

## Article

# The Coordination of Water Resources and Economic Development in a Water-Scarce Area: An Ecosystem Service Perspective

Jie Cao <sup>1</sup>, Jie Zhang <sup>2,\*</sup>, Zhengqi He <sup>1</sup> and Lianyan Xu <sup>3</sup>

<sup>1</sup> Department of Finance, Business School, Hohai University, Nanjing 211100, China; jayc@hhu.edu.cn (J.C.)  
hzq1309@hhu.edu.cn (Z.H.)

<sup>2</sup> Department of Accounting, Business School, Hohai University, Nanjing 211100, China

<sup>3</sup> Yangzhou University, Yangzhou 225012, China; xulianyan@126.com

\* Correspondence: jiecaohhu@gmail.com; Tel.: +86-18205163045

**Abstract:** In water-scarce areas, there is a complex interrelationship between water resources and economic development. This paper studies the relationship between water resources and economic development from an ecosystem services perspective. This paper selected the value of river ecosystem service functions and the comprehensive index of economic development in the Yellow River Basin (YRB) from 2007 to 2018 as the research object, tested the synergy of ecosystem service functions in the basin, and introduced a coupling coordination model to evaluate the synergy of developmental factors. The research results showed that (1) the overall river ecosystem service value in YRB was on the rise, and its distribution was characterized by a high value in the lower reaches and a gradual decrease from the middle reaches to the upper reaches; (2) the synergy of river ecosystem service functions in YRB was mainly reflected in the supply and regulation functions, and the synergy of cultural functions should be improved; (3) the overall coupling and coordination degree showed an upward trend. However, judging from the characteristics of coupled and coordinated degrees, backward ecological development is a long-term problem. This article will help to put forward countermeasures and suggestions for the coordinated development of the river ecosystem service value and regional economy in YRB.

**Keywords:** river ecosystem service; economic development; the coupling coordination degree; sustainable development; water resources



**Citation:** Cao, J.; Zhang, J.; He, Z.; Xu, L. The Coordination of Water Resources and Economic Development in a Water-Scarce Area: An Ecosystem Service Perspective. *Water* **2024**, *16*, 3636. <https://doi.org/10.3390/w16243636>

Academic Editor: Julie Kinzelman

Received: 1 November 2024

Revised: 3 December 2024

Accepted: 16 December 2024

Published: 17 December 2024



**Copyright:** © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

Ecosystem service function refers to the natural environmental conditions and utility formed by ecosystems and ecological processes on which human beings depend for survival and is an important basis for regional sustainable development [1]. Since the concept of ecosystem services was introduced, there has been a growing awareness that ecosystem services were much more important to human well-being than conventional economic thinking had given them credit for [2]. The evaluation of the value of ecosystem services has become an important part of ecosystem sustainability research. Many researchers, for example [3–5], used different methods to measure the value of different ecosystem services, including the material quantity and economic value methods. The economic value measurement method is a method of quantifying various services and their values provided by the ecosystem in the form of currency [6]; that is, ecosystem services with economic value are regarded as “natural capital” for accounting [7]. In terms of value assessment of ecosystem services, Costanza et al. [8] first proposed the scope of ecosystems, their service functions, and accounting methods in Nature, which pushed the research on ecosystem services to a new level centered on value accounting.

Among researchers focused on this area of study, water-related ecosystem services have received much attention. Xu [9] considered that the river ecosystem service system provides basic conditions such as water resources which are necessary for social and

economic development, convenient transportation and shipping, and a suitable climate environment. Wilson [10] used travel cost methods, hedonic pricing methods, and conditional valuation methods to account for the economic value of non-market goods and services provided by US surface freshwater systems. Ouyang [11] divided the service functions of China's water ecosystem into four categories, and constructed a water ecosystem indirect value evaluation index system consisting of eight functions, including flood regulation and storage, water storage, and soil conservation. Thiele et al. [12] and Young et al. [13] assessed river ecosystem services to study their importance in providing different functions. In some water-scarce areas, water-related ecosystems play a dramatic role in sustaining local economic development and human welfare. At the same time, socio-economic activities can have an impact on local water ecosystems. Costanza et al. [8] proposed that the linkages between ecosystem processes and functions and human well-being are complex and the various pathways are still not well understood. Pluralistic and preventive approaches should be taken to assess these linkages and assess their benefits.

The relationship between ecosystem and economic development and water resources and economic development has been extensively studied. Wang [14] used the coupled coordination model to study the temporal and spatial evolution of the coordination degree between the quality of ecological protection and the level of economic development in the Yangtze River Economic Belt. In discussing the synergistic relationship between single ecological resource such as water resources, land resources, and regional economic development, Yang [15] used the system-coordinated development model to conduct dynamic coupling and spatial pattern analysis on the economic development and water environment system of the Songhua River Basin. Cao [16] calculated the ecosystem service value of Chongqing based on different land use types and conducted spatial autocorrelation analysis with economic development indicators. Based on the water footprint theory and water resources balance table, a quantity–quality–benefit model was constructed to evaluate the sustainability of water resources, and a coupling coordination degree model was introduced to evaluate the sustainability of water resources in the Yangtze River [17]. Some scholars have also researched the coupling coordination relationships among complex systems, such as ecology–economy–energy [18], and energy–economy–environment–society [18].

Existing studies have provided rich research results and theoretical references related to the evaluation of ecosystem service value and the relationship between regional ecological protection and economic growth. However, it is insufficient to study the relationship between different functions of water and economic development from the perspective of ecosystem services alone, especially in water-scarce areas. There is a complex interrelationship between water resources and economic development in these locations, so it is necessary to expand new research perspectives to interpret the complex relationship between them. This paper took nine provinces in Yellow River Basin (hereinafter referred to as YRB) as the research object, calculated the value of ecosystem services in YRB from 2007 to 2018 and deeply analyzed the correlation of various ecological service values, the synergy between ecological protection and economic development, and the regular pattern of temporal and spatial evolution. The coupling coordination degree of economic development and ecosystem service value was measured and the contributing factors were analyzed.

## 2. Study Area

### 2.1. River Ecosystem Service System in YRB

The Yellow River Basin (YRB) is not only an important ecological security barrier in China but also an important area for regional social and economic development. The Yellow River Basin ecological protection and high-quality development planning outline proposes to further improve the human–water relationship in the basin by 2030, with the goal of achieving a healthy and stable YRB ecosystem by 2035. The realization of the above planning objectives requires the YRB to correctly acknowledge the relationship between ecological protection and economic development from a dialectical perspective.

The YRB is located in northern and central China, with a length of about 5464 km, flowing through the Qinghai–Tibet Plateau, the Inner Mongolia Plateau, the Loess Plateau and the North China Plain. The basin plays an important role in water, soil and biodiversity conservation. At the same time, the YRB is also an important economic region in China, covering several provinces and regions, including Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan and Shandong, which are sites of national grain production and act as energy bases. However, the region also faces environmental problems such as water shortages, soil erosion and pollution. The ecosystem service system of the YRB includes six categories: forest, grassland, farmland, wetland, river and desert [19]. Based on the theory of sustainable development, referring to the “three-circle model” proposed by Zhang et al. [20], the structure of the river ecosystem service system in the YRB is shown in Figure 1.

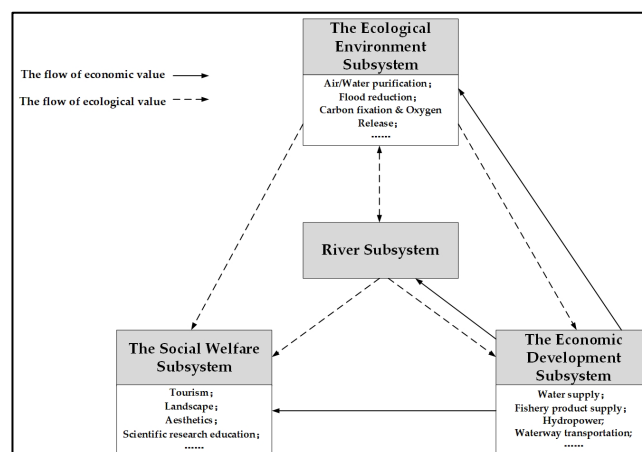


**Figure 1.** Structure of river ecosystem service system in the YRB.

It can be seen from Figure 1 that the river ecosystem service system in the YRB is composed of the ecological environment subsystem, the economic development subsystem, the social welfare subsystem, and the river subsystem. There is a flow of ecological value and economic value among the subsystems. Among them, the ecological environment subsystem mainly focuses on regulating functions, including functions such as water purification, air purification, carbon fixation and oxygen release, and flood regulation. The economic development subsystem mainly focuses on the supply functions, including water resource supply, fishery product supply, hydropower generation, and inland shipping. The social welfare subsystem mainly focuses on cultural functions, including functions such as tourism, cultural inheritance, ecological aesthetics, scientific research, and education. From the perspective of value flow, the river subsystem provides direct ecological value to the other subsystems. At the same time, the ecological environment subsystem provides ecosystem services value for the river subsystem, economic development service subsystem, and social welfare subsystem through various functions. The economic development service subsystem utilizes the ecosystem functions provided by the river subsystem and the ecological environment subsystem, transforms them into economic value, and then flows to the remaining subsystems. The social welfare subsystem provides a large amount of indirect ecological service value for human society by making full use of the economic value and ecological value. Only when the four subsystems are coupled and coordinated within the basin can the high-quality development of YRB as a whole be promoted.

## 2.2. River Ecosystem Services in Nine Provinces of YRB

According to the analysis of the YRB ecosystem service system, following the principles of data availability and operability, and based on the classification of river ecosystem service functions in existing literature, this paper divided the river ecosystem service functions of the YRB into supply, regulation and cultural functions. Among them, the

river subsystem and economic development subsystem provide the supply function, the ecological environment service subsystem provides the adjustment function, and the social welfare service subsystem provides the cultural function. The secondary functions are shown in Table 1. Due to the limitations of multiple factors, such as geographical location and climatic conditions, the ecosystem service functions of rivers in different provinces in YRB are different.

**Table 1.** River ecosystem services in nine provinces of YRB.

| Functional Classification | Specific Function                  | Shanxi | Inner Mongolia | Shandong | Henan | Sichuan | Shaanxi | Gansu | Qinghai | Ningxia |
|---------------------------|------------------------------------|--------|----------------|----------|-------|---------|---------|-------|---------|---------|
| Supply Function           | Fishery product supply             | ✓      | ✓              | ✓        | ✓     | ✓       | ✓       | ✓     | ✓       | ✓       |
|                           | Water supply                       | ✓      | ✓              | ✓        | ✓     | ✓       | ✓       | ✓     | ✓       | ✓       |
|                           | Hydropower                         | ✓      | ✓              |          | ✓     |         | ✓       | ✓     | ✓       | ✓       |
|                           | Waterway Transportation            | ✓      |                |          |       | ✓       | ✓       |       |         |         |
| Regulatory Function       | Water purification                 | ✓      | ✓              | ✓        | ✓     | ✓       | ✓       | ✓     | ✓       | ✓       |
|                           | Air purification                   | ✓      | ✓              | ✓        | ✓     | ✓       | ✓       | ✓     | ✓       | ✓       |
|                           | Carbon fixation and oxygen release | ✓      | ✓              | ✓        | ✓     | ✓       | ✓       | ✓     | ✓       | ✓       |
|                           | Flood regulation                   | ✓      | ✓              | ✓        | ✓     | ✓       | ✓       | ✓     | ✓       | ✓       |
| Cultural Function         | Tourism                            | ✓      | ✓              | ✓        | ✓     | ✓       | ✓       | ✓     | ✓       | ✓       |

### 3. Materials and Methods

#### 3.1. Methods

The first step was to calculate the value of river ecosystem services. Commonly used ecosystem service value assessment methods include market value, shadow engineering, and afforestation cost. The calculation formulas of river ecosystem service value (hereinafter referred to as ESV) and area-average river ecosystem service value (hereinafter referred to as AESV) and their change rates in the YRB were developed using these methods (Table 2).

**Table 2.** Index system and method of river ecosystem service value accounting in YRB.

| Functions       | Indicators              | Methods             | Formulas                                                                                                                                                                          |
|-----------------|-------------------------|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Supply function | Fishery product supply  | Market value method | $V_a = \sum V_n$ $V_n: \text{Production value of different types of aquatic products in rivers}$                                                                                  |
|                 | Water supply            |                     | $V_b = \sum (Q_i \times P_i)$ $Q_i: \text{Water consumption by different types of use } P_i: \text{Water prices for different types of use}$                                      |
|                 | Hydropower              |                     | $V_c = \sum (Y_i \times W_j)$ $Y_i: \text{The annual power generation of each hydropower station}$ $W_j: \text{unit electricity price}$                                           |
|                 | Waterway Transportation |                     | $V_d = T_i \times P_i + T_j \times P_j$ $T_i: \text{Annual turnover of goods}$ $T_j: \text{Annual Passenger Turnover}$ $P_i: \text{Shipping price}$ $P_j: \text{Passenger price}$ |

Table 2. Cont.

| Functions                                | Indicators                                                       | Methods                                            | Formulas                                                                                                                                                                                                                                                                                                                                                                                                      |
|------------------------------------------|------------------------------------------------------------------|----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Regulatory function                      | Water purification                                               | Shadow engineering method                          | $V_e = \sum(Q_i \times P_i)$ $Q_i$ : The weight of different kinds of pollutants<br>$P_i$ : Treatment costs for different types of pollutants                                                                                                                                                                                                                                                                 |
|                                          | Air purification                                                 |                                                    | $V_f = Q_i \times S_i \times P_i$ $S_i$ : Surface area of river water in different provinces<br>$P_i$ : Industrial dust treatment costs<br>$Q_i$ : The weight of dust absorbed on the surface of river water in different provinces                                                                                                                                                                           |
|                                          | Carbon fixation and oxygen release                               | Forestation cost method; shadow engineering method | $V_g = V_{g1} + V_{g2}; V_{g1} = Q_{g1} \times P_{g1}; V_{g2} = Q_{g2} \times P_{g2}$ $Q_{g1}$ : Amount of fixed carbon dioxide<br>$P_{g1}$ : Cost price of urban afforestation<br>$Q_{g2}$ : Amount of oxygen released<br>$P_{g2}$ : Industrial oxygen production cost<br>$V_{g1}$ : The value of carbon sequestration in river ecosystems<br>$V_{g2}$ : Value of oxygen release function in river ecosystem |
|                                          | Flood reduction                                                  | Shadow engineering method                          | $V_h = Q_h \times P_h; Q_h$<br>$Q_h$ : Reservoir annual storage capacity<br>$P_h$ : The construction cost per unit of reservoir storage capacity                                                                                                                                                                                                                                                              |
| Cultural function                        | Tourism                                                          | Travel expense method                              | $V_k = T_e + T_t + T_s; T_t = W_s \div 3; T_s = T_e \times 40\%$ $T_e$ : Comprehensive income of local tourism industry<br>$T_t$ : Traveler time cost<br>$T_s$ : Consumer surplus for tourists<br>$W_s$ : The average wage of urban workers divided by the annual working hours                                                                                                                               |
| Total ecosystem service value            | River ecosystem service value (ESV)                              |                                                    | $ESV = \sum(V_a + V_b + V_c + V_d + V_e + V_f + V_g + V_h + V_k)$                                                                                                                                                                                                                                                                                                                                             |
| Average land value of ecosystem services | Average river ecosystem service value (AESV) and its change rate |                                                    | $AESV = \frac{ESV}{S}$ $F = \frac{AESV_{t2} - AESV_{t1}}{AESV_{t1}} \times 100\%$ $AESV_{t1} \text{ \& } AESV_{t2}$ : Average river ecosystem service value at $t_1$ and $t_2$ time<br>$F$ : Average ecosystem service value change rate<br>$S$ : Area of each province                                                                                                                                       |

The second step was to design an index system for evaluating economic development and to calculate the index weight. To reflect the level of regional economic development, this paper drew on the existing literature [21–23] and adopted the comprehensive index method. According to current economic development in the YRB, and following the principles of scientificity, availability, and comparability, an index system including economic development scale, structure and quality was constructed. The weight of the index was calculated using the entropy method, as shown in Table 3.

Coupling coordination degree evaluation between ecology and economy adopted the coupling coordination degree model. The TOPSIS method was used to calculate the comprehensive index of river ecosystem service value (ESV) and economic development. TOPSIS is a multi-attribute decision-making evaluation method commonly used in system engineering, which can ensure the scientific rationality of data. The coupling coordination degree model is widely used in research on coupling coordination relationships among multiple systems, which can reflect the coupling strength between ESV and economic development. Referring to the work of Han et al. [24], who studied the coupling synergistic

effect between complex systems, this paper constructed the following “ESV–economic development” coupling coordination model.

$$D = \sqrt{C \times T} \quad (1)$$

$$C = 2 \times \sqrt{(U_1 \times U_2) \div (U_1 + U_2)^2} \quad (2)$$

$$T = a \times U_1 + b \times U_2 \quad (3)$$

**Table 3.** Economic development evaluation index system and weight.

| Division Criteria  | Indicators                                                  | Unit                                  | Weights |
|--------------------|-------------------------------------------------------------|---------------------------------------|---------|
| Economic scale     | Gross regional product                                      | 100 million CNY                       | 0.094   |
|                    | Total retail sales of consumer goods                        |                                       | 0.076   |
|                    | Local fiscal revenue                                        |                                       | 0.066   |
|                    | Total social investment in fixed assets                     |                                       | 0.083   |
| Economic structure | Contribution rate of the secondary industry                 | Percentage                            | 0.091   |
|                    | Contribution rate of the tertiary industry                  |                                       | 0.093   |
|                    | Proportion of employed population in the secondary industry |                                       | 0.064   |
|                    | Proportion of employed population in the tertiary industry  |                                       | 0.071   |
| Economic quality   | Energy consumption per ten thousand CNY GDP                 | Ton of standard coal/ten thousand CNY | 0.117   |
|                    | Urban residents' per capita disposable income               | CNY                                   | 0.078   |
|                    | Rural residents' per capita disposable income               | CNY                                   | 0.079   |
|                    | Income ratio of urban to rural residents                    | Percentage                            | 0.088   |

In Formula (1),  $D$  is the coupling degree of coordination, and the value range is from 0 to 1. The larger the value, the more coordinated the development of the two systems, and vice versa; the lower the value, the lower the degree of coordination between the two systems. In Formula (2),  $C$  is the degree of coupling, and the value range is from 0 to 1. The larger the value, the better the coupling state between the two systems; otherwise, the two systems will tend to develop in a disorderly manner.  $U_1$  and  $U_2$  are the composite indexes of ESV and economic development, respectively. In Formula (3),  $T$  is the composite coordination index of the two systems;  $a$  and  $b$  are hypothetical coefficients. This paper believes that the growth of ecosystem service value and economic growth need to be given equal attention, so  $a = b = 0.5$  was taken.

At the same time, to reflect the gap between ESV and economic development, this paper drew on Sun et al.'s [25] research results and introduced a relative development model to judge whether the ESV and economic development in the basin are in a lagging or leading state. The judgment criteria are detailed in Table 4.

$$Z = \frac{U_1}{U_2} \quad (4)$$

In the Formula (4),  $Z$  is the relative degree of development.  $U_1$ ,  $U_2$  are the composite index of ESV and economic development, respectively.

**Table 4.** Coupling coordinated development type and dividing standard.

| Coupling Degree of Coordination | Relative Degree of Development | Coupling Coordination Type | Developmental Characteristics        |
|---------------------------------|--------------------------------|----------------------------|--------------------------------------|
| $0 < D \leq 0.2$                | $0 < Z \leq 2$                 | Severe disorder            | Severe disorder—ecological lag       |
|                                 | $2 < Z \leq 4$                 |                            | Severe disorder                      |
|                                 | $Z > 4$                        |                            | Severe disorder—economic lag         |
| $0.2 < D \leq 0.4$              | $0 < Z \leq 2$                 | Moderate disorder          | Moderate disorder—ecological lag     |
|                                 | $2 < Z \leq 4$                 |                            | Moderate disorder                    |
|                                 | $Z > 4$                        |                            | Moderate disorder—economic lag       |
| $0.4 < D \leq 0.6$              | $0 < Z \leq 2$                 | Basic coordination         | Basic coordination—ecological lag    |
|                                 | $2 < Z \leq 4$                 |                            | Basic coordination                   |
|                                 | $Z > 4$                        |                            | Basic coordination—economic lag      |
| $0.6 < D \leq 0.8$              | $0 < Z \leq 2$                 | Moderate coordination      | Moderate coordination—ecological lag |
|                                 | $2 < Z \leq 4$                 |                            | Moderate coordination                |
|                                 | $Z > 4$                        |                            | Moderate coordination—economic lag   |
| $0.8 < D \leq 1$                | $0 < Z \leq 2$                 | High coordination          | High coordination—ecological lag     |
|                                 | $2 < Z \leq 4$                 |                            | High coordination                    |
|                                 | $Z > 4$                        |                            | High coordination—economic lag       |

### 3.2. Data Sources

Since the concept of China's ecological compensation policy was gradually clarified and solidified in 2006, relevant policies have been subsequently put into practice one after another. Comprehensively considering the availability of data, the research period was selected as 2007–2018. The agricultural, economic, and water conservancy data used in the study come from the statistical yearbooks of various provinces, the annual fishery data of the Ministry of Agriculture and Rural Affairs of the People's Republic of China, the Water Resources Bulletin, the *Water Conservancy Statistical Yearbook*, the Yellow River Water Resources Bulletin, data published by local price bureaus, and provincial tourism industry annual statistical reports. A small amount of missing data were filled by interpolation.

## 4. Results

### 4.1. Research Results of Ecosystem Service Value in YRB

Figure 2 shows that as of 2018, the order of river ecosystem service value in the nine provinces of YRB from high to low is as follows: Shanxi (CNY 671.192 billion), Shaanxi (CNY 648.308 billion), Henan (CNY 345.885 billion), Shandong (CNY 186.182 billion), Gansu (CNY 160.452 billion), Qinghai (CNY 140.092 billion), Inner Mongolia (CNY 116.852 billion), Sichuan (CNY 69.987 billion) and Ningxia (CNY 50.6 billion). Basin-wide, the river ecosystem service value of the middle reaches was greater downstream than that of the upstream reaches. In terms of changing trends, Shanxi Province had the largest increase (+592%), followed by Shaanxi (+503%), Sichuan (+415%), Henan (+195%), Qinghai (+205%), Inner Mongolia (+203%), Ningxia (+180%), Gansu (+157%) and Shandong (+150%). The areas with larger increases in river ecosystem service value were mainly distributed in the middle and lower reaches, especially the middle reaches, while the upper reaches had the smallest growth rate.

To study the regional differences in ecosystem service value more intuitively, this paper introduced the AESV and its change rate (the calculation formula, as presented in Table 2). The number of provinces with an average ecosystem service value of more than CNY 7000 per hectare rose from only one in 2007 to five in 2018, and the value of river ecosystem services also gradually improved (Figure 3). This change could possibly be attributed to greening projects such as watershed ecological restoration which have been implemented in recent years. From the perspective of space, AESV was characterized as low upstream and high in the middle and downstream. Specifically, high-value areas have been concentrated in Shaanxi, Shanxi, Henan, and Shandong provinces in recent years. Compared with the upstream areas, these areas are relatively scarce in natural resources, denser in population and have greater levels of urbanization and more developed economies. By 2018, Ningxia

also became a high-value area of ecosystem service value per land. On the one hand, this is because Ningxia is located in the upper reaches of the Yellow River, which is rich in ecological resources, and has a relatively large amount of ecological capital. On the other hand, this development is also related to Ningxia's vigorous implementation of the ecological zone strategy and the integration of ecological civilization construction into the track of legalization and institutionalization.

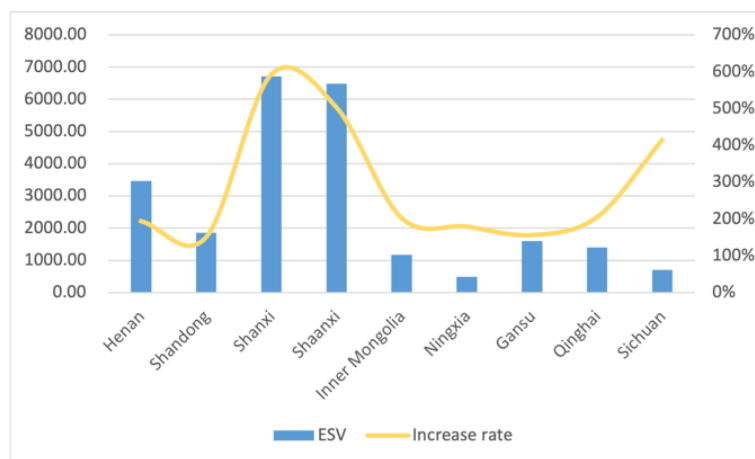


**Figure 2.** River ecosystem service value and change rate in 2018.

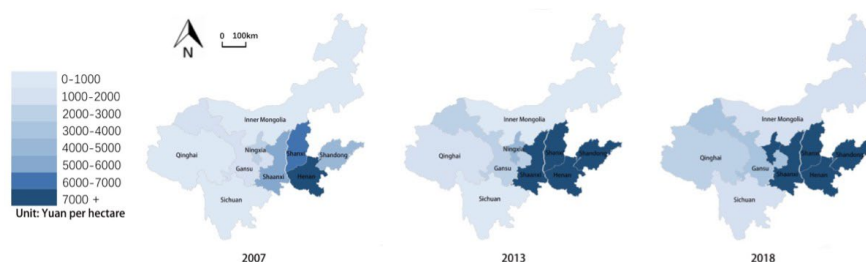


**Figure 3.** Spatial distribution of land average ecosystem service value of YRB from 2007 to 2018.

Judging from the temporal change in the land-average ecosystem service value change rate, the basin showed that the change rate of AESV in the whole region was greater than 0. The change rate was larger in the upper reaches and stable in the middle and lower reaches (Figure 4). The range of AESV change in the upper reaches can be divided into three types: “decrease first and then increase”, “first increase and then decrease”, and “continuous increase”. The area of “decrease first and then increase” was typified by Qinghai Province. The growth rate slowed down significantly from 2011 to 2015, and picked up slightly from 2015 to 2018. Typical regions of the “increase first and then decrease” type were Sichuan Province and Inner Mongolia Province. Typical regions of the “continuous increase” type were Gansu Province and Ningxia Province, which maintained a stable growth rate from 2007 to 2018. Shanxi and Shaanxi provinces, in the middle reaches, have maintained a stable, high growth rate for twelve years. In the downstream reaches, there was a decline in the increase rate of the AESV in Shandong from 2011 to 2015, but the rest of the area increased year by year.

To explore the synergistic relationship between various service functions in the river ecosystem of the YRB, this study used panel data based on the economic value of each river ecosystem service function in the provinces in 2007, 2011, 2015, and 2018. SPSS 19.0 software was used to calculate the correlation coefficients among the ecosystem service functions. The results are shown in Table 5.

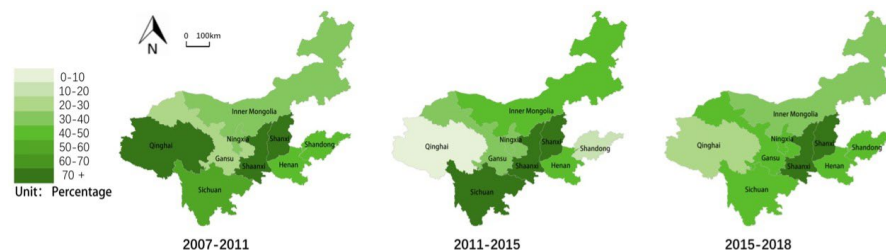


**Figure 4.** Spatial distribution of average land ecosystem service value in the nine YRB provinces from 2007 to 2018.

**Table 5.** Correlation of river ecological service functions in the YRB.

| Functions                          | Fishery Product Supply | Water Supply | Hydropower | Waterway Transportation | Water Purification | Air Purification | Carbon Fixation and Oxygen Release | Flood Reduction | Tourism |
|------------------------------------|------------------------|--------------|------------|-------------------------|--------------------|------------------|------------------------------------|-----------------|---------|
| Fishery product supply             | 1.000                  |              |            |                         |                    |                  |                                    |                 |         |
| Water supply                       | 0.671 **               | 1.000        |            |                         |                    |                  |                                    |                 |         |
| Hydropower                         | −0.245                 | −0.253       | 1.000      |                         |                    |                  |                                    |                 |         |
| Waterway transportation            | 0.244                  | 0.234        | −0.272     | 1.000                   |                    |                  |                                    |                 |         |
| Water purification                 | 0.198                  | 0.251        | −0.074     | −0.043                  | 1.000              |                  |                                    |                 |         |
| Air purification                   | −0.224                 | 0.008        | 0.473 **   | −0.436 **               | −0.112             | 1.000            |                                    |                 |         |
| Carbon fixation and Oxygen release | −0.229                 | 0.014        | 0.479 **   | −0.433 **               | −0.111             | 0.995 **         | 1.000                              |                 |         |
| Flood reduction                    | −0.255                 | −0.381 *     | 0.770 **   | −0.203                  | 0.107              | 0.383 *          | 0.400 *                            | 1.000           |         |
| Tourism                            | 0.039                  | 0.048        | −0.069     | 0.017                   | 0.523 **           | 0.080            | 0.078                              | 0.069           | 1.000   |

Notes: \*\* At the 0.01 level (two-tailed), the correlation is significant. \* At the 0.05 level (two-tailed), the correlation is significant.

From the perspective of the synergistic relationship of the nine river ecosystem service functions, the comparative combinations with positive and significant correlations included “water supply–fishery product supply”, “hydropower–air purification/carbon fixation and oxygen release/flood regulation”, “water purification–tourism”, “air purification– carbon fixation and oxygen release”. The contrasting combinations with negative and significant correlations were “water supply–flood regulation”, and “waterway transportation–air purification/carbon fixation and oxygen release”. The results listed above show that although the YRB has a variety of river ecosystem service functions, the coordinated development of various river ecosystem services during the study period was not ideal. In particular, it is necessary to pay more attention to the joint development of cultural and the other two major functions.

#### 4.2. Research Results of the Comprehensive Index of Economic Development in YRB

Changes in the comprehensive index of economic development can effectively reflect the economic development status in the region. The results are shown in Figure 5. From the perspective of the overall time change, the comprehensive economic development index of the nine provinces in YRB has been significantly improved after twelve years of development. From the perspective of the overall spatial change, the characteristics of the change can be summarized as “low in the west and high in the east”. As far as specific provinces are concerned, Shandong and Henan, in the middle and lower reaches, have long been recognized as provinces with good economic development in the YRB. The economic development of Gansu, Ningxia, Shaanxi, Shanxi and Inner Mongolia in the middle and upper reaches continue to improve, but their overall development level is relatively mediocre in the YRB. The economic development level of Qinghai Province, in the upper reaches, has improved significantly, from relatively slow economic development in 2007–2013 to the top four in the YRB in 2018, which was particularly outstanding compared with the other upstream provinces.

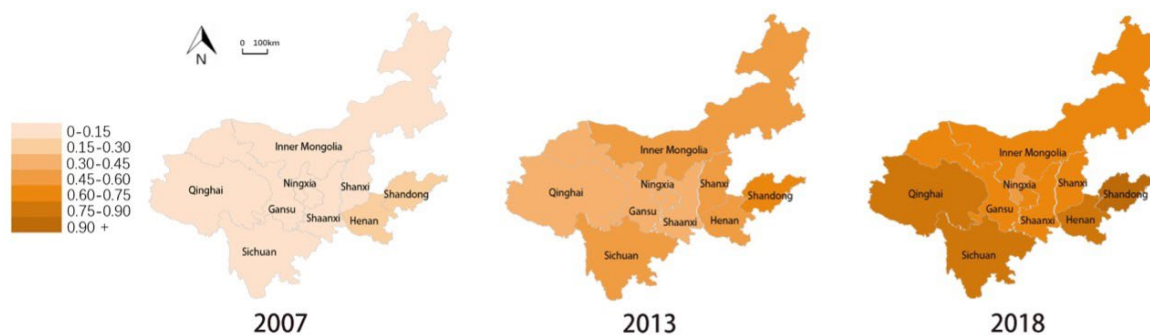


**Figure 5.** Spatial change in the economic development index of YRB from 2007 to 2018.

The changes in the comprehensive index of economic development in the YRB are largely related to the “contribution rate of the tertiary industry” and “energy consumption per ten thousand CNY of GDP” indicators with relatively high weights. From a more macroscopic perspective, it is related to the industrial structure and energy efficiency. The impacts of different industries on river ecology are dissimilar. The impact of the primary industry mainly includes positive impacts such as carbon sequestration of crops and ecological barriers of forestry, and negative impacts such as the use of pesticides and fertilizers that increase harmful inorganic substances in water bodies. But, generally speaking, the depth and breadth of the ecological impact of primary production on rivers is limited. The impact of the secondary industry on river ecology mainly includes the massive consumption of water resources and the discharge of high pollutants into the water. The stress effect on the river ecology is obvious. The impact of the tertiary industry on river ecology is smaller than that of the primary and secondary industries, and there is less direct consumption of river ecological resources. However, the development of tourism and transportation still has a direct impact on it. If not managed properly, extensive development may lead to the disappearance of some river landscapes located in ecologically sensitive areas. Energy efficiency refers to whether the use of less traditional energy can provide more economic benefits. The consumption of fossil energy has a huge impact on the ecology of rivers. On the one hand, the acquisition or purification of traditional energy requires a large amount of water resources. On the other hand, the consumption of fossil energy is accompanied by a large amount of carbon emissions and sewage discharge, which greatly increases the burden on rivers to fix carbon and purify water.

Combined with the above analysis of the spatial distribution characteristics of ESV, it was found that the spatial distribution characteristics of the comprehensive index of economic development and ecosystem service value were basically consistent; both were high in the middle and lower reaches and low in the upper reaches. However, judging from the resource endowment of the YRB, its abundance should have been higher in the upper and middle reaches and lower in the lower reaches. This is contrary to the distribution characteristics of the comprehensive index of economic development and the river ecosystem service value. That is to say, the economic development of the upper reaches, where ecological resources are rich, is relatively backward.

#### 4.3. Coordinated Evaluation of Ecosystem Service Value and Economic Development in the YRB

According to Formulas (1)–(3), the coupling coordination degree and relative development degree of ESV and economic development comprehensive index of nine provinces in the YRB were calculated. Combined with the evaluation criteria in Table 4, the characteristics of coupled and coordinated development of each province are shown in Figure 6.

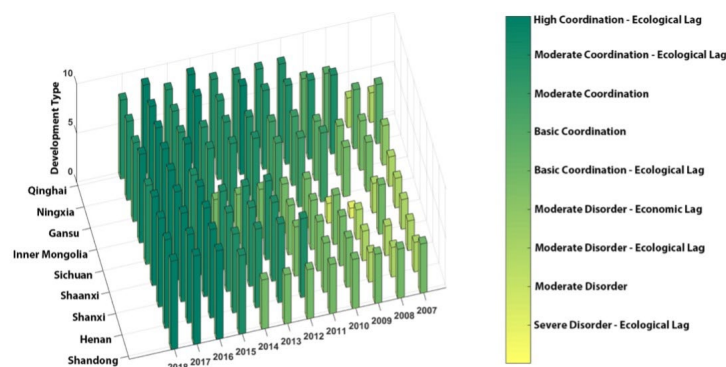


**Figure 6.** Characteristics of coupled and coordinated development in the YRB from 2007 to 2018.

From Figure 6, it can be seen that the overall coupling and coordination pattern of the YRB gradually improved during the study period, and gradually realized the transition from severe/moderate imbalance to medium/high coordination. At present, a basic pattern of medium/high coordinated development in the whole region has formed, and the differences between provinces are gradually narrowing. The characteristics of the coordinated development of the middle and lower reaches of the provinces have changed greatly, and the overall pattern from 2016 to 2018 has become balanced by degrees, indicating that the ecology and economy of the YRB are progressively realizing positive interaction and development. However, considering the development characteristics, the ecological development of nine provinces has lagged for long periods of time within the past twelve years. This showed that although the value of ecosystem services in the YRB continues to increase, its growth rate was far lower than the growth rate of the comprehensive index of economic development. They failed to form a high-quality development pattern, and a contradiction between ecological protection and economic development began to emerge.

The changes in the YRB's ecosystem service value matched the changes in the industrial structure of nine provinces and the level of energy use efficiency. The industrial structure of the YRB has long been dominated by secondary industries such as primary processing and energy mining, while the proportion of tertiary industries is lower than the national average, and the problem of "low-end industries" is more prominent. Energy consumption mainly consumes non-renewable resources such as coal resources, and the efficiency of energy use is relatively low. According to the above analysis of the interaction between industry, energy efficiency and ecological environment, the reason for the long-term ecological lag in the coordinated development of economy and ecological protection in the YRB can be explained as rapid economic development based on the excessive consumption of ecological resources. Basically, the efficiency of energy use has not been significantly improved during the development process. In addition, the ecological background of the YRB itself is extremely fragile. The negative effects of economic development on the ecology were far greater than the highest threshold of the ecological self-recovery ability, which required the consumption of excessive ecological service value. This kind of industrial development pattern led to ecological development lagging.

## 5. Conclusions

The links between ecosystems and human well-being are complex and multi-dimensional. In order to better assess these links and their impact on human well-being, this paper combines ecological, economic, and social factors to conduct interdisciplinary research. In this way, ecosystem services can be more fully understood and managed to ensure they provide sustainable benefits to human society. In the context of the high-quality development of the YRB, this paper used the economic value measurement method to calculate the river ecosystem service value of the nine provinces in the YRB from 2007 to 2018. An in-depth study was conducted on the correlation between the ecosystem service functions of rivers in the YRB and the coordination degree between the ecosystem

service value and economic development of the provinces in the basin. The main research conclusions were as follows:

- (1) From the perspective of the time dimension, the ecosystem service value of rivers in the YRB showed an overall upward trend. From the perspective of space, the ecosystem service value was highest downstream and gradually decreased from the middle reaches to the upper reaches. From the perspective of ecosystem service functions, different regions in the upper, middle and lower reaches had different functions that can truly provide a large number of efficient ecosystem service values. The functions providing ecosystem service value in the upper reaches were mainly water supply, hydropower, and tourism. The middle reaches' functions were mainly tourism, water purification, and hydropower. The downstream regions' functions were mainly tourism, water supply and fishery product supply.
- (2) From the research on the correlation of river ecosystem service functions, it can be seen that river ecosystem service functions of the provinces in the YRB were not completely synergistic. Only the supply function and the regulation function had synergy between sub-functions, but there was no synergy between sub-functions in the cultural function. Judging from the positive/negative significance of the synergy relationship, the synergy between cultural, supply regulatory functions needed to be improved.
- (3) During the study period, the provinces in the YRB developed rapidly, the river ecosystem was stable and the overall coupling and coordination degree showed an upward trend, gradually shifting from an imbalanced state to a coordinated state. However, the characteristics of coupling and coordinated development indicate that the growth rate of the ecosystem service value was far below the growth rate of economic development. Ecological protection has long lagged behind economic development, and the uncoordinated pattern of ecological lag has not been fundamentally changed.

This paper analyzed the ecological and economic development of the YRB from the perspective of ecosystem service value and its synergy with economic development, which has important practical significance for enriching the application system of ecosystem service value and promoting high-quality development. In particular, the study results found that economic development based on a large amount of resource consumption will cause problems post-ecological development, which should be paid attention to in other water-scarce areas worldwide. Through comprehensive management, policy support, scientific and technological innovation, community participation, regional cooperation, green transformation and other efforts, it can realize the sustainable use of water resources and the green development of the economy. These experiences have important implications for other countries and regions to address similar water resources and economic development challenges. In addition, building an ecosystem service value-economic development dual-accounting target system and adhering to an economic development route that matches the regional ecological pattern are important directions for achieving high-quality development in the new era.

**Author Contributions:** Conceptualization, J.C. and J.Z.; methodology, J.C.; software, J.C.; validation, J.C., Z.H. and L.X.; formal analysis, J.C.; investigation, J.C.; resources, J.C.; data curation, J.C.; writing—original draft preparation, J.C.; writing—review and editing, J.C., Z.H. and L.X.; visualization, J.C.; supervision, J.Z.; project administration, J.Z.; funding acquisition, Z.H. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by The National Social Science Fund of China, grant number 21CGL064.

**Data Availability Statement:** The agricultural, economic, and water conservancy data used in the study come from the statistical yearbooks of various provinces, the annual fishery data of the Ministry of Agriculture and Rural Affairs of the People's Republic of China, the Water Resources Bulletin, the *Water Conservancy Statistical Yearbook*, the Yellow River Water Resources Bulletin, data published by

local price bureaus, and the provincial tourism industry annual statistical report. A small amount of missing data were filled by interpolation.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Daily, G.C. *Nature's Services: Societal Dependence on Natural Ecosystems*; Island Press: Washington, DC, USA, 1997.
2. Parks, S.; Gowdy, J. What have economists learned about valuing nature? A review essay. *Ecosyst. Serv.* **2013**, *3*, e1–e10. [\[CrossRef\]](#)
3. Li, T.; Gao, X. Ecosystem services valuation of lakeside wetland park beside chaohu lake in china. *Water* **2016**, *8*, 301. [\[CrossRef\]](#)
4. Wang, F.; Zhang, S.; Hou, H.; Yang, Y.; Gong, Y. Assessing the changes of ecosystem services in the nansi lake wetland, China. *Water* **2019**, *11*, 788. [\[CrossRef\]](#)
5. Wu, L.; Fan, F. Assessment of ecosystem services in new perspective: A comprehensive ecosystem service index (cesi) as a proxy to integrate multiple ecosystem services. *Ecol. Indic.* **2022**, *138*, 108800. [\[CrossRef\]](#)
6. Wu, L. A Review of Research on Economic Value Evaluation of Ecosystem Service Functions. *For. Econ.* **2007**, *3*, 42–46.
7. Pearce, D.W.; Turner, R.K. Economics of Natural Resources and the Environment. *Int. J. Clin. Exp. Hypn.* **1990**, *40*, 21–43.
8. Costanza, R.; d'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J.; et al. The Value of the World's Ecosystem Services and Natural Capital. *Nature* **1997**, *387*, 253–260. [\[CrossRef\]](#)
9. Xu, T. The Relationship Between River Ecosystems and Human Economic Development. *China Water Transp.* **2006**, *10*, 81–82.
10. Wilson, M.A.; Carpenter, S.R. Economic Valuation of Freshwater Ecosystem Services in the United States: 1971–1997. *Ecol. Appl.* **1999**, *9*, 772–783.
11. Ouyang, Z.; Zhao, T.; Wang, X.; Miao, H. Ecosystem Services Analyses and Valuation of China Terrestrial Surface Water System. *Acta Ecol. Sin.* **2004**, *24*, 2091–2099.
12. Thiele, J.; Albert, C.; Hermes, J.; Haaren, C.V. Assessing and quantifying offered cultural ecosystem services of german river landscapes. *Ecosyst. Serv.* **2020**, *42*, 101080. [\[CrossRef\]](#)
13. Young, M.A.; Patel, K.; Crenshaw, L.C.; Moran, M.D.; Mcclung, M.R.; Chomphosy, W.H. Ecosystem services of the buffalo national river in arkansas. *Nat. Areas J.* **2022**, *42*, 293–300. [\[CrossRef\]](#)
14. Wang, W. Research on the Coupling and Coordinated Development Pattern of Ecological Protection and Economic Development in the Yangtze River Economic Belt. *Hubei Soc. Sci.* **2018**, *1*, 73–80.
15. Yang, L.H.; Tong, L.J. Dynamic coupling and spatial disparity of economic development and water environmental quality in Songhua River Basin of Jilin Province, Northeast China. *J. Appl. Ecol.* **2013**, *24*, 503–510.
16. Cao, Y.Q.; Zhao, S.K.; Yang, Y.L.; Guo, P.F. Research on the Spatio-temporal Dynamic Relationship Between the Ecosystem Services Value and the Regional Economic Growth in Chongqing. *Resour. Environ. Yangtze Basin* **2020**, *29*, 2354–2365.
17. Peng, Q.; He, W.; Kong, Y.; Shen, J. Spatio-temporal analysis of water sustainability of cities in the Yangtze River Economic Belt based on the perspectives of quantity-quality-benefit. *Ecol. Indic.* **2024**, *160*, 111909. [\[CrossRef\]](#)
18. Huhe, T.L.; Yuan, H.R.; Zhao, D.Q.; Chen, Y.; Du, X.W. Research on the Coordination Development between Ecological Civilization Construction and Energy, Economy Environment, Ecology. *Strateg. Study CAE* **2015**, *8*, 54–61.
19. Wang, Y.; Chen, R.S.; Xia, Z.L.; Guo, C.H. Evaluation of Ecosystem Service Value Change and Ecological Geology in the Yellow River Basin Survey Recommendations. *Geol. Bull. China* **2020**, *10*, 1650–1662.
20. Zhang, J.; Wu, S.M.; Zhang, Y. Measurement and Analysis of Green Development Level of Yangtze River Delta Urban Agglomeration. *J. Hohai Univ.* **2020**, *22*, 53–60.
21. Xu, Y. The Economic Development Quality Evaluation in Hebei Province. *J. Hebei Univ. Econ. Bus.* **2013**, *34*, 59–65.
22. Ren, B.; Han, L.; Cui, H. The Study on the Measure of the Quality of Economic Growth Index of Chinese Provinces and Municipalities. *Stat. Inf. Forum* **2015**, *30*, 3–8.
23. Tang, Y.; Wang, C.; Wang, R.; Xue, M.; Li, M. Study on the Spatial Correlation of Regional Transportation and Economic Development in the Yellow River Basin. *Econ. Geogr.* **2020**, *20*, 89–96.
24. Han, Z.; Zhao, Y.; Yan, X.; Zhong, J. Coupling Coordination Mechanism and Spatial-Temporal Relationship Between Gross Ecosystem Product and Regional Economy: A Case Study of Dalian. *Econ. Geogr.* **2020**, *40*, 1–10.
25. Sun, J.; Li, S.; Ji, X.; Qin, W.; Wang, F. Coupling Analysis and Optimization Measures of Cultural Resources Endowment and Tourism Industry in Shandong. *Econ. Geogr.* **2019**, *39*, 207–215.

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.