Measurement of Ecosystem Service Value in the Yellow River Basin under the Background of High-quality Development

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Abstract: As a critical ecological security barrier in China, the Yellow River Basin plays a pivotal role in delivering indispensable ecosystem services. Analyzing the ecosystem services' value in the Yellow River Basin is vital for enhancing ecological protection awareness and advancing ecological initiatives. This study delineates the spatiotemporal characteristics of the Yellow River Basin's ecosystem service value from 2010 to 2021, employing land use change and equivalent factor methods. The findings demonstrate a substantial increase in the Yellow River Basin's ecosystem service value from 2010 to 2021, exhibiting a spatial distribution of lower values centrally and higher values peripherally, a discrepancy that is progressively diminishing. Aquatic ecosystem services exhibited the highest value, succeeded by wetlands, forests, and other categories. Furthermore, our results emphasize the comprehensive spatiotemporal role of ecosystem service value in the Yellow River Basin, offering a theoretical framework and reference for policymakers in evaluating the ecological safety of barrier areas.

***Keywords*:** high-quality development, ecosystem services valuation, Yellow River basin ecology

1. Introduction

Scholars globally are engaged in multifaceted research on ecosystem services valuation. Ouyang Z et al. (2020) employed the Gross Ecosystem Product (GEP) for analyzing water-related ecosystem services, outlining investment channels in ecosystem asset protection and regional compensation provisions. Cao et al. (2021) conducted a comparative analysis of the Yangtze River Basin's ecosystem service value against other basins, establishing a foundation for ecological compensation policies crucial for spatial planning in China's major river basins. Raihan et al. (2023) applied a geographically weighted regression model to study the Loess Plateau's aquatic ecosystem services from 2010-2020, emphasizing the importance of such studies for realistic ecological compensation. Liu Shan (2021) investigated the impact of urbanization on ecosystem services in Beijing, Tianjin, and Hebei, identifying critical urbanization factors influencing their value. Fan Cunhui (2021) examined the Yellow River Basin's ecological compensation transfer system, applying theories of externality and regional development, and explored strategies for environmental protection using reward and punishment mechanisms, thereby aiding China's ecological civilization efforts. Chen Xiaobo et al. (2021) performed a field study on the spatiotemporal evolution and gradient effects of ecosystem service value in northeast Chongqing, utilizing land cover data from three distinct periods and statistical analysis. He Zhixue et al. (2022) analyzed land use changes and ecosystem service value's spatiotemporal effects in Yibin City over two decades, employing GIS mapping and area transition matrix techniques. Yun Jing (2022) investigated changes in wetland landscape patterns and their ecosystem service values in the Inner Mongolia section of the Yellow River Basin from 1990-2020, using the equivalent factor method and field surveys to analyze the impact of these changes. Yang Wenzhao (2022) evaluated ecological protection and high-quality development in 64 prefecture-level cities along the Yellow River, conducting spatiotemporal analyses based on these evaluations.

Reviewing existing literature indicates a notable research gap in quantifying ecosystem service values in the Yellow River Basin, particularly concerning their constraining factors and impacts on regional development. This paper investigates the ecological value of natural resources and ecosystem services from a high-quality development perspective, underscoring ecosystem services as an indicator of ecological capital. Ecosystem services are posited as an additional form of production input, alongside conventional factors such as material and human capital, shaping ecological economics and foundational to regional development. Additionally, ecosystem services are conceptualized as an output, critical in determining production efficiency levels. Moreover, the monetization of ecosystem service values in green development accounting lays a monetary groundwork for ecological protection in the Yellow River Basin. A profound comprehension that ecological protection entails preserving natural value and augmenting natural capital, pivotal for sustaining economic and social development, facilitates the ongoing realization of comprehensive benefits derived from natural resources.

This paper focuses on the ecosystem service value in the Yellow River Basin, conducting a comprehensive analysis of its calculation, spatial distribution, and spatiotemporal dynamics. Building on this, the study explores cooperative strategies for fostering ecological-economic growth in the Yellow River Basin. The study provides empirical evidence for economic development and ecological protection in the Yellow River Basin, encompassing Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, Shandong, and Hebei, with theoretical and practical significance in three key aspects: (1) Addressing the need for further research on the Yellow River Basin's ecosystem, this paper identifies its ecological spatial structure's evolutionary patterns, laying a theoretical groundwork for new ecological protection strategies. (2) Utilizing recent data, the paper measures the ecosystem services value, offering practical insights for the Yellow River Basin's economic and ecological development. The available, quantifiable, and comparable data enable a detailed analysis of green development.

2. Data and Research Methods

2.1 Research Area

The Yellow River Basin encompasses the geographical expanse covered by the Yellow River, from its source to the sea, primarily spanning nine provinces: Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, Shandong, and Hebei. Extending from west to east, the Yellow River Basin covers four geomorphological units: the Qinghai-Tibet Plateau, Inner Mongolia Plateau, Loess Plateau, and North China Plain. It boasts substantial forest and grassland areas and ranks high nationally for its water bodies, wetlands, deserts, and sandy lands. As a vital ecological security barrier, it plays a significant role in China's population dynamics and economic development, holding strategic political, economic, and ecological positions. (Figure 1)

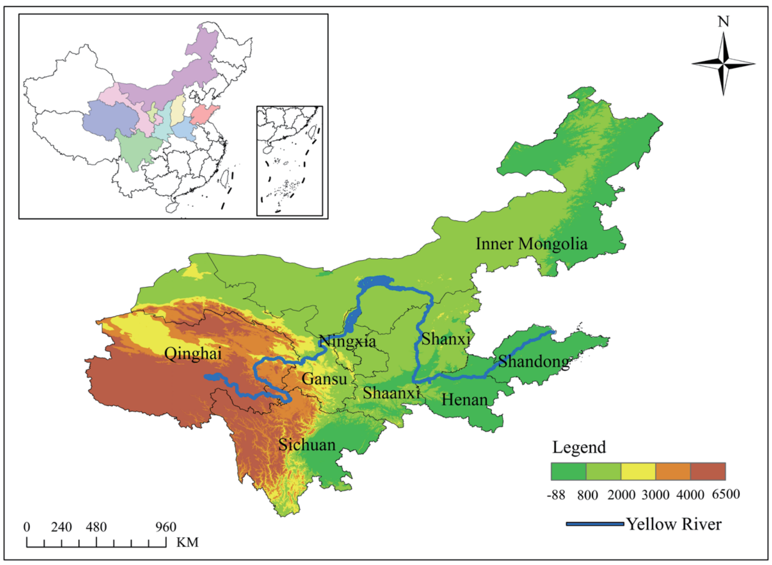

Figure 1. Geographical Location of the Yellow River Basin

2.2 Data

This study categorizes land use type data according to China's land use classification and regional variances in land resource units, resulting in diverse land use categories with unique characteristics for production and construction. Land types encompass cultivated land, gardens, forests, transportation areas, water bodies, sandy lands, etc., reflecting the fundamental aspects of land in terms of its usage, nature, and spatial distribution. Data sources comprise provincial and municipal statistical yearbooks, environmental statistical yearbooks, among others. For calculating economic value equivalents of production services, this study utilized average unit prices and sowing areas for grain crops like rice, wheat, corn, and potatoes across various provinces, as per the "Compilation of National Agricultural Product Income Data," employing specific formulas for the results.

2.3 Research Methods

2.3.1 Equivalent Factor Method

The equivalent factor table is developed based on the roles of various ecosystems in service provision, assigning value equivalents to each service function across ecosystem types, grounded in quantifiable standards. This approach reflects the relative potential of various ecosystems in contributing to ecological services, as noted by Xie Gaodi (2015). For ecosystem type classification, the table's foundation is the United Nations Millennium Ecosystem Assessment (MA). Equivalent factors are defined as the potential of ecosystems to contribute to ecological service production, representing the economic value of natural food production per hectare in targeted farmlands. The introduction and analysis of this method reveal that an ecosystem is a complex system influenced by multiple factors. Its classification criteria encompass various environmental factors affecting the ecosystem's structure, function, and stability, ensuring operability. While secondary classification systems may vary according to the study area, they align with the overall framework. Evaluating ecological value necessitates decomposing complex ecosystem structures and processes into distinct functions. These functions enable the transformation of natural resources into ecological capital, encompassing resource supply, environmental regulation, cultural and production support, and other economic benefits, summarizing various ecosystem services.

The growing global focus on ecosystem value research has led to rapid advancements in the assessment of ecosystem service functions. R. Costanza et al. (2014) categorized ecosystem service functions into 17 types and estimated the ecological value for each, foundational to ecological value research. R. Costanza introduced the ecological value equivalent factor table, assigning a value of 1 to food production per farmland unit, and basing other ecosystem service values on their relative importance to this function. This table facilitates the calculation of ecological value per unit area for various ecosystems. However, practical applications in various countries revealed discrepancies in ecological value estimates, particularly in developing countries. Consequently, Xie Gaodi et al. (2001) surveyed over 700 Chinese ecologists and revised Costanza's table to better reflect China's conditions. Researchers classified ecosystem services into 4 major and 9 subcategories, leading to the creation of the 2002 and 2007 global ecological value tables per ecosystem unit area. By 2015, using the Millennium Ecosystem Assessment (MA) method, Xie Gaodi et al. expanded the classification to 4 major categories and 11 subcategories, systematically enhancing the equivalent factor table. The 2015 version of the ecological value equivalent factor table, aligning with this paper's land use data and ecosystem classification, was chosen as the research basis, as depicted in Table 1.

To aid in calculating ecosystem service value in the Yellow River Basin, these values are categorized into four primary types: provisioning, regulating, supporting, and cultural services. These primary categories are further delineated into nine secondary categories. Provisioning services comprise two subcategories: food production and raw material production. Regulating services encompass three subcategories: gas regulation, climate regulation, and water conservation. Supporting services are divided into three subcategories: soil formation and protection, waste treatment, and biodiversity conservation. Cultural services mainly encompass one subcategory: recreational and cultural services, as detailed in Table 2.

2.3.2 Estimates of the ecosystem service value (ESV)

Given the spatial variability of ecosystem types and service values, and the per-unit-area basis of ecological value accounting, errors are inevitable, necessitating more detailed regional estimations. Enhancing the scientific validity of ecosystem service value assessments in practical applications requires eliminating human factor interference. Accurately measuring the value of ecosystem services in the Yellow River Basin, relying solely on natural process values, is extremely challenging. This study calculates the economic value of per-unit-area grain yield in the Yellow River Basin, where the economic value of an ecosystem service value equivalent factor equals 1/7th of that year's average grain yield market value per unit (Wei Jiahao, 2022).

The calculation formula is as follows:

$$E_a = \frac{1}{7}\sum_{i=1}^{n}\frac{m_i p_i q_i}{M} \tag{1}$$

In the formula, E_a represents the economic value of per-unit-area grain yield in the Yellow River Basin (ten thousand yuan/square kilometer); i denotes the type of crops, with this study focusing on rice, wheat, corn, and potatoes as the main crops planted in the Yellow River Basin; m_i is the sowing area of various crops (square kilometers); p_i is the average price of various crops in a given year; q_i is the average grain yield per unit area of crops (tons/square kilometer); M is the total planting area of all crops in a given year (square kilometers).

The ecosystem service value per unit area for various land types is calculated by multiplying the aggregated ecosystem service value equivalent factors for each land type across different cities with the standard equivalent factor value. The primary method for assessing ecological value utilizes Xie Gaodi's standard equivalent coefficients for unit area ecological value, adjusted according to the Yellow River Basin's specific conditions, to ascertain the suitable standard equivalent factor. Data on land area for different land use types and corresponding grain data are collected to calculate the economic value of grain production in the Yellow River Basin, leading to the assessment of ecosystem service value in this study.

Table 1. Ecological Value Equivalent per Unit Area of Ecosystem Services

Ecosystem classification		Supply services			Adjust the service				Support services			Cultural services
First-level classification	Second-level classification	Food production	Raw material production	Water resource supply	Gas regulation	Climatic regulation	Purify environment	Hydrology regulation	Soil keeping	Maintain and divide the cycle	Living things diversity	Aesthetics landscape
Farmland	Dry land	0.85	0.4	0.02	0.67	0.36	0.1	0.27	1.03	0.12	0.13	0.06
	Paddy field	1.36	0.09	-2.63	1.11	0.57	0.17	2.72	0.01	0.19	0.21	0.09
Forest	Needle	0.22	0.52	0.27	1.7	5.07	1.49	3.34	2.06	0.16	1.88	0.82
	Needle wide mix	0.31	0.71	0.37	2.35	7.03	1.99	3.51	2.86	0.22	2.6	1.14
	Broad leaf	0.29	0.66	0.34	2.17	6.5	1.93	4.74	2.65	0.2	2.41	1.06
	Bush	0.19	0.43	0.22	1.41	4.23	1.28	3.35	1.72	0.13	1.57	0.69
Grassland	Grasslands	0.1	0.14	0.08	0.51	1.34	0.44	0.98	0.62	0.05	0.56	0.25
	Shrubbery	0.38	0.56	0.31	1.97	5.21	1.72	3.82	2.4	0.18	2.18	0.96
	Marshy grassland	0.22	0.33	0.18	1.14	3.02	1	2.21	1.39	0.11	0.27	0.56
Water Body	River system	0.8	0.23	8.29	0.77	2.29	5.55	102.24	0.93	0.07	2.55	1.89
	Glacier snow	0	0	2.16	0.18	0.54	0.16	7.13	0	0	0.01	0.09
Wetland	Nunja	0.51	0.5	2.59	1.9	3.6	3.6	24.23	2.31	0.18	7.87	4.73
Desert	Desert	0.01	0.03	0.02	0.11	0.1	0.31	0.21	0.13	0.01	0.12	0.05
	Bare area	0	0	0	0.02	0	0.1	0.03	0.02	0	0.02	0.01

Table 2. Ecological Value Equivalent Factor Table per Unit Area of Ecosystem Services in the Yellow River Basin

Ecosystem-type	Supply services		Adjust the service			Support services			Cultural services
	Food production	Raw material	Gas regulation	Climatic regulation	Water conservation	Soil formation and conservation	Waste disposal	Bio diversity protection	Entertainment culture
Farmland	1.11	0.25	0.89	0.47	0.19	0.52	0.16	0.17	0.08
Forest	0.25	0.58	1.91	5.71	4.04	2.32	0.18	2.12	0.93
Grassland	0.23	0.34	1.21	3.19	2.53	1.47	0.11	1.00	0.59
Water Body	0.40	0.12	0.48	1.42	59.91	0.47	0.04	1.28	0.99
Wetland	0.51	0.50	1.90	3.60	26.82	2.31	0.18	7.87	4.73
Desert	0.01	0.02	0.07	0.05	0.13	0.08	0.01	0.07	0.03

The formula for ecological value and individual ecological value calculation is as follows:

$$ESV = \sum \sum A \times M \times E_a \quad (2)$$

In the formula, *ESV* represents the ecosystem service value of the Yellow River Basin (in billion yuan); *A* denotes the area of different ecosystem types; *M* is the ecological service value equivalent per unit area in the Yellow River Basin; E_a is the economic value of per-unit-area grain yield (ten thousand yuan/square kilometer).

3. Empirical Results

3.1 Total Ecosystem Service Value

Table 3. Ecosystem Service Value per Unit Area of Different Land Types in the Yellow River Basin

Land type	Farmland	Forest	Grassland	Water body	Wetland	Desert
2010	7067.29	33201.55	19637.50	119831.09	89114.13	865.01
2011	8203.16	38537.76	22793.68	139090.55	103436.72	1004.03
2012	8799.75	41340.49	24451.39	149206.17	110959.34	1077.05
2013	8708.17	40910.24	24196.91	147653.32	109804.54	1065.84
2014	9357.83	43962.29	26002.09	158668.79	117996.36	1145.36
2015	8532.36	40084.29	23708.39	144672.31	107587.67	1044.32
2016	7621.04	35803.03	21176.18	129220.35	96096.59	932.78
2017	8101.18	38058.67	22510.31	137361.40	102150.81	991.55
2018	7715.67	36247.59	21439.12	130824.86	97289.81	944.37
2019	8141.02	38245.82	22621.00	138036.86	102653.13	996.43
2020	9127.47	42880.09	25362.00	154762.89	115091.68	1117.16
2021	10084.76	47377.36	28021.98	170994.47	127162.53	1234.33

As indicated in Table 3, there were significant changes in the total ecosystem service value of various land types in the Yellow River Basin between 2010 and 2021.Notably, the unit area ecosystem service value of water bodies was the highest, followed by wetlands, forests, grasslands, farmlands, and deserts. The respective unit ecosystem service values for these land types were 106,611.94, 39,720.76, 23,493.38, 8,454.97, and 1,034.85 yuan per hectare.

Table 4. Changes in the Total Ecosystem Service Value in the Yellow River Basin, 2010-2021

Year	Farmland	Forest	Grassland	Water body	Wetland	Desert	Amount
2010	4989.90	38359.81	40636.82	7026.06	3755.89	210.27	94978.75
2011	5789.33	44496.43	47148.81	8150.43	4341.76	243.87	110170.63
2012	6205.91	47706.35	50556.47	8740.65	4640.32	261.50	118111.19
2013	6140.56	47184.36	50004.85	8645.99	4576.21	258.58	116810.56
2014	6597.91	50671.34	53703.21	9284.03	4900.39	277.77	125434.64
2015	6014.50	46186.49	48942.73	8468.39	4450.79	253.16	114316.06
2016	5373.48	41221.17	43698.04	7558.10	3957.93	225.99	102034.72
2017	5713.48	43783.83	46432.71	8028.09	4188.69	240.09	108386.89
2018	5442.98	41667.62	44205.65	7640.17	3971.66	228.54	103156.62
2019	5430.78	50984.67	42576.00	9017.76	18077.66	241.00	126327.87
2020	6069.64	57173.67	47699.44	10143.76	20257.68	270.05	141614.25
2021	6729.27	63273.09	52547.98	11230.66	22359.71	298.21	156438.92

Table 4 shows the changes in the total ecosystem service value of the Yellow River Basin from 2010 to 2021.Between 2010 and 2015, the ecosystem service value of the Yellow River Basin increased by 1,933.731 billion yuan. The ecosystem service values for different land types increased by 102.46 billion yuan for forests, 782.668 billion yuan for water bodies, 830.591 billion yuan for wetlands, 144.234 billion yuan for farmlands, 69.49 billion yuan for grasslands, and 4.289 billion yuan for deserts. Following the third national land survey in 2017, which altered land type categorization in China, the growth in the Yellow River Basin's ecosystem service value slowed in 2019, reaching 1,201.18 billion yuan. The ecosystem service values for forests, water bodies, and wetlands increased by 479.819 billion yuan, 54.936 billion yuan, and 1,362.686 billion yuan, respectively. Conversely, the values for farmlands, grasslands, and deserts decreased by 58.372 billion yuan, 636.673 billion yuan, and 1.215 billion yuan, respectively. From 2019 to 2021, there was a significant increase in the Yellow River Basin's ecosystem service value, totaling 3,011.105 billion yuan, surpassing the growth seen in other years. The service values of each ecosystem type increased by 129.849 billion yuan for forests, 1,228.841 billion yuan for water bodies, 997.198 billion yuan for wetlands, 221.291 billion yuan for farmlands, 428.206 billion yuan for grasslands, and 5.721 billion yuan for deserts.

Between 2010 and 2021, the ecosystem service value in the Yellow River Basin exhibited an overall upward trend, increasing by 39%.The ecosystem service values of various land types similarly displayed an upward trend, with increases of 26%, 39%, 23%, 37%, 83%, and 29%, respectively. Over this 12-year period, the ecosystem service values of forests and water bodies demonstrated stable growth, marked by minor decreases and subsequent rapid increases. The ecosystem service values of farmlands and grasslands saw short-term growth, with a gradual increase from 2010 to 2015 and a rapid surge from 2019 to 2021, exceeding previous growth rates. The ecosystem service values of wetlands and deserts remained comparatively stable. Land use area visually represents the value of regional ecosystem services. Over a decade in the Yellow River Basin, the area of various land types expanded, with significant conversion of unused land into forests, grasslands, water bodies, and wetlands. This trend aligns with policies like converting farmland to forests, afforestation of barren hills, and soil and water conservation efforts in the Yellow River Basin.

3.2 Spatial Changes in Ecosystem Service Value of the Yellow River Basin

According to Figure 2, the ecosystem service values across the nine provinces in the Yellow River Basin show a fluctuating yet increasing trend from 2010 to 2021.During this period, the total increase in ecosystem service value was 6,146.017 billion yuan. Notably, the forest ecosystem service value saw the largest increase of 6,327.309 billion yuan, followed by grasslands at 119.116 billion yuan, and deserts with the least growth at 8.794 billion yuan. Overall, there is a consistent increasing trend in ecosystem service values across all nine provinces in the Yellow River Basin. Regionally, the Inner Mongolia Autonomous Region's ecosystem service value significantly surpasses other provinces, followed by Qinghai Province, with the Ningxia Hui Autonomous Region historically having the lowest value. Spatially, there is a pattern in the ecosystem service values of the nine provinces, being higher on both sides and lower in the middle, decreasing from the Taihang Mountains towards the North China Plain.

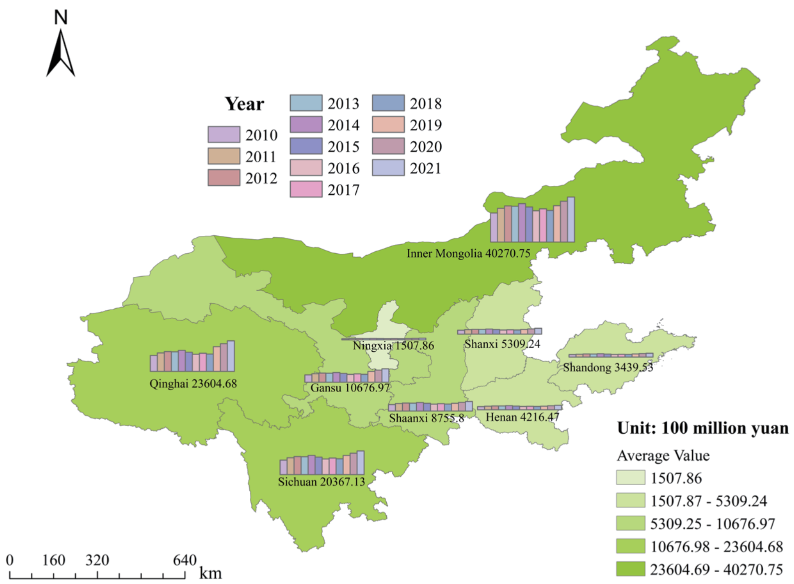

Figure 2. Spatiotemporal Evolution of Ecosystem Service Value in the Yellow River Basin, 2010-2021

The factors contributing to this spatial pattern can be analyzed from various perspectives. Firstly, economic growth has spurred increased investment in environmental protection and enhanced environmental governance, leading to ecological improvement. Secondly, scholarly research indicates significant ecological improvement in the Yellow River Basin over the past 15 years. Excluding Henan and Shandong, the increase is mainly observed in the middle and upper reaches of the Yellow

River Basin (7% to 27%), particularly in Gansu Province. The expansion of afforestation significantly enhances ecosystem services, whereas the reduction in wetlands (lakes, marshes) drives the decline in service values in the basin's middle and lower reaches.

Since the reform and opening-up era, China has undertaken numerous ecological restoration and construction projects in the Yellow River Basin. These projects include constructing a green ecological corridor in the lower Yellow River, enhancing ecological functions and the estuarine environment; protecting and restoring the Yellow River Delta wetlands; ceasing oil extraction legally in the estuary to aid aquatic life and fish spawning ground restoration; assessing the impact of water and sediment management on aquatic habitats; implementing ecological water replenishment in the Yellow River Delta; accelerating the Yellow River Estuary National Park's construction; and supporting the "Beautiful Bay" creation at the estuary. The aim of these projects is to bolster ecological protection and governance, ensuring the Yellow River's long-term stability, promoting high-quality development in its provinces, and fulfilling public demand for a healthy ecological environment. Since 1999, China has consistently implemented the initiative to convert farmland into forests and grasslands, with Sichuan, Shaanxi, and Gansu provinces leading these pilot projects. However, the evapotranspiration rate in the Yellow River's middle reaches has increased by 3 to 4 millimeters. While soil moisture remained mostly unchanged in the middle reaches, it exhibited a decreasing trend in the ecological restoration areas, decreasing at a rate of 0.0013% per year. Furthermore, the average runoff recorded at hydrological stations from 1961 to 2018 also displayed an annual decreasing trend.

4. Conclusion

This study assessed the ecosystem service value of the Yellow River Basin from 2010 to 2021, identifying that spatial heterogeneity in ecosystem service value is primarily driven by natural factors. Consequently, it is recommended to focus more on how ecological protection measures affect ecosystem services in the green development of each province within the Yellow River Basin.

The main research conclusions are as follows:

(1) Temporally, the ecosystem service value of the Yellow River Basin from 2010 to 2021 exhibited a pattern of an initial increase, followed by a decrease, and then a subsequent increase. The value at the end of the study period was higher than at the beginning. Throughout the study period, regulatory and support services significantly contributed to the ecosystem service value of the Yellow River Basin, maintaining a stable proportion among different types of ecosystem services.

(2) Spatially, the ecosystem service value in the Yellow River Basin is stable, exhibiting a distribution with higher values in the southern part, lower values downstream, and higher values in the upper and middle reaches. The high and sub-high value areas in the upper reaches are predominantly linked to rivers and lakes, while in the middle reaches, they correlate with mountainous regions.

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