International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18 (2026) pp. 1-14

https://doi.org/10.70917/ijcisim-2026-2211
Article

Research on the Path of Ecological Environment Governance under the Background of Ecological Protection and High-Quality Development of the Yellow River Basin

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Abstract: To clarify the coordination level and constraints of ecological protection and high-quality development in the Yellow River Basin and to achieve the modernization of ecological environment governance in the Yellow River Basin, this paper, based on the panel data of nine provinces in the Yellow River Basin, selected 29 evaluation indicators from two dimensions of ecological protection and high-quality development, and objectively weighted the indicators using the entropy method to avoid the deviation caused by subjective weighting. The coupling coordination degree model was adopted to measure the coordinated evolution trend of ecological protection and high-quality development from 2007 to 2021, and to quantify the interactive influence and coordination level between the two systems. The obstacle degree model was introduced to accurately identify the key indicators that constrain the coupling coordination of the two systems, and to anchor the direction for the formulation of governance paths. The research results show that the levels of ecological protection and high-quality development in each province of the Yellow River Basin vary greatly, and only Sichuan is in the state of excellent ecology and high-quality development. During the research period, the coupling coordination degree level increased from 0.20 to 0.40 to 0.77. The per capita water resources volume, the number of domestic invention patents authorized, and the daily urban sewage treatment capacity are the three key obstacle factors. This paper proposes governance paths such as leveraging the coordinating role of the government, promoting the green transformation of the secondary industry, formulating differentiated governance strategies, and playing the leading role of the central city, to provide decision-making references for the coordinated advancement of ecological protection and high-quality development in the Yellow River Basin.

Keywords: Yellow River Basin; Ecological protection; High-quality development; Coupling coordination degree; Obstacle factor diagnosis

1. Introduction

The Yellow River Basin is an important ecological security barrier in China and an important area for human activities and economic and social development. It plays a crucial role in the overall national development and the construction of socialist modernization. However, its fragility has restricted both the ecology and the economy. According to the results of China's remote sensing survey and assessment of the ecological environment, more than 70% of the moderately sensitive areas in the Yellow River Basin cover the entire basin. The high-altitude glaciers, grasslands and meadows in the upper reaches, the Loess Plateau in the middle reaches, and the Yellow River Delta in the lower reaches are all highly prone to degradation, and the restoration process is extremely difficult and slow [1-3]. At the same time, among the nine provinces in the Yellow River Basin, eight provinces have most of their counties and cities classified as key national ecological functional areas, which are related to the ecological security of the entire country or a larger area [4]. Therefore, the governance of the ecological vulnerability of the Yellow River Basin is the key to achieving ecological protection and high-quality development in the Yellow River Basin, and it is also an important prerequisite for maintaining ecological security and promoting sustainable development of humans and nature.

However, for a long time, the fragmented traditional administrative system has led to the fragmentation of environmental governance in the Yellow River Basin, which has a holistic and cross-border nature [5]. Collaborative governance, as an emerging governance model, conforms to the requirements of cross-domain environmental governance and can coordinate the interests of all parties, reach consensus, and promote the formation of a common understanding among stakeholders [6]. Regarding the research on collaborative governance of the ecological environment in the Yellow River Basin, literature [7] points out that "administrative collaboration" is an important measure proposed by the Chinese government to promote the ecological governance of the Yellow River Basin. Administrative collaboration refers to the government departments in different administrative regions within the basin conducting timely coordination and cooperation when water pollution incidents occur. Literature [8] constructs a social-ecological network to depict the collaboration relationships among prefecture-level cities, the ecological connections between sub-basins, and the jurisdiction of prefecture-level cities over sub-basins, and uses a multi-level index random graph model to study the role of social-ecological compatibility in promoting the formation of the collaborative network. Literature [9] points out that the core of collaborative governance lies in legislation, and a legal system centered on the "Yellow River Law" needs to be established to promote collaborative governance through clear rights and responsibilities and extensive participation of all parties in basin management. Literature [10] uses a three-layer driving chain analysis framework to systematically explore the obstacles faced by ecological co-governance in the Yellow River Basin, finding that the digital governance level in the green industry domain is insufficient, and structural defects are identified as key explicit obstacles. Literature [11] believes that the cross-provincial river basin ecological compensation (DEC) collaborative governance mechanism is an important measure for achieving high-quality development of long-term ecological compensation in the Yellow River Basin. Therefore, they have constructed an evolutionary game model of DEC collaborative governance among local governments and conducted dynamic simulation analysis using Shaanxi and Henan provinces as examples. Literature [12] systematically explores the spatial and temporal evolution characteristics and influencing factors of pollutant and carbon emission reduction at the scale of urban agglomerations in the Yellow River Basin, providing empirical references for formulating differentiated collaborative governance strategies, comprehensive green and low-carbon economic transformation plans, and high-quality green development paths. Literature [13] systematically quantifies the impact of institutional changes on water resource governance in the Yellow River Basin, finding that the 1998 "Unified Basin Management Law" (98-UBR) established the overall authority of the basin and strengthened the connections among stakeholders, achieving improvements in water resource governance.

With the development and integration of new-generation information technologies - big data, artificial intelligence, cloud computing, and blockchain, the digital transformation of ecological environment governance has become an inevitable trend. In October 2021, the Chinese government issued the "Outline for the Ecological Protection and High-Quality Development of the Yellow River Basin", clearly requiring strengthening the construction of data center nodes and networked layout in the Yellow River Basin [14]. The "Science and Technology Innovation Implementation Plan for Ecological Protection and High-Quality Development in the Yellow River Basin" released by the Ministry of Science and Technology of China in November 2022 emphasizes the role of scientific and technological innovation in supporting and leading the protection and governance of the Yellow River. This indicates that the transformation of the ecological environment governance system is inevitable, and the embedding of digital technology will become an important opportunity for local governments to promote ecological environment governance in the Yellow River Basin [15].

Regarding the research on the digital transformation of ecological environment governance, literature [16] uses machine learning models to analyze social media data to depict the public's attitudes towards ecological protection and constructs differentiated governance strategies. Literature [17] proposes a comprehensive governance model that uses intelligent technologies such as digital twins, AI-driven analysis, IoT networks, and multi-source remote sensing to solve the nonlinear interdependence among water, energy, food, and ecology (WEFE); the research results show that with the enhanced digital twin technology based on artificial intelligence and the "perception-analysis-decision-execution" system based on IoT, it is possible to achieve a dynamic balance between ecological protection and economic and social development. Literature [18] collects ecological environment data from the downstream of the Yellow River Basin through IoT technology and conducts in-depth analysis of ecological remote sensing big data, providing data references for achieving sustainable development in the downstream of the Yellow River. Literature [19] discovers that although local governments have implemented digital environmental governance advocated by the central government, the information disclosure of pollution data is still far from being transparent, revealing the complex relationship between emerging information communication technologies, environmental activism, and digital governance. Literature [20] constructs an intelligent system for sustainable ecological governance and intelligent environmental management based on artificial intelligence through large-scale data collection, advanced data analysis, cloud data international transmission, and pollution emergency response. Literature [21] develops a multi-objective coupled hydrological and sediment regulation model, using the reinforced Q-learning algorithm to obtain the optimal strategy from multiple objectives of reducing sediment, flood control, and ecological restoration under different hydrological years, aiming to minimize siltation and flood losses and maximize ecological value in the downstream of the Yellow River Basin.

This study first constructed a dual-system evaluation index system for ecological protection and high-quality development to provide a complete analytical framework and data foundation for subsequent collaborative measurement. The entropy method was used to objectively assign weights to each index, solving the subjective deviation problem in the weight allocation of the multi-index system. The coupling coordination degree model was used to measure the collaborative evolution trend of the two systems. The barrier degree model was used to explore the coupling coordination obstacles factors between the two systems of ecological protection and high-quality development. Based on the panel data of the nine provinces and regions in the Yellow River Basin from 2007 to 2021, an empirical analysis was conducted to lay a data foundation for the design of differentiated ecological environment governance paths.

2. Research Design

2.1. Indicator Selection

The ecological protection indicator system is based on three dimensions: pollution emissions, pollution control, and ecological construction. It selects 10 indicators such as industrial wastewater discharge volume. The high-quality development indicator system is based on five dimensions: innovation-driven development, coordinated development, green development, open development, and shared development. It selects 19 indicators such as R&D investment intensity. The specific ecological protection indicators and high-quality development indicators are presented in Tables 1 and 2 respectively.

Table 1. Ecological protection evaluation index system

Target layer	Dimension	Index layer	Attribute
Ecological protection	Pollution discharge (X1)	Industrial effluent discharge(Y1)	-
		Industrial sulfur dioxide emissions(Y2)	-
		Industrial smoke (powder) dust emissions(Y3)	-
	Pollution control (X2)	General industrial solid waste(Y4)	+
		Treatment capacity of urban sewage day(Y5)	+
		Life garbage harmless treatment rate c(Y6)	+
	Ecological construction (X3)	Forest coverage(Y7)	+
		Per capita park(Y8)	+
		Afforestation area(Y9)	+
		Water per capita(Y10)	+

Table 2. High quality development index

Target layer	Dimension	Index layer	Attribute
High quality development	Innovative development(X4)	R&d expenditure (r&d expenditure/CDP) (Y11)	+
		R&d expenditure (number of r&d personnel/total number of employees) (Y12)	+
		Technical trading activity (the ratio of transaction amount to the total amount of transactions in the market) (Y13)	+
		Domestic invention patent authorization(Y14)	+
	Coordinated development(X5)	Urban and rural income per capita income ratio(Y15)	-
		Urban and rural consumption level ratio(Y16)	-
		Rationalization index of industrial structure(Y17)	-
	Green development(X6)	Industrial structure high level index(Y18)	+
		The improvement rate of the construction area(Y19)	+
		Unit CDP energy consumption(Y20)	-
	Open development(X7)	Unit GDP waste water discharge(Y21)	-
		Unit CDP emissions(Y22)	-
		Unit GDP solid waste emissions(Y23)	-
		Proportion of foreign investment (foreign investment/CDPP) (Y24)	+
	Shared development(X8)	Foreign trade dependency (total import and export trade total/cdp5) (Y25)	+
		Urban unemployment rate(Y26)	-
		Every 10,000 people have bed(Y27)	+
		The number of college students per 10,000 people(Y28)	+
		Number of Internet users per person(Y29)	+

2.2. Sample Selection and Data Sources

The Yellow River Basin spans three major regions - the East, Central and Western regions. It flows through Qinghai, Sichuan, Gansu, Ningxia, Shaanxi, Shanxi, Henan and Shandong, covering an area of approximately 3,597,600 square kilometers. The research period selected is from 2007 to 2021. The original data of each indicator is sourced from the annual "China Statistical Yearbook", the annual "Statistical Yearbooks" of the nine provinces (regions) in the Yellow River Basin, the CSMAR database and the website of the National Bureau of Statistics. For some missing data, interpolation methods are used to fill in.

2.3. Research Methods

1) Entropy Method

Both index systems contain numerous indicators. Due to the different units, they cannot be directly compared and analyzed. Therefore, the data must be standardized first to avoid errors caused by different units. The formula for positive and negative indicators is as follows: h represents the number of years, m represents the number of cities, n represents the number of indicators, h is the time length, and $x_{\lambda ij}$ is the value of the j th indicator of the i th city. The standardized numerical value of the indicators $Y^*_{\lambda ij} \in [0,1]$, and X_{max} and X_{min} represent the maximum and minimum values of the current sample data of each indicator respectively.

$$Y^*_{\lambda ij} = x_{\lambda ij} - x_{\min} / x_{\max} - x_{\min} \left(\text{Positive indicators}\right) \tag{1}$$

$$Y^*_{\lambda ij} = x_{\max} - x_{\lambda ij} / x_{\max} - x_{\min} \left(\text{Negative indicators}\right) \tag{2}$$

In order to eliminate the influence of the "0" values after the indicators are standardized on the subsequent calculations, drawing on the research of relevant scholars, we set $Y_{\lambda ij} = Y^*_{\lambda ij} + 10^{-4}$.

The weight of the indicators indicates the importance of the indicators for the development level of the system and will affect the result of the system development level. This paper adopts the panel entropy method to objectively calculate the indicator weights. The specific steps are as follows:

The formula for the characteristic proportion of the indicators: $P_{\lambda ij} = Y_{\lambda ij} \Big/ \sum_{i=1}^{m}\sum_{j=1}^{h} Y_{\lambda ij}$; The entropy value E_j and redundancy degree D_i of each indicator:

$E_j = -k\sum_{\lambda=1}^{h}\sum_{i=1}^{m} P_{\lambda ij}\ln P_{\lambda ij}$, where $k = 1/\ln(m*h)$; $D_j = 1 - E_j$; Calculate the weights of each indicator: $W_j = D_j / \sum_{j=1}^{n} D_j$.

Based on the standardized data and calculated index weights, the development levels of ecological protection and high-quality development were obtained. System development level: $U_1 = \sum_{j=1}^{n} W_j Y_{\lambda ij}$

2) Coupling calculation model construction

Referring to the research of relevant scholars, the coupling coordination degree of ecological protection and high-quality development was calculated using the coupling coordination degree, and the specific model formula is as follows:

$$C = 2\left[(U_1U_2)\big/(U_1+U_2)^2\right]^{1/2} \quad (3)$$

$$D = \sqrt{CT} \quad (4)$$

$$T = \alpha U_1 + \beta U_2 \quad (5)$$

$$\rho = U_1/U_2 \quad (6)$$

D represents the coupling and coordination degree of ecological protection and high-quality development, which can be used to determine the interrelationship between the two; U_1 and U_2 are the comprehensive indices of the two systems; C represents the coupling degree of ecological protection and high-quality development; T indicates the coordinated development degree of the two systems; α and β are weights, with $\alpha + \beta = 1$, representing the importance of the two subsystems to the overall system. This paper believes that both are equally important, so $\alpha = \beta = 0.5$; ρ represents the relative development level of ecological protection and high-quality development. The coupling coordination degree of ecological protection and high-quality development is classified into the following types, as shown in Table 3.

Table 3. The combination of ecological protection and high quality development

Coupling coordination	Coupling coordination level	Coupling coordination	Coupling coordination level
0.00~0.09	Extreme dissonance	0.50~0.59	Grudging
0.10~0.19	Severe disorder	0.60~0.69	Primary coordination
0.20~0.29	Moderate disorder	0.70~0.79	Intermediate coordination
0.30~0.39	Mild disorder	0.80~0.89	Good coordination
0.40~0.49	On the brink	0.90~1.00	Quality coordination

3) Two-Dimensional Quadrant Method

The two-dimensional quadrant method is an analytical approach that differentiates and identifies solutions by using two important attributes of a thing as the basis for analysis and classification. Specifically, one important attribute A of the thing is taken as the X axis, and the other important attribute B is taken as the Y axis. A coordinate axis is formed and marked with divisions. A straight line is drawn to form a "square" shape, creating a two-dimensional four-quadrant analysis block. The scale divisions of the X and Y axes mainly summarize the two manifestations of a situation using numbers, size, height, length, and whether they are equal. There are two methods for judging the scale representation: quantitative and qualitative. The most commonly used method is the qualitative one. Each matter is analyzed and weighed based on the two attributes, and then each matter is filled into each quadrant block. After completion, the characteristics of the matters in the same quadrant block are summarized to find a solution. The main advantage of the two-dimensional quadrant method lies in its intuitive clarity, emphasis on classification, and simplicity. This paper draws on the two-dimensional quadrant method and designs a two-dimensional quadrant model for ecological protection and high-quality development. The schematic diagram of the two-dimensional quadrant model for ecological protection and high-quality development is shown in Figure 1.

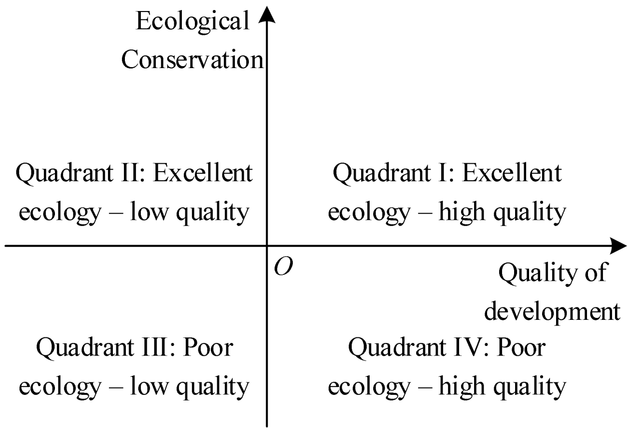

Figure 1. Two dimensional quadrant model

4) Obstacle Degree Model

Based on the evaluation of ecological protection and high-quality development in the Yellow River Basin, the obstacle degree model is used to calculate the deviation degree and factor contribution degree of various basic indicators and criterion layer indicators for ecological protection and high-quality development in the Yellow River Basin. This helps clarify the main obstacle factors and factors affecting the ecological protection and high-quality development of the Yellow River Basin. The diagnostic results can provide strong support for the exploration of ecological environment governance paths in the context of ecological protection and high-quality development of the Yellow River Basin, so as to propose more targeted suggestions. The formula is as follows:

$$c_{ij} = \frac{\left(1 - X_{ij}\right) \times \omega_i}{\sum_{i=1}^{n} \left[\left(1 - X_{ij}\right) \times \omega_i\right]} \tag{7}$$

$$C_{ij} = \sum_{i=1}^{n} c_{ij} \tag{8}$$

In the formula: c_{ij} represents the degree of obstruction for the i th indicator, and the larger the value of c_{ij}, the higher the degree of obstruction, and the greater the resistance to the ecological protection and high-quality development of the Yellow River Basin. The smaller the value of c_{ij}, the lower the degree of obstruction. X_{ij} is the standardized value of the i th indicator, and $1 - X_{ij}$ represents the deviation degree of the indicator. ω_i is the weight of the indicator, used to represent the contribution degree of the factor; the degree of obstruction of the criterion layer is C_{ij}.

3. Result Analysis

3.1. Calculation Results of Indicator Weights

The entropy method was used to calculate the data of the two indicator systems respectively. The specific indicator weights for ecological protection and high-quality development are shown in Tables 4 and 5. Among the two evaluation indicator systems, the ones with the largest weights are the per capita water resources volume and the domestic patent authorization volume, with the weights of 0.384 and 0.147 respectively.

Table 4. The specific index weight of ecological protection

Target	Dimension	Index layer	Index

layer			weight
Ecological protection	Pollution discharge(X1)	Industrial effluent discharge(Y1)	0.032
		Industrial sulfur dioxide emissions(Y2)	0.049
		Industrial smoke (powder) dust emissions(Y3)	0.016
	Pollution control(X2)	General industrial solid waste(Y4)	0.106
		Treatment capacity of urban sewage day(Y5)	0.155
		Life garbage harmless treatment rate c(Y6)	0.022
	Ecological construction(X3)	Forest coverage(Y7)	0.102
		Per capita park(Y8)	0.056
		Afforestation area(Y9)	0.078
		Water per capita(Y10)	0.384

Table 5. The specific index weight of high quality development

Target layer	Dimension	Index layer	Index weight
High quality development	Innovative development(X4)	R&d expenditure (r&d expenditure/CDP) (Y11)	0.042
		R&d expenditure (number of r&d personnel/total number of employees) (Y12)	0.138
		Technical trading activity (the ratio of transaction amount to the total amount of transactions in the market) (Y13)	0.132
		Domestic invention patent authorization(Y14)	0.147
	Coordinated development(X5)	Urban and rural income per capita income ratio(Y15)	0.025
		Urban and rural consumption level ratio(Y16)	0.013
		Rationalization index of industrial structure(Y17)	0.004
	Green development(X6)	Industrial structure high level index(Y18)	0.056
		The improvement rate of the construction area(Y19)	0.013
		Unit CDP energy consumption(Y20)	0.007
	Open development(X7)	Unit GDP waste water discharge(Y21)	0.006
		Unit CDP emissions(Y22)	0.015
		Unit GDP solid waste emissions(Y23)	0.024
		Proportion of foreign investment (foreign investment/CDPP) (Y24)	0.049
	Shared development(X8)	Foreign trade dependency (total import and export trade total/cdp5) (Y25)	0.055
		Urban unemployment rate(Y26)	0.028
		Every 10,000 people have bed(Y27)	0.074
		The number of college students per 10,000 people(Y28)	0.068
		Number of Internet users per person(Y29)	0.104

3.2. Calculation Results of High-Quality Development and Ecological Protection Index

Calculate the high-quality development index and the ecological protection index for the 30 provinces (autonomous regions, and municipalities directly under the Central Government) excluding Hong Kong, Macao, Taiwan and Xizang. The index calculation results are shown in Table 6. Based on the national average high-quality development index of 0.033 and the ecological protection index of 0.033, the positions of each province (region) in the Yellow River Basin in the two-dimensional quadrant were determined. The positions of each province (region) in the Yellow River Basin in the two-dimensional quadrant are shown in Figure 2. The ecological protection and high-quality development levels of the provinces (regions) in the Yellow River Basin vary greatly, with prominent problems of imbalance and inadequacy.

Highly Ecological and High-Quality Provinces (Regions). The province (region) belonging to highly ecological and high-quality is only Sichuan. Since the "Twelfth Five-Year Plan" period, Sichuan has placed innovation-driven development at the core of the overall development, providing sufficient impetus for high-quality development and significantly improving the levels of high-quality development and ecological protection. However, Sichuan still has some problems in economic growth and social equity; in terms of ecological protection, the emissions of industrial "three wastes" are relatively high, the investment in pollution control is relatively low, and the environmental conditions are relatively poor.

Highly Ecological and Low-Quality Provinces (Regions). The provinces (regions) belonging to highly ecological and low-quality are Qinghai, Gansu, Shanxi and Inner Mongolia. They have in common that they have relatively good ecological protection conditions but relatively low levels of high-quality development. Among them: Qinghai is the source of the Yellow River and has abundant water resources. The ecological protection effect is remarkable, but the social and economic development is relatively lagging. The high-quality development index of Qinghai is the smallest among the provinces (regions) in the Yellow River Basin; Gansu is an important water source replenishment area in the Yellow River Basin. It has invested relatively more in pollution control and has relatively lower fertilizer application and emissions of "three wastes". It has a relatively good ecological environment, but there is a significant gap in the level of high-quality development compared to the national average; In terms of high-quality development, the innovation investment and output are significantly insufficient, and the income gap between urban and rural residents is relatively large; Shanxi is an important ecological barrier and energy base in North China. The ecological protection status is only slightly higher than the national average. Its development mode based on energy economy has made the ecological environment very fragile. In terms of social and economic development, the per capita GDP is far below the national average, the proportion of imports is relatively low, and innovation investment and output are insufficient; The education and medical security levels are relatively far from the high-quality development levels of the provinces (regions) with higher levels of high-quality development.

Low Ecological and Low-Quality Provinces (Regions). The provinces (regions) belonging to low ecological and low-quality are Ningxia, Shaanxi and Henan. They have in common that the ecological protection conditions and the level of high-quality development are relatively poor. Among them: Ningxia is located in the upper reaches of the Yellow River. Compared with other upstream provinces (regions), the ecological environment problems are more severe. In terms of social and economic high-quality development, it has abundant coal resources, but with large-scale mining, it will face the dilemma of lacking economic development momentum due to insufficient resources. It needs to comprehensively solve environmental pollution problems and economic development problems; Shaanxi is an important region for ecological protection and high-quality development reform. In recent years, its attention to high-quality development has gradually increased, resulting in a steady improvement in the level of high-quality development, but it has problems such as water resource shortage and fragile ecological environment in ecological protection; Henan is a major agricultural province and population province in China. The proportion of forests, wetlands and nature reserves is relatively low. The amount of agricultural fertilizer application and pollution are relatively serious, and the ecological environment is relatively fragile. In terms of social and economic development, the innovation investment intensity is relatively insufficient, the proportion of high-end manufacturing is relatively low, and regional development is unbalanced and insufficient. The gap between the education and medical security levels and the high-quality development levels of provinces (regions) with higher levels is relatively large.

Low Ecological and High-Quality Provinces (Regions). Among the provinces (autonomous regions) located in the fourth quadrant, only Shandong is considered to have a low ecological and high-quality profile. This province is situated in the lower reaches of the Yellow River and is a newly approved comprehensive pilot zone for the transformation of old and new growth drivers by the State Council. In terms of economic and social development, it has problems such as an over-reliance on heavy industry in the industrial structure, an unreasonable transportation structure, an energy structure heavily dependent on coal, insufficient infrastructure, and slow progress in the green and circular development of agriculture. In terms of the environment, the emissions of three wastes are excessively high and the proportion of investment in pollution control is relatively low. Therefore, it is necessary to pay particular attention to pollution reduction and the development of clean energy.

Table 6. National high quality development and ecological protection index

Province (district, city)	High quality development index	Ecological index	Province (district, city)	High quality development index	Ecological index
Guangdong	0.118	0.028	Guangxi	0.018	0.028
Beijing	0.092	0.016	Jilin	0.019	0.026
Jiangsu	0.081	0.031	Yunnan	0.017	0.036
Zhejiang	0.060	0.025	Guizhou	0.016	0.028
Shanghai	0.058	0.079	Xinjiang	0.013	0.035
Tianjin	0.034	0.034	Heilongjiang	0.011	0.037
Hupei	0.037	0.028	Shandong	0.054	0.030
Anhui	0.034	0.023	Sichuan	0.040	0.043
Fujian	0.030	0.026	Henan	0.028	0.020
Hunan	0.028	0.029	Shaanxi	0.025	0.026
Hebei	0.027	0.025	Ningxia	0.017	0.032
Liaoning	0.024	0.023	Shanxi	0.013	0.040
Chongqing	0.020	0.025	Inner Mongolia	0.013	0.054
Jiangxi	0.019	0.029	Kansu	0.010	0.043
Hainan	0.019	0.031	Qinghai	0.011	0.067
Mean of high quality development index	0.033		Mean of ecological index	0.033	

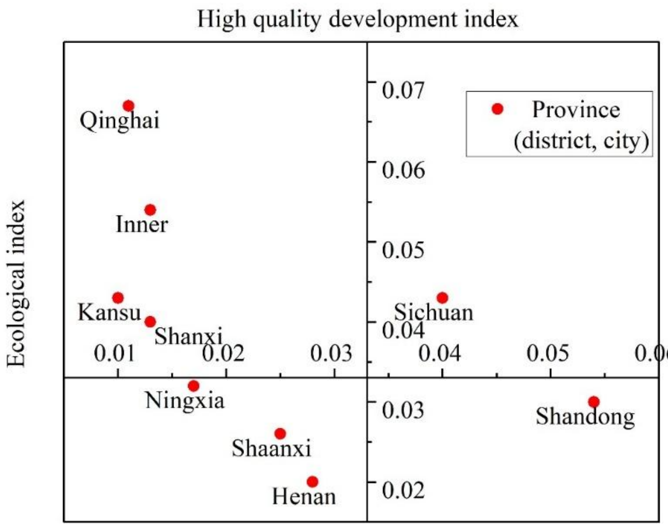

Figure 2. The location of the provinces in two dimensional quadrant

3.3. Calculation Results of Coupling Coordination Degree

Figure 3 shows the changes in the coupling and coordination degree of ecological protection and high-quality development in the Yellow River Basin from 2007 to 2021. It can be seen that: from 2007 to 2009, the consistency of the high-quality development index and the ecological protection index was poor, and the coupling and coordination degree fluctuated wildly within the range of 0.20 to 0.40 (swinging between moderate imbalance and approaching imbalance); after 2010, the changes in the high-quality development index and the ecological protection index tended to be consistent, and the coupling and coordination degree gradually increased from 0.60 to 0.77, with a good coupling and coordination situation between ecological protection and high-quality development in 2021, and the coupling and coordination level reached excellent coordination.

The changes in the coupling and coordination degree of the nine provinces (regions) in the Yellow River Basin from 2007 to 2021 are shown in Figure 4. It can be seen that: the coupling and coordination degree of ecological protection and high-quality development in each province (region) showed an upward trend during the research period, and after 2018, the coupling and coordination levels of the nine provinces (regions) all changed from imbalance to coordination. Among them:

Sichuan and Inner Mongolia had relatively high coupling and coordination degrees, and the coupling and coordination levels had already changed to coordination at the beginning of the research period; Shaanxi, Shanxi and Shandong had medium-level coupling and coordination degrees, and the coupling and coordination levels were in imbalance from 2007 to 2012, and changed to coordination after 2012; Qinghai, Gansu, Ningxia and Henan had overall lower coupling and coordination degrees, and the coupling and coordination levels changed from imbalance to coordination relatively late.

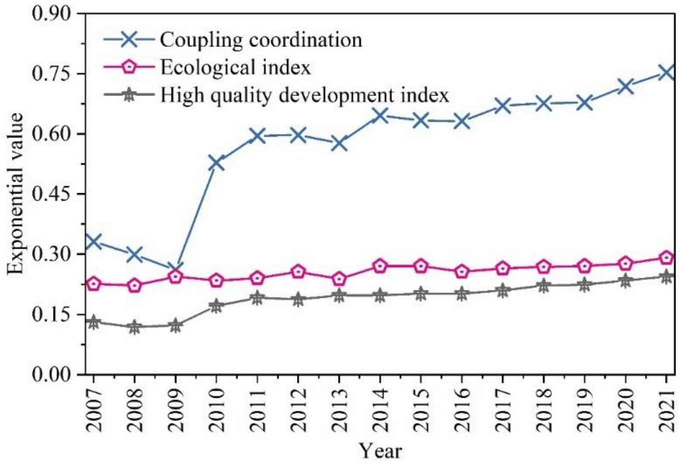

Figure 3. The coupling coordination of ecological and high quality development

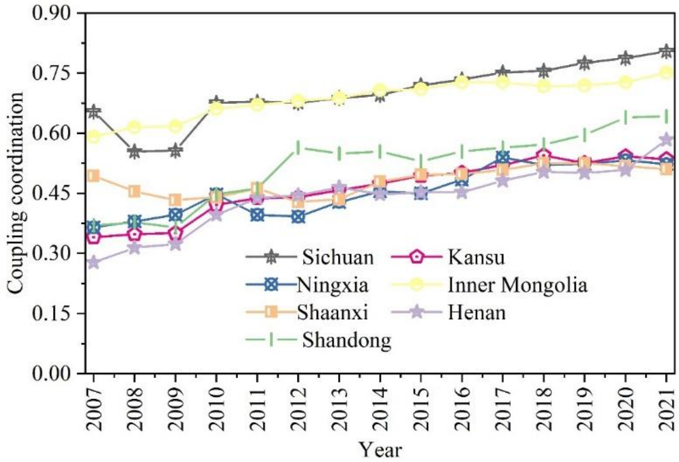

Figure 4. Change of coupling coordination in the Yellow River basin (zone)

3.4. Diagnosis of Obstacles to Ecological Protection and High-Quality Development

Based on the degree of obstacles, the impact of the obstacle factors is ranked. Here, only the top three obstacle factors in terms of ranking for the nine provinces (regions) in 2007, 2011, 2016, and 2021 are listed. The main obstacle factors and their obstacle degrees are shown in Table 7.

From the perspective of ranking the obstacle degrees of the obstacle factors in each province (region), the top 5 obstacle factors are Y10, Y14, Y12, Y5, and Y13. Specifically, at the four time points of 2007, 2011, 2016, and 2021, the coupling and coordination obstacles of the Yellow River Basin's ecological protection and high-quality development were ranked by dimension as: ecological construction > innovation development > pollution control > shared development > open development > coordinated development > pollution discharge > green development. It can be seen that ecological construction has always been the difficulty in the ecological protection of the Yellow River Basin and an important task for high-quality development. Among the top 5 obstacle factors Y10, Y14, Y5, Y12, and Y13, the ones that appeared more than 20 times in the top three obstacle factors of each province (region) are Y10, Y14, and Y5. Therefore, it is believed that Y10, Y14, and Y5 are the key obstacle factors affecting the coupling and coordination relationship of the Yellow River Basin's ecological protection and high-quality development, while Y12 and Y13 are important obstacle factors.

From the perspective of the Yellow River Basin's space, the overall first obstacle factor of the Yellow River Basin has always been Y10, indicating that water resource shortage is the biggest problem for the development of the Yellow River Basin. Relevant literature studies also show that water resources are the greatest rigid constraint for the high-quality development of the Yellow River Basin. Therefore, promoting economic growth while reducing water resource consumption and water environmental pollution is an important way to achieve the ecological protection and high-quality development of the Yellow River Basin. High-level innovation capabilities are the key to improving energy utilization efficiency and can solve problems such as energy shortage in the Yellow River Basin from the source.

Table 7. Major obstacle factors and obstacles

Province (district)	2007	2011	2016	2021
	Y10(44.78)	Y10(48.56)	Y10(52.22)	Y10(56.58)
Shanxi	Y14(17.64)	Y14(17.78)	Y14(18.98)	Y14(19.66)
	Y5(15.94)	Y5(16.83)	Y12(17.41)	Y13(18.35)
	Y10(43.37)	Y10(49.62)	Y10(52.95)	Y10(55.56)
Inner Mongolia	Y5(17.63)	Y5(19.14)	Y5(20.23)	Y5(20.71)
	Y14(17.57)	Y14(17.41)	Y14(17.72)	Y14(17.64)
	Y10(49.27)	Y10(54.59)	Y10(58.32)	Y10(67.72)
Shandong	Y14(19.78)	Y12(20.85)	Y12(24.34)	Y13(48.04)
	Y12(19.28)	Y13(19.47)	Y13(21.97)	Y24(13.36)
	Y10(45.12)	Y10(48.87)	Y10(52.65)	Y10(60.34)
Henan	Y14(18.02)	Y14(18.53)	Y12(21.57)	Y13(30.11)
	Y12(16.53)	Y12(17.84)	Y13(20.74)	Y14(18.92)
	Y10(43.98)	Y10(48.12)	Y10(52.32)	Y10(55.98)
Sichuan	Y14(18.45)	Y14(17.88)	Y12(21.13)	Y12(29.21)
	Y5(16.55)	Y12(17.41)	Y13(18.29)	Y14(18.72)
	Y10(46.84)	Y10(50.61)	Y10(55.08)	Y10(57.53)
Shaanxi	Y14(19.46)	Y14(19.42)	Y14(21.62)	Y14(22.56)
	Y5(17.33)	Y5(18.41)	Y5(17.32)	Y12(20.91)
	Y10(42.85)	Y10(44.37)	Y10(47.01)	Y10(47.66)
Kansu	Y14(17.73)	Y14(18.04)	Y14(19.53)	Y14(19.92)
	Y5(16.21)	Y5(16.98)	Y5(17.02)	Y5(18.23)
	Y5(23.64)	Y5(26.44)	Y10(26.82)	Y5(36.18)
Qinghai	Y10(23.62)	Y4(18.22)	Y5(24.91)	Y7(24.67)
	Y14(17.62)	Y7(18.05)	Y14(18.01)	Y4(18.66)
	Y10(43.87)	Y10(47.16)	Y10(47.97)	Y10(49.94)
Ningxia	Y14(16.94)	Y5(17.67)	Y5(17.95)	Y5(18.19)
	Y5(16.71)	Y14(16.72)	Y14(17.14)	Y14(18.02)

4. Ecological Environment Governance Path in the Yellow River Basin

The effective exertion of the government's overall guiding role requires not only its coordinated advancement at the strategic level but also the formulation of clear development goals in laws and regulations. Specifically, this includes three aspects: planning guidance, policy support, and legal protection. Referring to the existing "Guiding Opinions" and the 14th Five-Year Plan, a strategic planning for the coordinated protection and high-quality development of the Yellow River Basin should be established. Secondly, increase the construction of urban infrastructure and the introduction of talents in the Yellow River Basin, and provide policy support. Thirdly, optimize the "Yellow River Protection Law" and promote the linkage of law enforcement and judicial proceedings to provide a solid legal guarantee for the protection of the Yellow River Basin's ecology and high-quality development.

The large amount of wastewater discharged by the secondary industry in the Yellow River Basin has a significant adverse impact on the environment. Therefore, its green development will contribute to the sustainable development of both the industry and the environment. At the government level, there should be institutional constraints for secondary industry enterprises. At the enterprise level, a modern industrial system should be constructed. Develop modern agriculture, modern manufacturing, and modern services to promote the upgrading and rationalization of the industry. At the social level, all citizens should participate. The coordinated development of ecological protection and high-quality development in the Yellow River Basin is not only the responsibility of government departments such as environmental protection departments and enterprises, but also an obligation that the entire society should fulfill.

The ecological protection situation and the level of high-quality development in the upper, middle and lower reaches of the Yellow River differ, so the strategies for the coordinated development of ecology and high-quality development in each river section are also different. For the Yellow River Basin as a whole to achieve comprehensive development, a systematic collaborative mechanism needs to be established to ensure it. Therefore, on the one hand, strategies for the coordinated development of ecology and high-quality development in the upper, middle and lower reaches of the basin should be formulated based on local conditions. On the other hand, a collaborative mechanism within the basin that is interrelated, interdependent, and with clear responsibilities should be established. Break the spatial correlation of high-high concentration and low-low concentration within the basin, and achieve coordinated and linked development throughout the basin.

Strengthen the construction of urban clusters in the Yellow River Basin and enable the central cities to play a leading role in exerting their radiating effects. The measurement results of the ecological and high-quality coordination degree of each city in the Yellow River Basin indicate that the central cities often have a relatively high coordination level within the basin, and the coordination degree of the basin shows global spatial autocorrelation. Therefore, we must accelerate the development of an urban cluster model centered on key cities within river basins to foster major economic growth poles. First, we must expedite the development of key cities in the Yellow River Basin to promote synergy between ecological conservation and high-quality development in the basin. Second, we must build urban clusters centered on these key cities to fully unleash their radiating influence. Finally, we must strengthen communication and exchange among key cities to further enhance the region's overall coordinated development.

5. Conclusion

This paper constructs an evaluation index system for the ecological protection and high-quality development of the Yellow River Basin. Based on the data of the nine provinces (regions) in the Yellow River Basin from 2007 to 2021, it conducts a study on the changes in the coupling coordination degree of the two systems and the identification of the obstructive factors.

Based on the two-dimensional quadrant method, the coordination status of ecological protection and high-quality development in each province (region) of the Yellow River Basin is divided into four types. The provinces with an excellent ecological and high-quality state are only Sichuan; the other provinces are all in an uncoordinated state such as excellent ecological - low quality, low ecology - low quality, and low ecology - high quality. The above results indicate that the levels of ecological protection and high-quality development in each province (region) of the Yellow River Basin vary greatly, and the problem of imbalance in development is particularly prominent.

The coupling coordination degree of ecological protection and high-quality development in the Yellow River Basin fluctuated greatly between 2007 and 2009, and the coupling coordination grades were all in an imbalanced state. After 2010, the coupling coordination degree of ecological protection and high-quality development in the Yellow River Basin gradually increased, and the coupling coordination grades also changed from primary coordination to high-quality coordination. However, there are still significant differences in the coupling coordination degree and grades among the provinces (regions), further indicating the imbalance in the development of the coupling coordination degree of ecological protection and high-quality development among the provinces (regions).

The coupling coordination degree of ecological protection and high-quality development in the Yellow River Basin is mainly constrained by obstructive factors such as per capita water resources volume, domestic invention patent authorization volume, R&D funding input intensity, urban sewage daily treatment capacity, and the activity of technology transactions, with the influence of per capita water resources volume being the most significant.

Based on the above findings, this paper proposes several paths for ecological environment governance in the Yellow River Basin, including leveraging the government's overall guiding role, promoting the green development of the secondary industry, establishing coordinated strategies and mechanisms for the basin, and releasing the demonstration vitality of the central cities. These proposals enrich the research perspectives on sustainable development in the Yellow River Basin.

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