a total increase of CNY 145.67 billion. Among the five land use types, the ESV of forests accounts for the largest share of the total value, reaching 55.77%, followed by grassland and farmland, accounting for 42.92%, and unused land accounts for the smallest share. Except for unused land, water ecosystem service value grows the fastest, followed by forest, farmland, and grassland (Table 6).

Table 6. Changes in the value of ecosystem services in different land types in the Qinba Mountains from 2000 to 2015 (CNY 100 million).

Year	Farmland	Forest	Grassland	Water Area	Unused Land	Construction Land	Total
2000	48.25	210.51	115.95	4.57	0.00	0.00	379.28
2005	70.99	314.58	173.52	6.94	0.00	0.00	566.03
2010	97.97	432.39	232.39	10.52	0.01	0.00	773.28
2015	91.72	405.65	218.15	9.97	0.02	0.00	725.51
ESV increment	43.47	195.14	102.20	5.40	0.02	0.00	346.23
Average weight %	12.64	55.77	30.28	1.31	0.00	0.00	100.00
Growth rate%	90.09	92.70	88.14	118.16	438.20	0.00	/

The proportion and change rate of the value for each ecosystem service in 2000, 2005, 2010, and 2015 were calculated and integrated. Over the 16 years, the proportion of each functional value fluctuated in a small range, and the proportion composition was relatively stable (Table 7). These data indicate that the functions of soil formation and retention and biodiversity protection occupy the largest share of the composition, followed by hydrological regulation, climate regulation, and gas regulation (Table 7). It is worth noting that, although the four functions of soil formation and retention, biodiversity protection, gas regulation, and climate regulation accounted for a large proportion, their proportions showed a decreasing trend year by year for 2000–2015. From the perspective of increment change in value, for 2000–2015, the value of nine ecosystem services all increased, to a certain extent. Among these, the soil formation and retention and the biodiversity protection function value increments were the largest; the value increase for each function changed by nearly 50%, and for 2010–2015, the value increase of each function decreased slightly. The change in the growth rate in each period is characterized by a gradual decline. For 2010–2015, there was a small negative growth. Overall, the value of ecosystem services changed significantly for 2000–2015. The forest is the most important ecosystem in the Qinba Mountains. In 2015, the forest area accounted for 32.10% of all land use types, and its ESV accounted for 55.77%.

Table 7. Changes in the value of different ecosystem services in the Qinba Mountains from 2000 to 2015.

Categories	Proportion (%)				ESV Increment (CNY 100 Million)				Annual Rate of Change (%)			
	2000	2005	2010	2015	2000–2005	2005–2010	2010–2015	2000–2015	2000–2005	2005–2010	2010–2015	2000–2015
Food production	3.40	3.38	3.38	3.38	6.25	7.01	−1.64	11.62	48.42	36.59	−6.25	90.06
Raw material	7.46	7.46	7.49	7.49	13.94	15.66	−3.59	26.02	49.27	37.07	−6.19	91.93
Gas regulation	13.63	13.63	13.62	13.62	25.48	28.16	−6.51	47.13	49.30	36.50	−6.18	91.19
Climate regulation	13.73	13.73	13.72	13.72	25.65	28.39	−6.56	47.48	49.25	36.52	−6.19	91.15
Hydrological regulation	13.82	13.83	13.87	13.87	25.88	28.96	−6.59	48.24	49.38	36.99	−6.15	92.07
Waste treatment	9.48	9.47	9.49	9.49	17.65	19.78	−4.52	32.91	49.07	36.89	−6.16	91.49
Soil formation and retention	16.18	16.17	16.13	16.12	30.17	33.19	−7.72	55.64	49.18	36.26	−6.19	90.68
Biodiversity protection	15.53	15.53	15.52	15.52	29.02	32.08	−7.42	53.68	49.27	36.48	−6.18	91.14
Recreation and culture	6.77	6.78	6.78	6.78	12.71	14.03	−1.64	11.62	49.46	36.54	−6.15	91.51

3.1.3. Spatial Patterns of Change in the ESV

For 2000–2005, the ESV change rate for each county was 48.46–50.50%; for 2005–2010, the ESV change rate for each county was from 33.06% to 35.15%, and for 2010–2015, the ESV change rate was from −7.75% to 6.01%. The change rate of ESV in the counties in the Qinba Mountains over the past 16 years was above 80% for all counties, and the range of change was between 84.29% and 93.29%; the change in the average ecosystem service value of each county was 3606.26–6694.95 yuan/hm^2, with large spatial heterogeneity. Among these, the change rate of ESV in the whole area of Ankang City is relatively obvious, concentrated in Hanbin, Shiquan, Ziyang, and Langao counties and other places in the central district of Ankang City. The variability of Hanzhong and Shangluo cities is relatively small, while Shangzhou and Lueyang counties show prominent changes, in comparison with other counties. On the whole, the change in the counties in the Qinling Mountains is smaller than those in the Bashan Mountains (Figure 4a). According to the average value of land change (Figure 4b), the four counties in Ankang City showed little change, and the average land change value in Hanzhong and Ankang cities, located in the Bashan Mountains, is at a lower level, and the average land change values in Shangluo, Ankang City, and the northern part of Hanzhong City in the Qinling Mountains is relatively large. Thus, the ESV in the Qinling Mountains has a greater contribution to the region and is more stable than that of the Bashan Mountains.

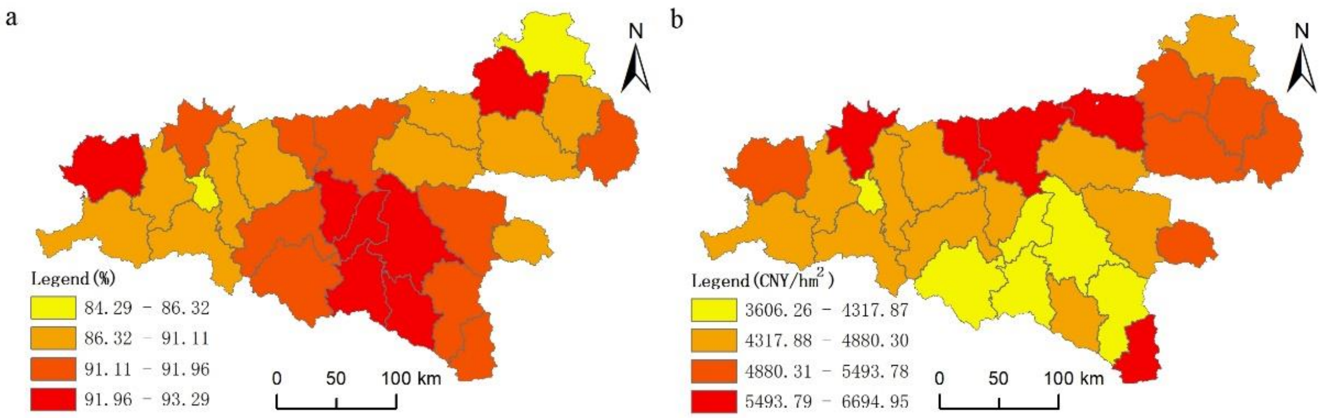

Figure 4. (**a**) Rate of change in ecosystem service value; (**b**) distribution of average ecosystem service value in the Qinba Mountains from 2000 to 2015.

3.1.4. Sensitivity Analysis

By increasing or decreasing the ESV of each land type by 50%, the sensitivity index of the ESV of each land type in four periods was obtained (Table 8). The sensitivity index was less than 1, indicating that the ecosystem services value coefficient of each land type in four periods was reliable. The sensitivity index of each type of land use, from large to small, is forest, grassland, farmland, water area, and unused land. Among these, forest land has the greatest impact and contribution on the total value of regional ecosystem services, and unused land makes the lowest contribution. The sensitivity index of various types of land differed little in the four periods of 2000, 2005, 2010, and 2015. The sensitivity index of forest land and water area increased slightly over time, while that of grassland decreased slightly.

Table 8. Coefficient of sensitivity derived from equivalence coefficient adjustment.

Land Use Types	2000	2005	2010	2015
Farmland	0.127	0.125	0.127	0.126
Forest	0.555	0.556	0.559	0.559
Grassland	0.306	0.307	0.301	0.301
Water area	0.012	0.012	0.014	0.014
Unused land	0.000	0.000	0.000	0.000

3.2. Analysis of Socioeconomic Development Level

3.2.1. Time Change of Socioeconomic Development Level

The score for the socioeconomic development level of each county in the Qinba Mountains for 2000–2015 was obtained using the comprehensive index method (Table 9). For 2000–2015, the socioeconomic development level of the Qinba Mountains increased significantly. The average level of socioeconomic development in 2000 was 0.025, 0.111 in 2005, 0.287 in 2010, and 0.577 in 2015. Over the past 16 years, the level of socioeconomic development has increased by 23 times. On the whole, from 2000 to 2015, the rapid economic growth of the counties in the Qinba Mountains benefited from the introduction of various national economic policies and ecological compensation measures. After 2000, the country began to fully implement the Western Development Strategy, led by the state to increase investment in the Western economy, laying the foundation for the rapid development of the Western region economy. The government of the Qinba mountains seized the opportunity to adjust the economic structure and change the mode of development, adopting the concept of circular economy to promote regional development. Due to this, the socioeconomic development of southern Shaanxi has achieved remarkable improvement.

Table 9. Scores of socioeconomic development levels of counties in the Qinba Mountains.

County	Si			
	2000	2005	2010	2015
Hanbin	0.018	0.098	0.301	0.583
Hanyin	0.022	0.082	0.294	0.602
Shiquan	0.030	0.086	0.315	0.569
Ningshan	0.028	0.114	0.300	0.557
Ziyang	0.010	0.180	0.289	0.521
Langao	0.026	0.112	0.280	0.582
Pingli	0.024	0.112	0.286	0.578
Zhenping	0.026	0.129	0.290	0.555
Xunyang	0.006	0.157	0.284	0.553
Baihe	0.019	0.074	0.309	0.597
shangzhou	0.006	0.085	0.299	0.610
Luonan	0.004	0.080	0.290	0.625
Danfeng	0.003	0.100	0.290	0.607
Shangnan	0.010	0.080	0.303	0.607
Shanyang	0.010	0.101	0.281	0.608
Zhen'an	0.162	0.213	0.154	0.471
Zhashui	0.021	0.074	0.339	0.566
Hantai	0.023	0.064	0.269	0.644
Nanzheng	0.034	0.077	0.248	0.641
Chenggu	0.009	0.104	0.270	0.617
Yangxian	0.001	0.084	0.349	0.567
Xixiang	0.005	0.056	0.328	0.611
Mianxian	0.015	0.072	0.320	0.592
Ningqiang	0.001	0.125	0.302	0.572
Lueyang	0.137	0.236	0.261	0.367
Zhenba	0.008	0.091	0.278	0.623
Liuba	0.006	0.159	0.270	0.566
Foping	0.041	0.158	0.236	0.565

3.2.2. Regional Differences in Socioeconomic Development Level

The socioeconomic development level of the counties in the Qinba Mountains showed a continuous upward trend for 2000–2015. However, the socioeconomic development within the region is unbalanced (Table 9, Figure 5). In 2000, there was little difference in socioeconomic level among counties in southern Shaanxi, except for Zhen'an County of Shangluo City and Lyuyang County of Hanzhong City, which had outstanding socioeconomic development levels, relying on local characteristic industries. In 2005, the socioeconomic development level of Zhen'an and Lueyang county continued to maintain their advantages. In addition, Ziyang and Xunyang counties in Ankang City relied on local tea brands and industrial and mining enterprises to promote economic development. Differences in the level of regional economic development have been highlighted. In 2010, with the national policy of southern Shaanxi boosting the economy of southern Shaanxi, the overall level of socioeconomic development of each county has improved, and Zhen'an and Lueyang counties no longer have a noticeable advantage. Zhashui and Yang counties, as well as other areas with beneficial transportation locations, have shown rapid development. In 2011, the formulation of the circular economy policy in southern Shaanxi coordinated the development of the inter-regional economy. In 2015, the economy developed rapidly in various regions, and the internal differences were obvious. Hantai District was in a dominant position, but Zhen 'an and Lueyang counties were still in a catch-up position. It was different traffic locations and resource advantages in different counties that led to different economic development rates.

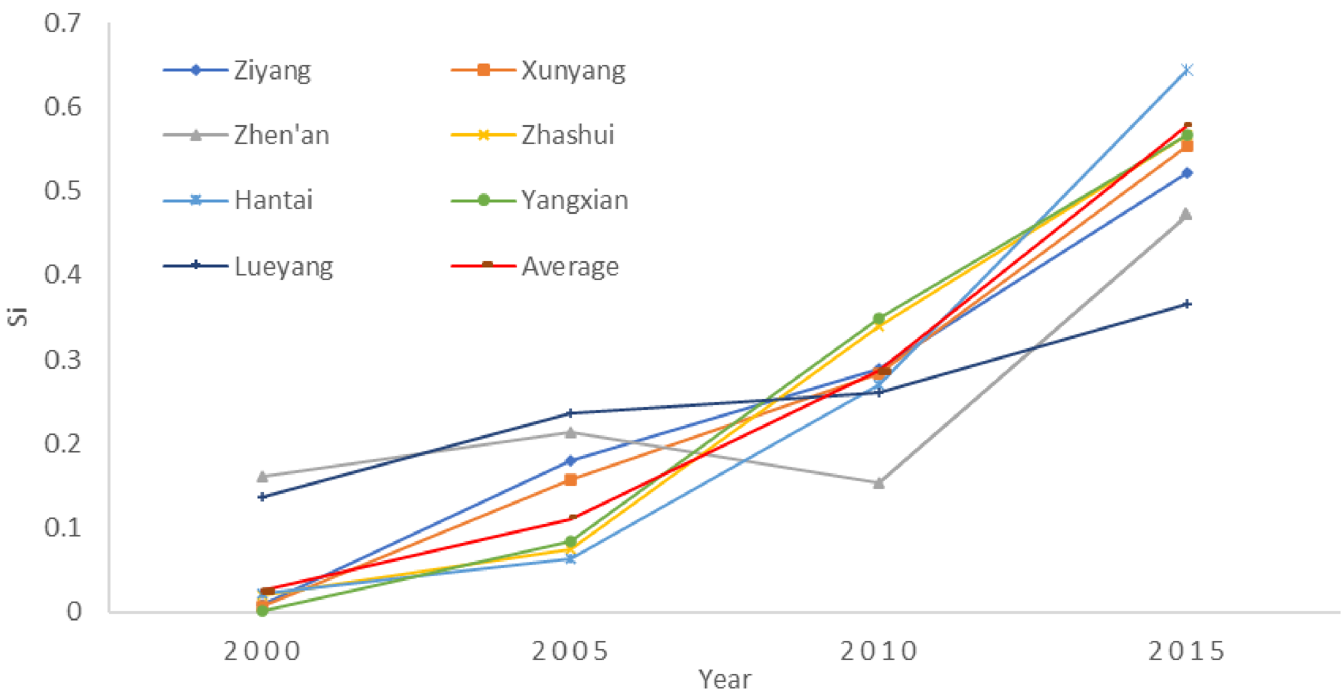

Figure 5. Socioeconomic development level of each county in the Qinba Mountains.

3.3. Coordination Analysis of ESV and Socioeconomic Development

The ecological and socioeconomic coupling coordination status of the study area improved during 2000–2015, and the number of highly incoordinated and basically coordinated counties decreases year by year, from the initial basically uncoordinated status to the final mediumly coordinated status. In 2000, 72.40% of the regions showed a basically uncoordinated status, and Hantai, Ningqiang, Yangxian, and Danfeng counties were in the highly uncoordinated state. By 2005, most of the counties designated as basically uncoordinated in 2000 had changed to a low coordination status, and the low coordination area accounted for about 84.05%. Zhen'an, Hanyin, and Baihe counties were still in a basically uncoordinated state, and only Hantai District was left as a highly uncoordinated area. In 2010, the medium coordination status was dominant, followed by the low coordination status, accounting for 61.15% and 38.07%, respectively. In 2015, medium coordination gradually replaced the low coordination status, and the medium coordination counties accounted for as high as 83.05% of the area, Ningshan and Shanyang counties showed a high degree of coordination, and the low coordination status (e.g., Foping, Shiquan, and Hanyin counties) did not change (Figure 6). It is worth noting that during the four periods, Hantai District has always shown a highly uncoordinated status. Further analysis shows that the socioeconomic development of Hantai District was better from 2000 to 2015, but its ESV showed negative growth. The rapid development of the economy led to the deterioration of the environmental situation, and finally led to the imbalance of economic and ecological development. On the whole, the ecological and socioeconomic coupling coordination level of the study area has increased year by year.

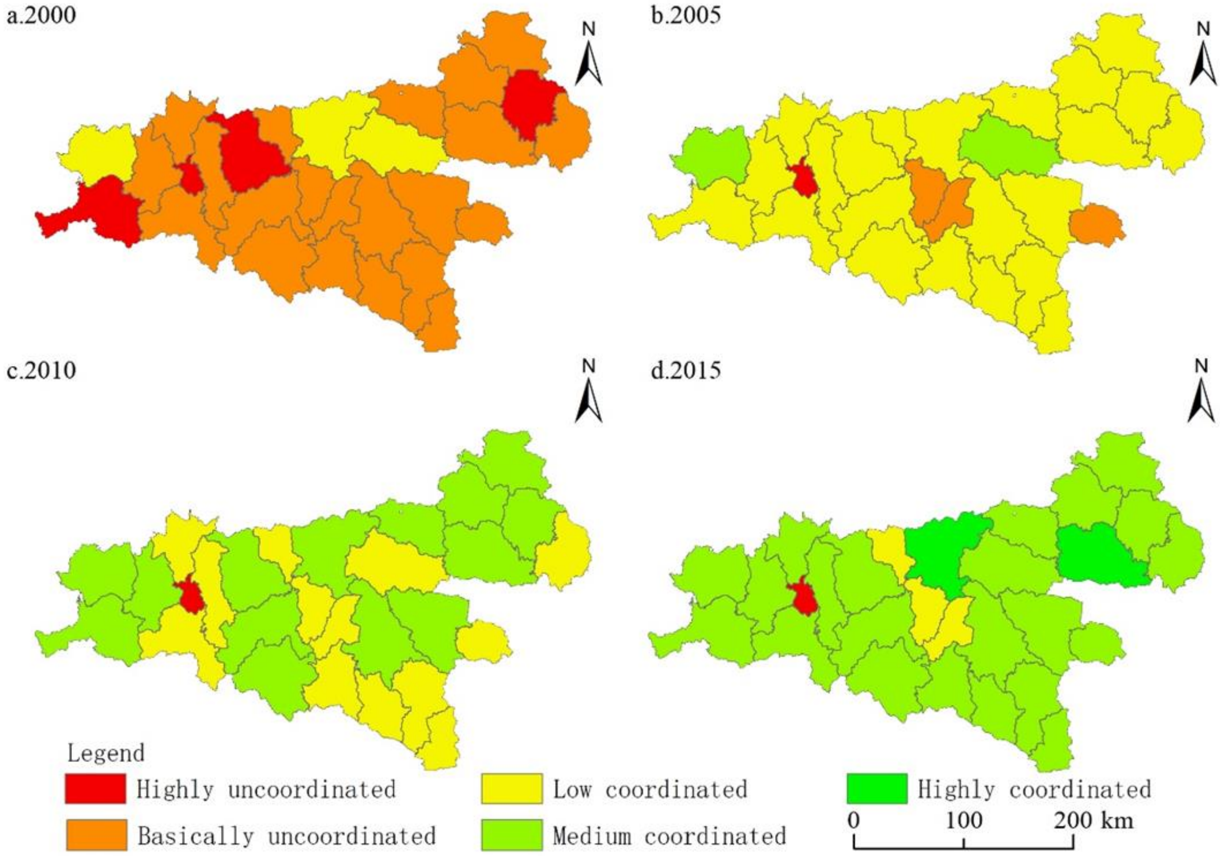

Figure 6. Ecological and socioeconomic coupling coordination degree of various counties in the Qinba Mountains in (**a**) 2000, (**b**) 2005, (**c**) 2010, and (**d**) 2015.

4. Discussion

The natural system is a fundamental condition for the coordinated development of ecological protection and socioeconomic development. How to balance ecological and environmental protection with socioeconomic development is an important issue to be addressed in the construction of ecological civilization. Without a better ecological environment, the cost of blind economic development will lead to the degradation of ecosystem functions, and the economic effect will drop sharply [46,47]. Therefore, to achieve the sustainable development of ecology and economy in the Qinba Mountains, more attention should be paid to continuing to implement the Grain for Green project, optimizing the land use structure, and improving the efficiency of land allocation in future development, according to local conditions. First of all, we should maintain the current coordinated development trend, promoting the development model of a green circular economy, such as in Ningshan and Shanyang counties, and then promote sustainable development throughout the Qinba Mountains. Faced with the problem of uncoordinated ecological and economic development in the Hantai District, the change in regional land use has led to serious ecosystem degradation [25,48]. It is necessary to fully consider the carrying capacity of the regional ecological environment. In the two aspects of strengthening ecological and environmental protection and adjusting the economic structure, we must strike a balance between development and protection.

Compared with the same research content in the existing studies, the current coupling studies focus on the urban agglomerations [26,33], economic belts [27,28], and other areas around the large towns or the economically active areas in the east. Relatively little attention has been paid to the special geographical location of ecological function in contiguous destitute areas. Compared with the ESV assessment study using the same study area [49], the research results of the two in terms of the year-by-year change of ESV and regional differentiation are basically the same, which proves that the results of this study are reliable. This study further discusses the coupling relationship between ecology and economy, in combination with the change in socioeconomic development level in the study area. However, the value evaluation method based on the equivalent value factor also has shortcomings and defects, such as over-reliance on data interpreted by remote sensing satellite images [1]. Ecosystems are complex and diverse, and the food yield data cannot fully explain the problem. For example different vegetation coverage, stand structures, and the estimation of land type value of regional locations are not fully considered in the assessment [50]. Moreover, the urban green space in the construction is neglected in the calculation process. Whether this approach is scientific or not, it still deserves further study and reflection. At the same time, ESV is affected by climate change and cultural and economic factors [47,51], the assessment of ecosystem services is sometimes inaccurate [52,53]. In future studies, it will be necessary to use a more accurate computational model of the ESV and to employ a variety of methods to correct it. We should also start with more dimensions of ecological environment elements and more diverse socioeconomic development data. Further research is needed to explore the mechanisms of coupling and mutual feedback between ecology and economy. The relationship between economy and ecology is both separate and interconnected. First of all, socioeconomic development will coerce or facilitate ecosystem services. Secondly, weak ecosystem services can slow down or inhibit social and economic development. Only by coordinating the relationship between the two above can we achieve sustainable development [8,9,29,54]. The value realization mechanism for ecological products should be established and improved to promote the effective conversion of ESV. The coordinated development of the social-ecological systems is an important condition for the sustainable development of contiguous destitute areas, which have some capacity for self-organization and are affected by both human activities and climate change. The variations in the relationship between the economy and ecology show nonlinear and non-stationary complex dynamic features. The ecosystem is an important support for human well-being and socioeconomic development [6]. Only under the premise of reasonable ESV and sustainable transformation can a regional economy develop with high quality and attract more investment. Blindly pursuing the conversion ESV can easily lead to problems such as the overburdening of the ecosystem's carrying capacity, etc. [55]. In short, we should focus more on development and protection.

5. Conclusions

(1) In terms of changes in ESV, changes in forest area have the greatest impact on ESV. With the increase in forest area, the ecosystem service value of the study area also increased. For 2000–2015, the forest area increased by 230.09 km^2, and the value of ecosystem services in the study area increased by CNY 19.514 billion.

(2) In the aspect of socioeconomic development, with the help of relevant policies, the level of socioeconomic development in the study area has risen steadily, and the vitality of

socioeconomic development has continued to improve. The socioeconomic development level score rose from 0.025 in 2000 to 0.577 in 2015. In the course of development, there is still the problem of unbalanced economic development within the region.

(3) In the coordinated development of natural ecology and socio-economy respect, Hantai District has been highly uncoordinated. The coordinated development of the counties in the Qinba Mountains is in good condition, and the degree of coupling coordination shows a trend of improvement. In 2015, 83.05% of the districts were mediumly coordinated, and Ningshan and Shanyang counties were highly coordinated.

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