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Coupling coordination and spatio-temporal pattern evolution between ecological protection and high-quality development in the Yellow River Basin

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A B S T R A C T

The Yellow River Basin is one of the most important economic development belt and ecological management regions in China, it is of vital importance to study the coupling coordination between ecological protection and high-quality development. However, the systematic research from the perspective of ecological-production-living is still lacking. Therefore, a comprehensive evaluation index system including 29 indicators is constructed from ecological, production and living dimension. To evaluate the high-quality development level and coupling coordination degree of 61 cities in the Yellow River Basin, a comprehensive measurement model and coupling coordination model are established using the entropy weight TOPSIS method. With the help of ArcGIS, the spatial characteristics of high-quality development level and coupling coordination are visually illustrated. The results showed that: (1) From 2011 to 2020, the high-quality development of 61cities in the Yellow River Basin showed an increasing trend, and the level of upper and lower reaches was higher than that of the middle reaches. (2) According to the high-quality development level of 61 cities, it was divided into three types: sustainable growth type with 44 cities, the fierce fluctuation type with 11 cities and the other 6 cities was stable type. (3) The coupling coordination degree of ecology, production and living system also showed an increasing trend, while the degree was not high. (4)About the year-on-year growth rate of coupling coordination degree for 61 cities in 2020 compared with 2011, there are 19 cities more than 30 %, and 23 cities between 20% and 30 %, 11cities was 10%–20 %, the other 8 cities was less than 10 %. (5) There is a significant spatial difference in the level of high-quality development in the Yellow River Basin, while coupling coordination degree does not significant in spatial layout. Therefore, the development of different regions should adjust measures to local conditions, give full play to their advantages, and make up for their shortcomings to promote the overall development of the city.

1. Introduction

The Yellow River Basin is an important ecological barrier and economic development belt in China, however, the economic and social development mode, focused on agricultural production and energy development, does not match the environment carrying

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capacity of the Yellow River Basin. In 2021, the Communist Party of China of China Central Committee and the State Council issued an outline document on the ecological protection and high-quality development of the Yellow River Basin, pointing out efforts should be made to strengthen ecological protection and management, ensure the long-term stability of the Yellow River, promote high-quality development and improve the lives of the people. This provides a favorable basis for the coordinating development of high-quality economic and ecological protection. Therefore, it is of great practical significance to systematically study the coupling and coordinated development of high-quality economic development and eco-environmental protection in the Yellow River Basin.

The research of ecological environment measurement are mainly focused on water pollution, air pollution and other indicators to measure ecological protection from the aspects of nature, biological environment and so on [1,2]. At the same time, foreign scholars often use a single source of pollution to assess its impact on the environment [3,4]. The studies of domestic scholars are also similar. The main measurement indicators include dust emissions, SO_2 emissions, soot emissions, solid waste, waste gas emissions and other pollutants emissions, and environmental optimization indicators such as greening coverage, per capita green space area and wetland area in built areas are selected as ecological environment measurement indicators [5–9]. Different scholars have great differences in the study of production level, like the aspects of output value and industry [10], the aspects of agricultural and non-agricultural production [11,12]. The evaluation criteria of social life are also diverse. Some consider indicators such as population, infrastructure, urban-rural gap and employment structure, which are closely related to daily working life [13–15], while others focus on economic development [16]. Others link ecology to human health, exploring the impact of ecological footprint, ecological carrying capacity, years of education and energy using on human health [17].

The understanding of high-quality development is different from economic development in the general sense. The high-quality development is reflected by the improvement of economic growth rate and the welfare level of all social residents, emphasizing that the quality of economic growth can play a role in reducing poverty [18,19]. Some scholars combine social health environment with tourism service economy, and believe that the emergence of COVID-19 has led to global health and economic crisis, seriously hit the performance of global enterprises. The ongoing pandemic has had a huge impact on the service sector, affecting economic development [20]; Some scholars link ecological environment with economic development and believe that natural resources benefit the economy through economic growth and development, that is, explores the role of environmental regulatory quality in the relationship between natural resources and environmental sustainability [21]. Some scholars studied the high-quality development from five new development concepts (innovation, coordination, green, openness and sharing), and based on these indicators, other indicators such as safety, structural optimization and balanced development are added [22–27]. The research on the high-quality development of the Yellow River Basin is mainly focused on water resources, environmental pollution, economic development and other aspects [28].

The research results on the coupling coordination development of ecological protection and high-quality development mainly include the following aspects. Some scholars assessed the coordination development of ecological and economic systems of the Russian Federation in 2005–2011 [29]. WeiJie et al. studied the development of coordination between high-quality development and ecological environment in Henan Province by using the coupling coordination model [30]. MenghuaDeng et al. believe that the coupled and coordinated development of environment and economy is a core issue of sustainable development, so they choose China's Yangtze River Delta region for research [31]. LianyanFu et al. set up a coupled and coordinated model to determine the coordinated development of China's digital economy and ecological environment and calculate its development level [32]. Some scholars have studied the coupling coordination development between the two industries and proposed corresponding development strategies [33]. In addition, the research on the coupling and coordination between scientific and technological innovation and industrial development has also become the focus of scholars [34]. From the perspective of the coupled and coordinated development of logistics industry, new-type urbanization and ecological environment, ChongYe et al. provide certain references for enterprises and the government to formulate sustainable industrial and urbanization development strategies [35]. Some scholars evaluated the coordination degree of the four systems in Kenya from four aspects: environment, economy, society and management [36].

In a comprehensive view, the research on ecological environment measurement , high-quality development and the coupling coordination has been gradually enriched, but there are still some shortcomings that need to be addressed. The literature is active on concerns about ecological environment and economic development. However, ecological protection, production level and social life, represent the comprehensive development level and quality of the Yellow River Basin, are complemented and promoted each other. They are three components in the process of ecological protection and high-quality development of the Yellow River Basin. Therefore, this research study the coupling coordinated development of Yellow River Basin from the perspective of ecological-production-living. Based on a comprehensive evaluation index system, including 29 indicators from ecological, production and living dimension, a comprehensive measurement model and coupling coordination model are established using the entropy weight TOPSIS method. The results are verified by the actual data from 2011 to 2020 and the spatial characteristics are visually illustrated with the help of ArcGIS.

The remainder of the study is laid out as follows: The materials and methods that include the construction of comprehensive index system, measurement model and coupling coordination degree model are presented in Section 2. The results and discussion are the main emphasis of Section 3. Section 4 reveals the Conclusions, while Section 5 explains the limitation and policy implications.

2. Materials and methods

2.1. Research methods

2.1.1. The construction of index system

From the three dimensions of ecology, production and living, a comprehensive index system of high-quality development in the

Yellow River Basin is constructed, which includes 29 indicators of ecological environment, consumption level and economic development. Considering the complex natural environmental conditions and special geographical location, based on the reference of relevant literature [8], the index system established is shown in Table 1:

The 10 years from 2011 to 2020 include two five-year plans, namely, the Outline of the 12th and 13th Five Year Plan for National Economic and Social Development of the People's Republic of the China. During the time period, it was made clear on September 18, 2019 that ecological protection and high-quality development in the Yellow River Basin are major national strategies. Therefore, 29 tertiary index data of 61 cities from 2011 to 2020 were selected, with a total amount of 17,690 pieces of data for corresponding research. Among them, some missing data are filled by interpolation and three moving average method.

In order to evaluate the quality of urban development more accurately, the collected data are processed per capita or ten thousand people, and the percentage and pollution emissions are not dealt with.

2.1.2. Research object

Taking the prefecture-level cities (states, leagues) along the Yellow River Basin as the main research object, taking into account the availability of data, remove some of the serious lack of core indicators of prefecture-level cities (states, leagues), a total of 61 cities are retained, as shown in Table 2.

2.2. Measurement model

2.2.1. A comprehensive measurement model of high-quality development

Entropy weight TOPSIS, combining the entropy weight and TOPSIS method together, is an objective weighted comprehensive evaluation method. For this method, the weights of indicators are determined by the variation degree of data, so as to avoid the bias brought by human factors. The statistical data can be converted into points in multidimensional coordinate system and then the distance between each point and the positive and negative ideal solution can be calculated. This method can comprehensively consider the scores of each index to make the evaluation results more comprehensive and objective. Therefore, this paper uses entropy weight TOPSIS method to establish a comprehensive measurement model to measure the high-quality development of cities along the Yellow River Basin. The measurement model is expressed as follows:

Table 1
Index system of high-quality development in the Yellow River Basin [8].

First-level index	Secondary index	Third-level index	Unit	Index attribute
Ecological dimension	Ecological environment.	Per Capita Area of Green Land	Square metre	Positive
		Per Capita Area of Parks and Green Land	Square metre	Positive
		Per Capita Green Covered Area as % of Completed Area	%	Positive
	Environmental treatment	Ratio of Waste Water Centralized Treated of Sewage Work	%	Positive
		Rate of Domestic Garbage Harmless Treatment	%	Positive
	Pollution emission	Volume of Industrial Waste Water Discharged	tons	negative
		Volume of Industry Sulphur Dioxide Produced	tons	negative
		Volume of Sulphur Dioxide Emission	tons	negative
Production dimension	Consumption level	Year-end Per Capita Balance of Savings of Urban and Rural Residents	yuan	Positive
		Per Capita Total Retail Sales of Consumer Goods	yuan	Positive
		Average Wage of Employed Staff and Workers	yuan	Positive
	Corporation Development	Total Fixed Assets of Industrial Enterprises Per Capita	yuan	Positive
		Year-end Per Capita Loan Balance of Financial Institutions	yuan	Positive
		Number of Industrial Enterprises Per Million People	enterprise	Positive
	Fiscal revenue and expenditure	Per Capita Local General Public Budget Revenue	yuan	Positive
		Per Capita Local General Public Budget Expenditure	yuan	Positive
	Expenditure on science and education	Per Capita Expenditure on Science and Technology	yuan	Positive
		Per Capita Expenditure on Education	yuan	Positive
	Economic development.	Tertiary Industry as Percentage to GRP	%	Positive
		GRP Growth Rate	%	Positive
		Per capita GRP	yuan	Positive
Living dimension	Social security.	Persons Covered of Unemployment Insurance Per 10000 People	person	Positive
		Number of Employees Joining Urban Basic Pension Insurance Per 10000 people	person	Positive
		Registered Unemployed Persons in Urban Areas Per 10000 People	person	negative
	Public life	Number of Buses and Trolley Buses under Operation at Year-end Per 10000 People	car	Positive
		Number of Beds of Hospitals Per 10000 People	bed	Positive
		Number of Licensed (Assistant) Doctors	person	Positive
	Higher Education	Undergraduate in Regular HEIs Per 10000 People	person	Positive
		Regular Higher Education Institutions Per Million People	institution	Positive

Table 2
Object of the research.

Province	cities
Qinghai	Xining Haidong
Gansu	Lanzhou Baiyin Dingxi Tianshui Qingyang Pingliang Longnan
Ningxia	Yinchuan Zhongwei Wuwei Wuzhong
Nei Monggol	Huhhot Shizuishan Guyuan Ordos Baotou Bayannur Wuhai
Shaanxi	Xi'an Baoji Xianyang Shangluo Weinan Tongchuan Yan'an Yulin
Shanxi	Taiyuan Shuozhou Xinzhou Yangquan Datong Lvliang Jinzhong Changzhi Linfen Jincheng Yuncheng
Henan	Zhengzhou Xinxiang Shangqiu Jiaozuo Luoyang Sanmenxia Kaifeng Puyang Hebi Anyang
Shandong	Jinan Zibo Qingdao Binzhou Dongying Weifang Heze Liaocheng Jining Taian Dezhou

$$T_j = \frac{D_j^-}{D_j^+ + D_j^-} = \frac{\sqrt{\sum_{i=1}^{n}\left(V_i^+ - v_{ij}\right)^2}}{\sqrt{\sum_{i=1}^{n}\left(V_i^+ - v_{ij}\right)^2} + \sqrt{\sum_{i=1}^{n}\left(V_i^- - v_{ij}\right)^2}} \tag{1}$$

Among them ,

$$V^+ = \left\{ \max_{1\le i\le n} v_{ij} \middle| i = 1, 2, \dots, n \right\} = \left\{V_1^+, V_2^+, \dots, V_n^+\right\} \tag{2}$$

$$V^- = \left\{ \min_{1\le i\le n} v_{ij} \middle| i = 1, 2, \dots, n \right\} = \left\{V_1^-, V_2^-, \dots, V_n^-\right\} \tag{3}$$

$$\mathbf{V} = \left(v_{ij}\right)_{nm} = \left(y_{ij} w_i\right)_{nm} = \left(y_{ij} \frac{1 - e_i}{\sum_{i=1}^{n}(1 - e_i)}\right)_{nm} \tag{4}$$

$$e_i = -\ln(n)^{-1} \sum_{j=1}^{m} p_{ij} \ln p_{ij} = -\ln(n)^{-1} \sum_{j=1}^{m} \frac{y_{ij}}{\sum_{j=1}^{m} y_{ij}} \ln \frac{y_{ij}}{\sum_{j=1}^{m} y_{ij}}, i = 1, 2, \dots, n \quad , \quad 0 \le e_i \le 1 \tag{5}$$

$$y_{ij} = \begin{cases} \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)} x_{ij} \text{ is positive indicator} \\ \frac{\max(x_i) - x_{ij}}{\max(x_i) - \min(x_i)} x_{ij} \text{is negative indicator} \end{cases} \tag{6}$$

where, y_{ij} *and* x_{ij} are the standardized value and the original value of the *j*th city and the *i*th index, and the summary of the *i*th index are represented by x_i. p_{ij} represents the proportion of the *i*th indicator of the *j*th city to the total number of indicators. e_i is the information entropy of the *i*th index and **V** is the evaluation matrix based on the framework of entropy weight. V_i^+ is the maximum value of the first index, which is called the positive ideal solution, while the negative ideal solution is V_i^- which is the minimum value of the index. The distance between the *i*th index in the *j*th city and V_i^+ is D_j^+. The distance between the *i*th index in the *j*th city and V_i^- is D_j^-. T_j indicates the degree to which the index of the *j*th city is close to the optimal level, which is called "the ideal progress". The range of T_j is $[0, 1]$. The larger the index, the higher the development level of the city. When the index is equal to 1, it indicates that the quality of urban development has reached the ideal state.

2.2.2. The coupling coordination degree model of ecology, production and living in the Yellow River Basin

The coupling coordination model is a model to test the degree of coordination development between things, which is used to study the coordination degree of two or more systems. It can be used to comprehensively reflect the coordinated development level between ecological environment, social life and economic development. In this paper, the coupling and coordination model of ecology, production and life in the Yellow River Basin will be constructed as follows:

$$T = \alpha U_1 + \beta U_2 + \gamma U_3 \tag{7}$$

$$C = \left[\frac{U_1 \times U_2 \times U_3}{\prod_{i\ne j}\left(U_i + U_j\right)}\right]^{1/3} \tag{8}$$

$$D = \sqrt{C \times T} \tag{9}$$

where, T represents the comprehensive coordination index. U_1、U_2 and U_3 are the comprehensive level indexes of the three systems respectively. The values of α、β and γ are all 1/3 (assigned equal weight). C is the degree of coupling. D is the coupling coordination degree. $i,j = 1,2,3$.

On the basis of reference to relevant literature [10,14,35], the coupling coordination degree is divided into ten levels according to the method of uniform distribution, as shown in Table 3.

3. Results and discussion

3.1. 1Comprehensive measurement of high-quality development

3.1.1. Measurement results of high-quality development of cities along the Yellow River Basin

According to formula (1)-(6), the measurement model established above by the entropy weight TOPSIS method, the high-quality development of cities along the Yellow River Basin from 2011 to 2020 can be measured and analyzed with the help of R language. The results are shown in Table 4.

Table 4 shows that the comprehensive score of the high-quality development measure of 61 cities along the Yellow River basin is less than 0.5041, and the overall level of high-quality development is not high. The comprehensive score of the top 10 cities is more than 0.37, most of them are provincial capitals and second-tier cities, and the level of high-quality development is better. However, the level of high-quality development of most cities is low, and about 69 % of the cities have a comprehensive score of less than 0.2 in ten years. This shows that there are great differences in the level of high-quality economic development among cities in the Yellow River basin, and the development quality of provincial capitals and second-tier cities is higher, which is mainly due to the rapid economic development from 2011 to 2020.

3.1.2. Spatial distribution of high-quality development level in the Yellow River Basin

In order to directly display the comprehensive measurement results of the high-quality development level of different cities along the Yellow River Basin from 2011 to 2020, the analysis results are shown with the help of ArcGIS software. According to reference literature [37], the analysis results are shown in Fig. 1.

Fig. 1 further visually shows the high-quality development level of different cities in the Yellow River basin, with higher development quality in the provincial capitals and second-tier cities such as Qingdao, Jinan, Taiyuan, Hohhot, Xi'an, Lanzhou and Yinchuan. This is mainly due to the rapid economic development between 2011 and 2020. Other cities at all levels, such as Wuhai, Shizuishan, Ordos and other cities, although their economic development lags behind those in the middle and lower reaches, they have done a relatively better job in ecological protection and less pollutant emissions, so the overall ranking is also higher.

In order to show the level of high-quality development of cities in the Yellow River Basin in different years, 2011, 2014, and 2017 and 2020 were selected as representative years, and the spatial distribution characteristics of high-quality development level of 61 different cities along the Yellow River Basin in the four years are respectively shown in Fig. 2 (a) - (d).

Fig. 2 shows that the high-quality development level of 61 cities has gradually improved over the past 10 years, especially after 2017, the concept of "Green Water and Green Mountains is Jinshan and Silver Mountain" has been deeply rooted in the hearts of the people, and major cities have paid attention to the quality of urban development instead of blindly pursuing quantity, so that the development quality of each city has been significantly improved in the next few years. Especially in the head of several cities, the absolute value of the improvement of the level of high-quality development is more obvious.

3.1.3. Time series of high-quality development level in the Yellow River Basin

In order to more clearly reflect the changes of the high-quality development level of 61 cities in the Yellow River Basin in the past ten years, according to the development trend of urban high-quality development level, they are divided into three types: sustainable growth type, fierce fluctuation type and stable type. As a representative, the ideal progress of the cities with the top 10, middle and bottom 10 overall scores are respectively shown in Fig. 3(a)-(c).

The development trend types of 30 cities are shown in Table 5:

As can be seen from Fig. 3 and Table 5, the high-quality development levels of 25 cities showed an obvious upward trend during the

Table 3
Grading of coordination degree [14].

Coupling coordination degree	Level
[0,0.1)	Extreme disorder
[0.1,0.2)	Severe disorder
[0.2,0.3)	Moderate disorder
[0.3,0.4)	Mild disorder
[0.4,0.5)	On the verge of disorder
[0.5,0.6)	Barely coordinate
[0.6,0.7)	Primary coordination
[0.7,0.8)	Intermediate coordination
[0.8,0.9)	Good coordination
[0.9,1.0]	High quality coordination

Table 4
Measurement results of high-quality development of cities along the Yellow River Basin.

city	Comprehensive score	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jinan	0.5041	0.4257	0.4435	0.4861	0.4943	0.5016	0.5332	0.5290	0.5417	0.5436	0.5475
Taiyuan	0.4917	0.4864	0.5148	0.5286	0.5464	0.4839	0.4702	0.4504	0.4631	0.4810	0.4918
Xi'an	0.4766	0.4013	0.4235	0.4526	0.4622	0.4979	0.4535	0.5053	0.5671	0.5452	0.4576
Lanzhou	0.4615	0.3843	0.4041	0.4658	0.4721	0.4805	0.5098	0.4718	0.4698	0.4947	0.4588
Yinchuan	0.4337	0.3459	0.3738	0.4086	0.4227	0.4423	0.4612	0.4801	0.4914	0.4989	0.4052
Qingdao	0.4266	0.3131	0.3508	0.3929	0.4000	0.4067	0.4360	0.4580	0.4762	0.5007	0.5195
Hohhot	0.4201	0.3708	0.3737	0.3904	0.3986	0.4187	0.4329	0.4449	0.4325	0.4717	0.4656
Wuhai	0.4150	0.3785	0.3906	0.4342	0.4457	0.4201	0.4307	0.4150	0.4050	0.4157	0.4142
Zhengzhou	0.3907	0.3161	0.3294	0.3470	0.3558	0.3655	0.3913	0.3975	0.4267	0.4765	0.4923
Zibo	0.3793	0.3590	0.3684	0.3942	0.3975	0.3797	0.3868	0.3816	0.3905	0.3721	0.3626
Baotou	0.3641	0.3152	0.3268	0.3445	0.3435	0.3429	0.3791	0.3960	0.4044	0.4029	0.3824
Dongying	0.3441	0.2478	0.2789	0.3196	0.3400	0.3418	0.3783	0.4014	0.3718	0.3840	0.3744
Shizuishan	0.3427	0.3287	0.2962	0.3372	0.3267	0.3091	0.3431	0.3374	0.3818	0.3666	0.3996
Xining	0.3371	0.3723	0.2824	0.2809	0.3225	0.3563	0.3618	0.3526	0.3435	0.3451	0.3502
Ordos	0.3267	0.2928	0.2986	0.3192	0.3160	0.3307	0.3274	0.3435	0.3412	0.3595	0.3367
Yangquan	0.2823	0.2384	0.2718	0.3198	0.2931	0.2515	0.3114	0.2679	0.2866	0.2899	0.2900
Tongchuan	0.2523	0.2242	0.2778	0.2289	0.2281	0.2343	0.2348	0.2390	0.2943	0.2697	0.2897
Datong	0.2352	0.1742	0.2024	0.2391	0.2474	0.2615	0.2578	0.2227	0.2288	0.2461	0.2690
Jinzhong	0.2007	0.1223	0.1289	0.1890	0.1993	0.2015	0.2081	0.2209	0.2299	0.2432	0.2564
Hebi	0.1856	0.1549	0.1598	0.1665	0.1795	0.1820	0.1933	0.1890	0.1956	0.2076	0.2286
Luoyang	0.1825	0.1182	0.1476	0.1612	0.1709	0.1771	0.1852	0.1968	0.2023	0.2281	0.2351
Changzhi	0.1669	0.1274	0.1482	0.1514	0.1505	0.1524	0.1595	0.1644	0.1800	0.2125	0.2211
Jincheng	0.1658	0.1159	0.1424	0.1580	0.1620	0.1610	0.1615	0.1712	0.1821	0.1975	0.2039
Binzhou	0.1648	0.1057	0.1197	0.1290	0.1486	0.1612	0.1720	0.1957	0.1997	0.1982	0.2142
Yulin	0.1640	0.1061	0.1343	0.1336	0.1740	0.1426	0.1784	0.1780	0.2020	0.2002	0.1855
Jiaozuo	0.1616	0.1276	0.1352	0.1475	0.1615	0.1613	0.1593	0.1696	0.1793	0.1841	0.1906
Taian	0.1605	0.1216	0.1410	0.1434	0.1819	0.1544	0.1594	0.1686	0.1683	0.1803	0.1858
Baoji	0.1570	0.1211	0.1212	0.1195	0.1499	0.1489	0.1686	0.1650	0.1724	0.1908	0.2120
Weifang	0.1565	0.1142	0.1244	0.1405	0.1458	0.1440	0.1594	0.1701	0.1770	0.1891	0.1989
Shuozhou	0.1550	0.1289	0.1525	0.1413	0.1606	0.1415	0.1453	0.1536	0.1608	0.1805	0.1844
Xianyang	0.1489	0.1188	0.1378	0.1324	0.1365	0.1391	0.1489	0.1601	0.1646	0.1668	0.1834
Yan'an	0.1487	0.1156	0.1343	0.1443	0.1611	0.1388	0.1654	0.1491	0.1877	0.1585	0.1294
Sanmenxia	0.1395	0.0902	0.1018	0.1115	0.1218	0.1229	0.1474	0.1601	0.1706	0.1823	0.1850
Xinxiang	0.1368	0.1161	0.1186	0.1235	0.1318	0.1263	0.1334	0.1440	0.1529	0.1600	0.1610
Kaifeng	0.1364	0.0900	0.0930	0.1157	0.1489	0.1802	0.1231	0.1434	0.1471	0.1593	0.1613
Wulanchabu	0.1362	0.1188	0.1072	0.1124	0.1195	0.1265	0.1422	0.1452	0.1424	0.1954	0.1487
Jining	0.1348	0.0873	0.0982	0.1264	0.1261	0.1342	0.1390	0.1515	0.1562	0.1617	0.1665
Wuzhong	0.1302	0.0887	0.1096	0.1156	0.1232	0.1284	0.1343	0.1391	0.1497	0.1556	0.1570
Anyang	0.1241	0.1017	0.1031	0.1096	0.1146	0.1168	0.1220	0.1376	0.1424	0.1444	0.1488
Wuwei	0.1230	0.0814	0.0904	0.1111	0.1178	0.1296	0.1300	0.1367	0.1214	0.1314	0.1796
Zhongwei	0.1202	0.0762	0.0953	0.1074	0.1106	0.1145	0.1252	0.1407	0.1396	0.1467	0.1452
Bayannur	0.1164	0.0797	0.0979	0.1016	0.1118	0.1239	0.1300	0.1294	0.1282	0.1307	0.1296
Guyuan	0.1159	0.1035	0.0828	0.0877	0.0905	0.1004	0.1184	0.1321	0.1408	0.1372	0.1643
Dezhou	0.1156	0.0777	0.0839	0.0956	0.1250	0.1197	0.1177	0.1198	0.1432	0.1351	0.1378
Linfen	0.1145	0.0752	0.0971	0.1054	0.1098	0.1166	0.1256	0.1244	0.1308	0.1384	0.1211
Baiyin	0.1130	0.0922	0.0973	0.1008	0.1047	0.1119	0.1156	0.1210	0.1212	0.1225	0.1429
Lvliang	0.1114	0.1321	0.1816	0.0789	0.0863	0.0888	0.0938	0.0986	0.1186	0.1156	0.1130
Fuyang	0.1040	0.0834	0.0865	0.0892	0.0959	0.0996	0.1060	0.1098	0.1121	0.1202	0.1374
Liaocheng	0.1030	0.0706	0.0772	0.0856	0.1044	0.1129	0.1009	0.1067	0.1084	0.1274	0.1352
Yuncheng	0.0995	0.0675	0.0723	0.0853	0.1712	0.0877	0.0901	0.0920	0.1003	0.1063	0.1184
Xinzhou	0.0995	0.0748	0.0835	0.0895	0.0965	0.1018	0.1007	0.1017	0.1074	0.1199	0.1181
Tianshui	0.0975	0.0704	0.0747	0.0809	0.0848	0.0940	0.1016	0.1019	0.1131	0.1168	0.1362
Qingyang	0.0875	0.0592	0.0695	0.0761	0.0808	0.0894	0.0906	0.0936	0.0992	0.1058	0.1095
Pingliang	0.0839	0.0573	0.0607	0.0684	0.0733	0.0787	0.0855	0.0940	0.1022	0.1027	0.1150
Shangqiu	0.0830	0.0618	0.0634	0.0667	0.0727	0.0759	0.0835	0.0901	0.0967	0.1059	0.1133
Shangluo	0.0798	0.0708	0.0613	0.0994	0.0698	0.0717	0.0745	0.0726	0.0822	0.0916	0.1026
Heze	0.0796	0.0542	0.0604	0.0647	0.0679	0.0712	0.0861	0.0900	0.0970	0.0991	0.1052
Haidong	0.0780	0.0641	0.0652	0.0546	0.0637	0.0841	0.0945	0.0861	0.0941	0.0908	0.0822
Weinan	0.0725	0.0538	0.0576	0.0606	0.0646	0.0695	0.0737	0.0769	0.0819	0.0894	0.0967
Longnan	0.0718	0.0539	0.0594	0.0566	0.0631	0.0676	0.0739	0.0732	0.0770	0.1064	0.0859
Dingxi	0.0638	0.0467	0.0538	0.0535	0.0549	0.0587	0.0626	0.0690	0.0730	0.0820	0.0831
Upper reaches mean	0.1692	0.1769	0.1921	0.1955	0.1990	0.2122	0.2149	0.2196	0.2292	0.2250	0.1692
Middle reaches mean	0.1465	0.1620	0.1672	0.1790	0.1745	0.1801	0.1845	0.1998	0.2076	0.2104	0.1465
Lower reaches mean	0.1561	0.1682	0.1857	0.1995	0.2018	0.2100	0.2195	0.2249	0.2316	0.2380	0.1561

Notes: The order of the cities were ranked according to the Comprehensive score.

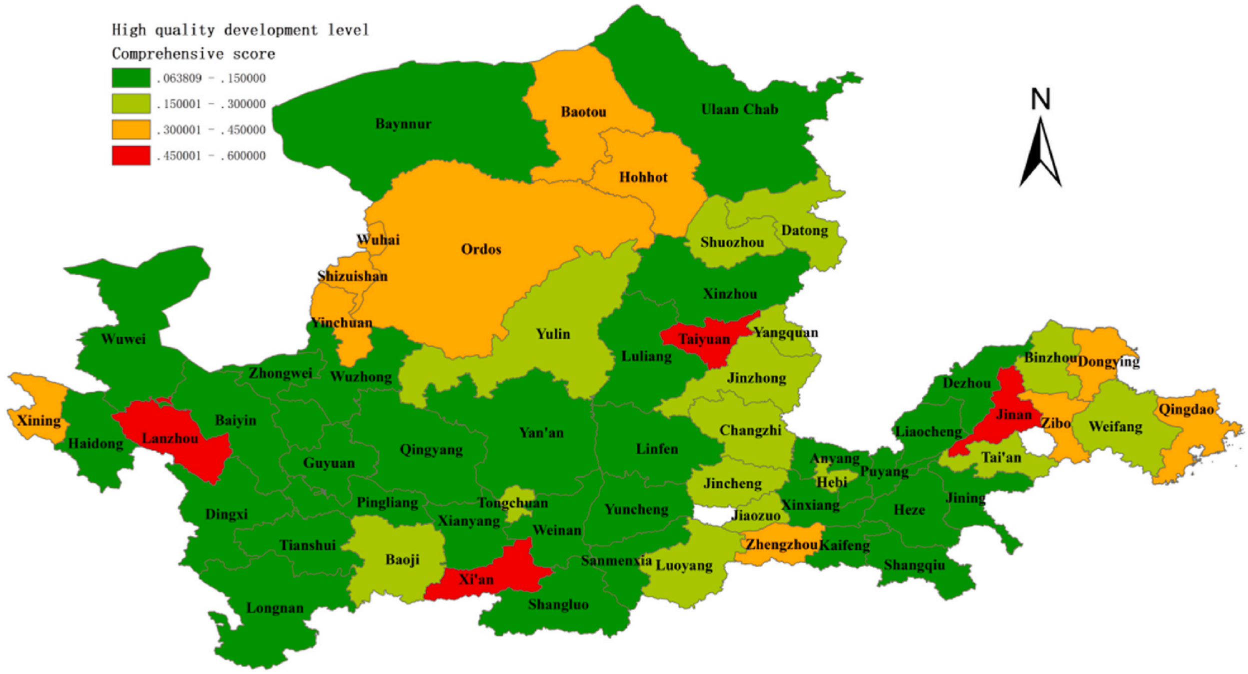


Fig. 1. Comprehensive score of high-quality development.

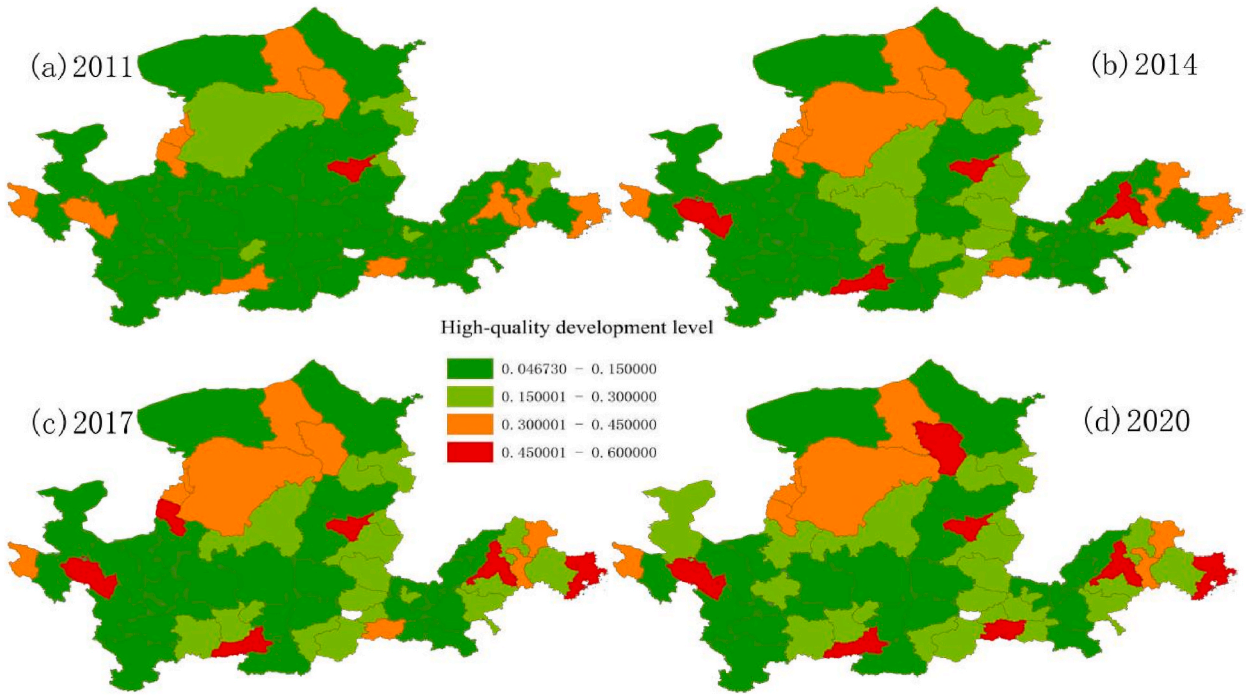
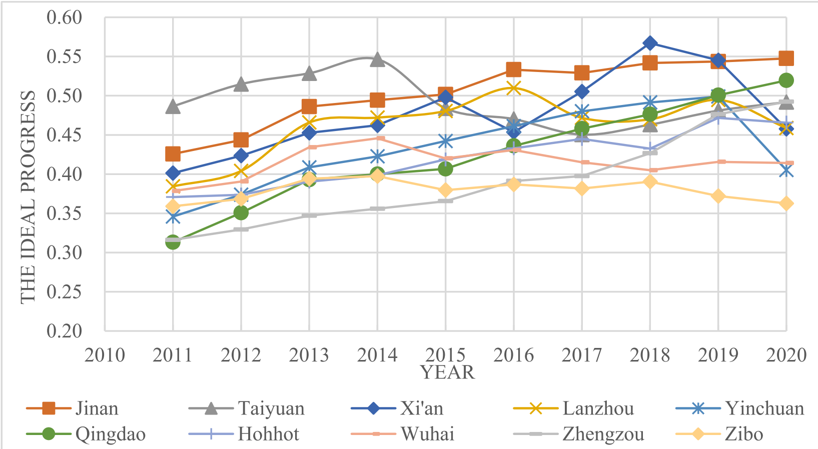


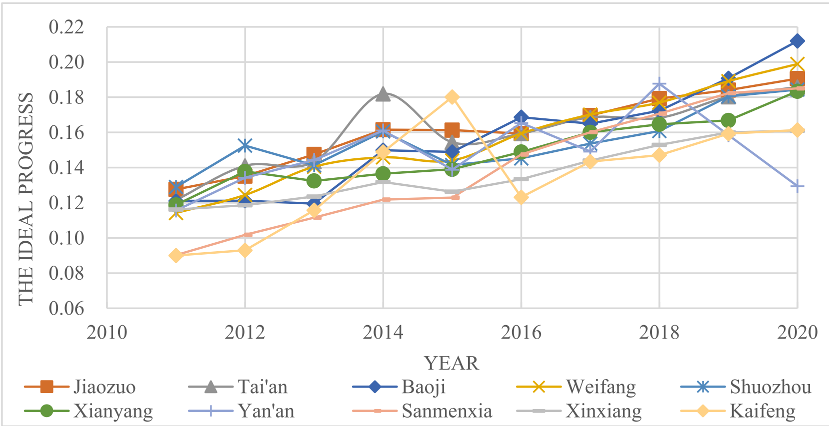
Fig. 2. Spatial distribution of high-quality development level of cities along the Yellow River Basin.

decade 2011–2020, of which Jinan, Qingdao and Zhengzhou grew the fastest. All of them have increased from about 0.4 to about 0.5, which fully shows that these leading cities have made great efforts to achieve high-quality development in the past ten years.

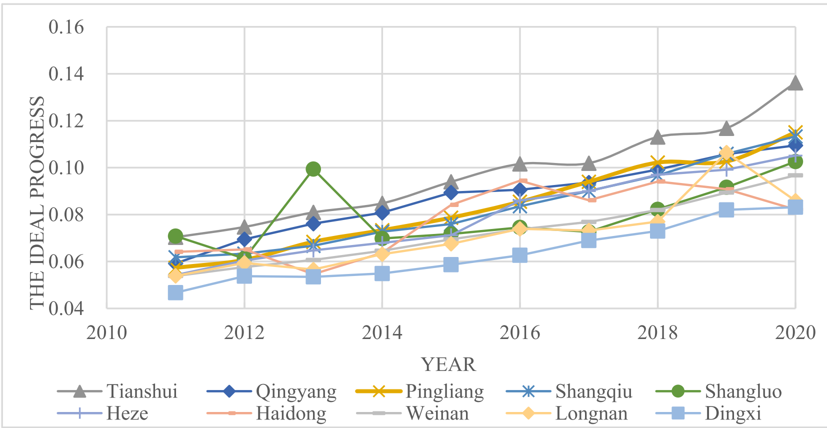
The development level of Taiyuan fluctuates greatly in the process of development, and the high-quality development level shows an obvious downward trend after 2014, and begins to rise gradually after 2017. Through the analysis of the three subsystems of Taiyuan, it is found that the reason for the fluctuation in Taiyuan is mainly due to the obvious decline in the number of residents' old-



（a） Development trend of the top ten cities with comprehensive scores



（b） Development trend of the middle ten cities with comprehensive score



（c） Development trend of bottom ten cities with comprehensive scores

Fig. 3. Development trend of the top 10, middle and bottom 10 comprehensive scores.

Table 5
The types of the top ten, middle ten and last ten cities with comprehensive scores.

	sustainable growth type	fierce fluctuation type	stable type
Top 10 cities	Jinan Lanzhou Qingdao Hohhot Wuhai Zhengzhou	Taiyuan Xi'an	Zibo
Middle 10 cities	Jiaozuo Tai'an Baoji Weifang Shuozhou Xianyang Sanmenxia Xinxiang	Yan'an Kaifeng	
Bottom 10 cities	Tianshui Qingyang Pingliang Shangqiu Shangluo Heze Haidong Weinan Longnan Dingxi		

age insurance and unemployment insurance in the “living dimension”, resulting in the decrease of the social security level of residents. The level of high-quality development in Xi’an from 2019 to 2020 also showed an obvious downward trend. Through the analysis of subsystems, it was found that it was mainly due to the decline in the development quality of “production dimension”, in which “science and technology expenditure, education expenditure, GRP growth rate, per capita GRP” were significantly lower than those in the previous two years. The development level of Yan’an showed fluctuating growth from 2011 to 2018, but decreased obviously from 2019 to 2020. On the one hand, it is because the per capita fixed assets of industrial enterprises and the growth rate of regional GDP in the “production dimension” have declined obviously. On the other hand, the population data obtained from the census led to a large increase in the population in 2020, and the data values of various per capita indicators decreased significantly. The high-quality development level of Kaifeng suddenly decreased in 2016 because the number of unemployment insurance participants per 10,000 people and the number of hospital beds per 10,000 population are all decreased significantly, and then increased year by year. Shangluo in 2013 due to the obvious growth in the number of urban workers’ basic old-age insurance, Longnan in 2019, there is a significant increase in the number of bus operating vehicles at the end of the year, the two cities showed a more outstanding level of development in that year. The development level of Zibo has not changed significantly in the past ten years.

In order to more clearly reflect the changes of the high-quality development level of 61 cities in the Yellow River Basin in the past ten years, according to the development trend of urban high-quality development level, they are divided into three types: sustainable growth type, fierce fluctuation type and stable type. Sustainable growth types include 44 cities. The intense fluctuation type includes 11 cities, while the stable type includes 6 cities. The details are shown in Table 6.

Through the analysis of the 61 cities, it can be found that the overall high-quality development of cities in the Yellow River Basin shows an obvious upward trend. Among the 61 cities, 44 cities are of sustained growth, accounting for 72 %. But it’s still at a low level. There are great differences in the level of development between cities, especially between the top ten and the last ten cities. In 2020, the comprehensive scores of the top ten cities are all above 0.35, compared with them, while the last ten cities are all below 0.14. At the same time, through the study of the average growth value and average growth rate of each city in the past ten years, it is found that the average growth value of the top 10 cities is 0.083, the average growth rate is 23.8 %. The average growth rate of the middle 10 cities was 0.065, the average growth rate was 58.4 %, and the average growth rate of the bottom 10 cities was 0.044 and 74.6 %. It shows that the higher level of development, the less speed of development slows down. Although the growth rate of cities with a lower level of high-quality development is higher, the absolute value of growth is still at a low level, and it is still necessary to continue to strengthen development efforts to ensure high-quality and rapid development.

3.1.4. Development trend of the upper, middle and lower reaches of the Yellow River Basin

The Yellow River basin has a large span, complex topography and great differences in development. The above analysis also shows that there are obvious differences in the level of high-quality development among the cities in the upper, middle and lower reaches of the Yellow River basin. Fig. 4 shows the changing trend of the high-quality development level in the upper, middle and lower reaches of the Yellow River basin in the past ten years.

Fig. 4 shows the changes of the high-quality development level of the upper, middle and lower reaches of the Yellow River basin from 2011 to 2020. At the same time, referring to the changes of the high-quality development level of cities in different years in Fig. 2, the cities in the upper reaches of the Yellow River showed a higher level of development from 2011 to 2015. This may be attributed to the lower pollution emissions of upper reach cities than the middle and lower reaches. Before 2015, lower reach cities focused on economic development and ignored ecological protection, so they did not show a high level, but after 2015, with the strengthening of awareness of ecological environment protection, the high-quality development level of lower reach cities has achieved rapid growth, and the high-quality development level has always been the highest since 2016. Except for some cities with high level of economic development, such as Xi’an and Zhengzhou, the high-quality development level of other cities is relatively mediocre, may be due to soil erosion and dependence on resources. Ignore the protection of ecology, and the economy does not show a strong advantage, so the overall high-quality development level of the middle reaches is poor.

3.2. Coupling coordination degree measurement

3.2.1. Measurement results of the coordination degree of ecology, production and living in the Yellow River Basin

The comprehensive index of ecosystem, production system and living system calculated by entropy weight TOPSIS is substituted into the above coupling coordination degree development model, and the coupling coordination degree of each city from 2011 to 2020 is calculated by formula (7)-(9), the results are shown in Table 7.

Table 6
Development trend types of 61 cities in the Yellow River Basin.

	sustainable growth type	fierce fluctuation type	stable type
cities	Jinan, Lanzhou, Yinchuan, Qingdao, Hohhot, Wuhai, Zhengzhou, Baotou, Dongying, Shizuishan, Jiaozuo, Taian, Baoji, Weifang, Shuozhou, Xianyang, Sanmenxia, Xinxiang, Jinzhong, Hebi, Changzhi, Binzhou, Wuwei, Jining, Wuzhong, Anyang, Zhongwei, Puyang, Liaoyang, Linfen, Xinzhou, Qingyang, Shangqiu, Shangluo, Haidong, Weinan, Dingxi, Luoyang, Jincheng, Guyuan, Tianshui, Pingliang, Heze, Longnan (44)	Taiyuan,Xi’an,Xining, Yangquan, Yulin, Wulanchabu, Datong,Lvliang, Yuncheng, Yan’an,Kaifeng (11)	Bayannur, Ordos, Dezhou, Tongchuan, Baiyin, Zibo (6)

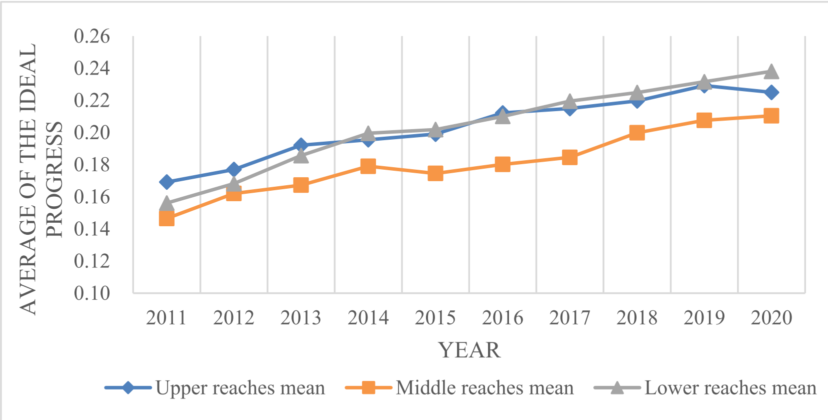


Fig. 4. Changes of high-quality development level in the upper, middle and lower reaches of the Yellow River Basin.

On the whole, the coupling coordination degree of the cities along the Yellow River basin is at a low level, the highest reaches the level of "barely coordinated", and most of them are in the stage of "Severe disorder" and "Moderate disorder". The coupling coordination of ecology, production and living system in the Yellow River basin is poor.

3.2.2. Evolution trend of coupling coordination time series of different cities in the Yellow River Basin

In order to more clearly reflect the ten-year evolution trend of the cities along the Yellow River basin from 2011 to 2020, the changing trends of the coupling coordination degree of the top 10, middle and last ten cities in 2020 are shown on a line chart, as shown in (a)–(c) of Fig. 5 below.

As can be seen from Fig. 5, there are obvious differences in the coupling coordination degree of ecology, production and living in the Yellow River Basin from 2011 to 2020. With the change of time, the coupling coordination degree of different cities will change. And the growth of the coupling coordination degree of the top cities is more obvious in the past decade, while the growth rate of the cities with lower coupling coordination degree is also lower.

Compared with the year-on-year growth rate in 2020 compared to 2011:

There are 19 cities with year-on-year growth of more than or equal to 30 %, accounting for 31.1 % of the 61 cities in the Yellow River Basin. There are 23 cities with year-on-year growth of between 20 % and 30 %, accounting for 37.7 % of the 61 cities in the Yellow River Basin. There are 11 cities with year-on-year growth between 10 % and 20 %, accounting for 18 %. There are 8 cities with year-on-year growth of less than 10 %, accounting for 13 %. Yan'an and Ordos are basically unchanged. It can be clearly seen that 61 cities in the Yellow River basin have shown an obvious upward trend in the past 10 years, and most of them have increased by a large extent, showing a good trend of development.

3.2.3. Spatial evolution trend of coupling coordination among cities in the Yellow River Basin

In order to better describe the spatial evolution pattern of cities in the Yellow River Basin from 2011 to 2020, ArcGIS was used to draw the spatial distribution of ecological-production- living coupling coordination degree of cities in the Yellow River Basin in 2011, 2014, 2017 and 2020, as a representative of the change of coupling coordination degree among cities in the Yellow River Basin. See (a)–(d) in Fig. 6 below for details.

As can be seen from Fig. 6, the cities with high degree of coupling coordination are aggregated and distributed, mainly concentrated in several cities, such as Hohhot, Wuhai, Baotou, and several cities near the entrance to the sea, such as Qingdao, Jinan, Dongying and other cities; others are scattered in other areas of the Yellow River basin, mainly provincial capitals. The cities with serious imbalance of coupling coordination are mainly concentrated in Dingxi, Longnan in Gansu Province and Haidong in Qinghai Province in the upper reaches of the Yellow River, while other cities are mainly in the degree of mild and moderate imbalance.

The coupling coordination degree of ecology, production and living of each city has not changed greatly in the past ten years, and the coupling coordination degree of cities in the upper and lower reaches of the Yellow River Basin is higher than that of cities in the middle reaches of the Yellow River Basin. This is similar to the measurement result of the comprehensive development level of urban ecological-production- living in the Yellow River Basin.

Specifically, the coupling coordination degree of the cities in Shandong Province near the estuary of the sea is relatively high, some of them are in a state of barely coordinate and On the verge of disorder, and spatial aggregation appears. The main reason is that the production level of Shandong cities belongs to a higher level in the Yellow River Basin, which affects the other two major systems, so it shows a higher degree of coupling coordination. The coupling coordination degree of Nei Mongol is also high, mainly because the ecological environment of the region has been at a high level, at the same time, the level of economic development is not poor, so the overall performance of a high degree of coupling and coordination. From the performance of each city, the coupling coordination degree of ecology, production and living in Qingdao, Jinan, Xi'an, Zhengzhou, Taiyuan, Hohhot, Lanzhou and Xining is relatively high. The main reason is that there is a correlation between the coupling coordination degree and the high quality development degree of the

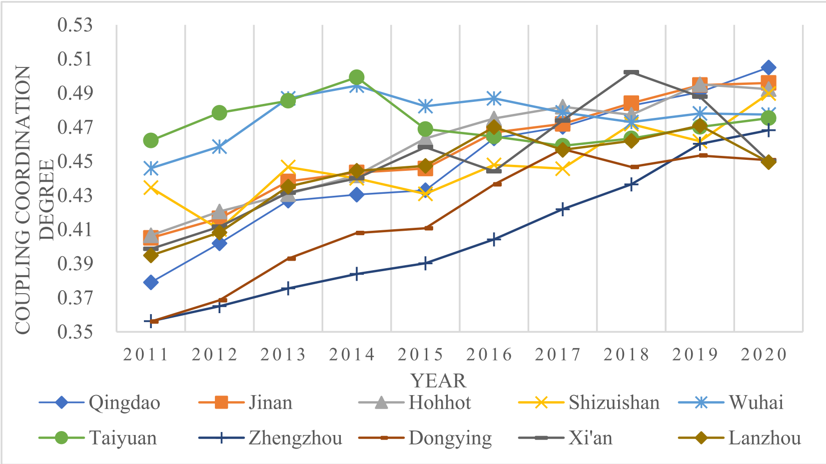
Table 7
Urban Coupling Coordination degree in the Yellow River Basin from 2011 to 2020.

citiy	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Qingdao	0.3790	0.4019	0.4269	0.4304	0.4330	0.4634	0.4702	0.4826	0.4906	0.5050
Jinan	0.4051	0.4165	0.4382	0.4435	0.4458	0.4669	0.4719	0.4841	0.4947	0.4959
Hohhot	0.4066	0.4206	0.4308	0.4418	0.4633	0.4751	0.4820	0.4773	0.4951	0.4923
Shizuishan	0.4345	0.4101	0.4466	0.4400	0.4309	0.4479	0.4457	0.4718	0.4617	0.4897
Wuhai	0.4459	0.4586	0.4869	0.4944	0.4823	0.4869	0.4786	0.4730	0.4781	0.4774
Taiyuan	0.4622	0.4785	0.4855	0.4992	0.4689	0.4646	0.4591	0.4634	0.4702	0.4753
Zhengzhou	0.3562	0.3651	0.3755	0.3839	0.3902	0.4042	0.4219	0.4365	0.4602	0.4682
Dongying	0.3560	0.3685	0.3928	0.4080	0.4107	0.4364	0.4572	0.4467	0.4534	0.4506
Xi'an	0.3986	0.4117	0.4316	0.4400	0.4583	0.4441	0.4739	0.5022	0.4878	0.4501
Lanzhou	0.3948	0.4083	0.4351	0.4444	0.4473	0.4700	0.4567	0.4620	0.4709	0.4495
Baotou	0.3988	0.4050	0.4132	0.4137	0.4145	0.4378	0.4502	0.4539	0.4511	0.4392
Zibo	0.4113	0.4172	0.4309	0.4352	0.4308	0.4357	0.4361	0.4425	0.4372	0.4324
Yinchuan	0.4020	0.4240	0.4508	0.4599	0.4729	0.4809	0.4904	0.4966	0.4891	0.4260
Xining	0.4024	0.3547	0.3620	0.3884	0.4044	0.4081	0.4051	0.4009	0.4025	0.4078
Tongchuan	0.3183	0.3428	0.3330	0.3334	0.3425	0.3465	0.3498	0.3794	0.3704	0.3841
Ordos	0.3748	0.3806	0.3857	0.3939	0.4037	0.3980	0.4223	0.4122	0.4198	0.3729
Yangquan	0.3320	0.3515	0.3725	0.3557	0.3406	0.3766	0.3486	0.3568	0.3592	0.3636
Datong	0.2855	0.3166	0.3388	0.3361	0.3459	0.3468	0.3234	0.3356	0.3405	0.3635
Hebi	0.2853	0.2894	0.2951	0.3040	0.3057	0.3129	0.3106	0.3154	0.3234	0.3395
Jinzhong	0.2397	0.2463	0.2777	0.2835	0.2887	0.2938	0.3024	0.3094	0.3317	0.3383
Luoyang	0.2439	0.2653	0.2769	0.2857	0.2912	0.3001	0.3086	0.3104	0.3266	0.3363
Changzhi	0.2480	0.2624	0.2653	0.2682	0.2714	0.2766	0.2761	0.2905	0.3172	0.3250
Baoji	0.2459	0.2519	0.2457	0.2713	0.2682	0.2857	0.2841	0.2902	0.3033	0.3164
Binzhou	0.2387	0.2519	0.2609	0.2789	0.2889	0.2940	0.3133	0.3132	0.3104	0.3155
Jincheng	0.2398	0.2631	0.2732	0.2762	0.2768	0.2766	0.2856	0.2924	0.3026	0.3116
Shuozhou	0.2516	0.2705	0.2660	0.2779	0.2658	0.2697	0.2747	0.2844	0.2971	0.3093
Weifang	0.2404	0.2481	0.2611	0.2658	0.2638	0.2752	0.2826	0.2895	0.2982	0.3045
Tai'an	0.2453	0.2625	0.2637	0.2834	0.2730	0.2848	0.2923	0.2912	0.3005	0.3045
Jiaozuo	0.2438	0.2519	0.2643	0.2735	0.2748	0.2788	0.2873	0.2948	0.3000	0.3044
Sanmenxia	0.2168	0.2292	0.2358	0.2448	0.2437	0.2716	0.2811	0.2879	0.2941	0.3021
Guyuan	0.2307	0.2128	0.2178	0.2199	0.2305	0.2472	0.2699	0.2800	0.2740	0.3005
Jining	0.2087	0.2217	0.2502	0.2505	0.2577	0.2631	0.2758	0.2800	0.2845	0.2890
Wulanchabu	0.2560	0.2460	0.2515	0.2584	0.2658	0.2861	0.2889	0.2834	0.3262	0.2890
Wuzhong	0.2223	0.2479	0.2549	0.2620	0.2675	0.2718	0.2742	0.2812	0.2858	0.2884
Wuwei	0.1947	0.2056	0.2308	0.2431	0.2544	0.2545	0.2672	0.2450	0.2539	0.2873
Kaifeng	0.2111	0.2145	0.2309	0.2455	0.2735	0.2501	0.2658	0.2702	0.2813	0.2851
Xianyang	0.2320	0.2513	0.2479	0.2510	0.2471	0.2580	0.2674	0.2726	0.2728	0.2811
Zhongwei	0.2048	0.2305	0.2433	0.2469	0.2516	0.2611	0.2776	0.2751	0.2762	0.2770
Xinxiang	0.2300	0.2328	0.2372	0.2426	0.2416	0.2500	0.2587	0.2653	0.2704	0.2723
Baiyin	0.2155	0.2248	0.2308	0.2349	0.2429	0.2472	0.2519	0.2530	0.2540	0.2720
Yulin	0.2140	0.2307	0.2293	0.2722	0.2424	0.2635	0.2570	0.2878	0.2697	0.2686
Liaocheng	0.1940	0.2020	0.2116	0.2307	0.2344	0.2283	0.2339	0.2362	0.2568	0.2663
Deizhou	0.2052	0.2101	0.2205	0.2589	0.2456	0.2458	0.2492	0.2620	0.2608	0.2648
Fuyang	0.2030	0.2086	0.2159	0.2231	0.2267	0.2337	0.2387	0.2415	0.2483	0.2614
Tianshui	0.1906	0.1968	0.2039	0.2099	0.2225	0.2301	0.2314	0.2399	0.2431	0.2613
Anyang	0.2183	0.2206	0.2271	0.2329	0.2365	0.2425	0.2545	0.2583	0.2590	0.2610
Bayannur	0.2068	0.2268	0.2347	0.2444	0.2598	0.2637	0.2626	0.2561	0.2564	0.2483
Linfen	0.1996	0.2172	0.2253	0.2307	0.2371	0.2459	0.2440	0.2494	0.2551	0.2427
Pingliang	0.1783	0.1824	0.1920	0.1988	0.2037	0.2142	0.2223	0.2309	0.2311	0.2424
Shangqiu	0.1775	0.1804	0.1863	0.1963	0.2000	0.2086	0.2152	0.2221	0.2333	0.2408
Yan'an	0.2397	0.2509	0.2567	0.2650	0.2521	0.2630	0.2619	0.2780	0.2691	0.2405
Yuncheng	0.1890	0.1958	0.2090	0.2515	0.2117	0.2164	0.2159	0.2230	0.2298	0.2390
Xinzhou	0.1921	0.2019	0.2105	0.2199	0.2247	0.2230	0.2213	0.2247	0.2342	0.2329
Heze	0.1706	0.1781	0.1847	0.1882	0.1931	0.2099	0.2155	0.2238	0.2263	0.2325
Qingyang	0.1786	0.1923	0.1997	0.2038	0.2104	0.2126	0.2147	0.2236	0.2284	0.2309
Shangluo	0.1937	0.1833	0.2119	0.1935	0.1957	0.1991	0.1970	0.2088	0.2161	0.2259
Weinan	0.1723	0.1781	0.1822	0.1870	0.1928	0.1975	0.2021	0.2072	0.2124	0.2217
Lvliang	0.2149	0.2213	0.1849	0.1908	0.1912	0.1984	0.2005	0.2106	0.2119	0.2164
Dingxi	0.1552	0.1704	0.1664	0.1672	0.1734	0.1757	0.1844	0.1886	0.1963	0.1980
Haidong	0.1734	0.1771	0.1620	0.1721	0.2034	0.2168	0.1973	0.2095	0.2058	0.1959
Longnan	0.1584	0.1713	0.1614	0.1669	0.1712	0.1863	0.1739	0.1765	0.2278	0.1848

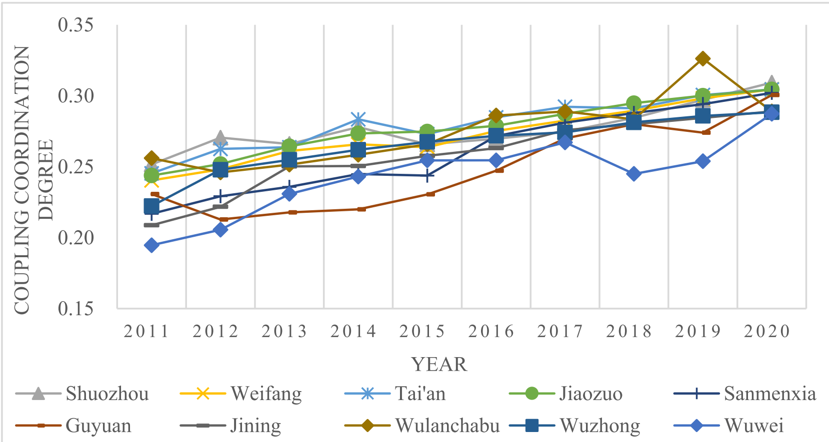
Notes: The order of the cities were ranked according to the Coupling Coordination degree in 2020.

city. Because of the high quality development level of these cities, the overall coupling coordination degree is relatively high.

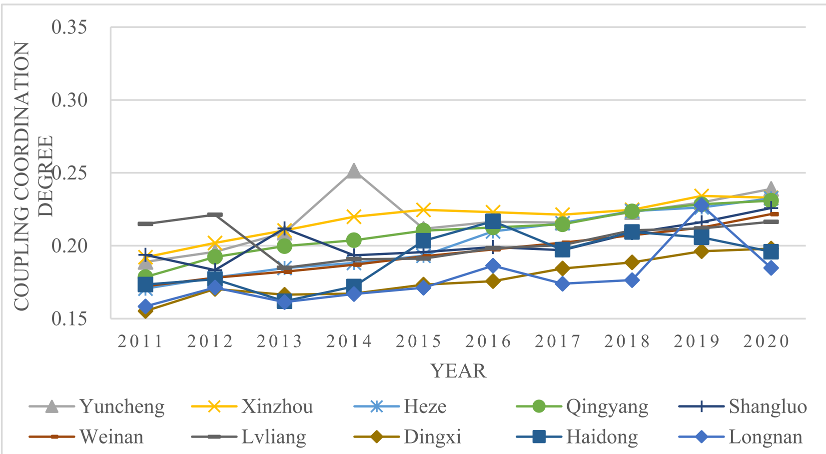
Based on the above analysis, the coupling coordination degree of ecology, production and living systems showed an increasing trend, while the degree is relatively low and there are still obvious deficiencies in the coupling coordinated development in the Yellow River Basin. Part of the reason may be that the COVID-19 [38] at the end of 2019 has curbed the overall development of the Yellow



(a) The changing trend of coupling coordination degree of the top ten cities



(b) The changing trend of coupling coordination degree of the middle ten cities



(c) The changing trend of coupling coordination degree of the bottom ten cities

Fig. 5. The changing trend of coupling coordination degree of the top, middle and bottom ten cities.

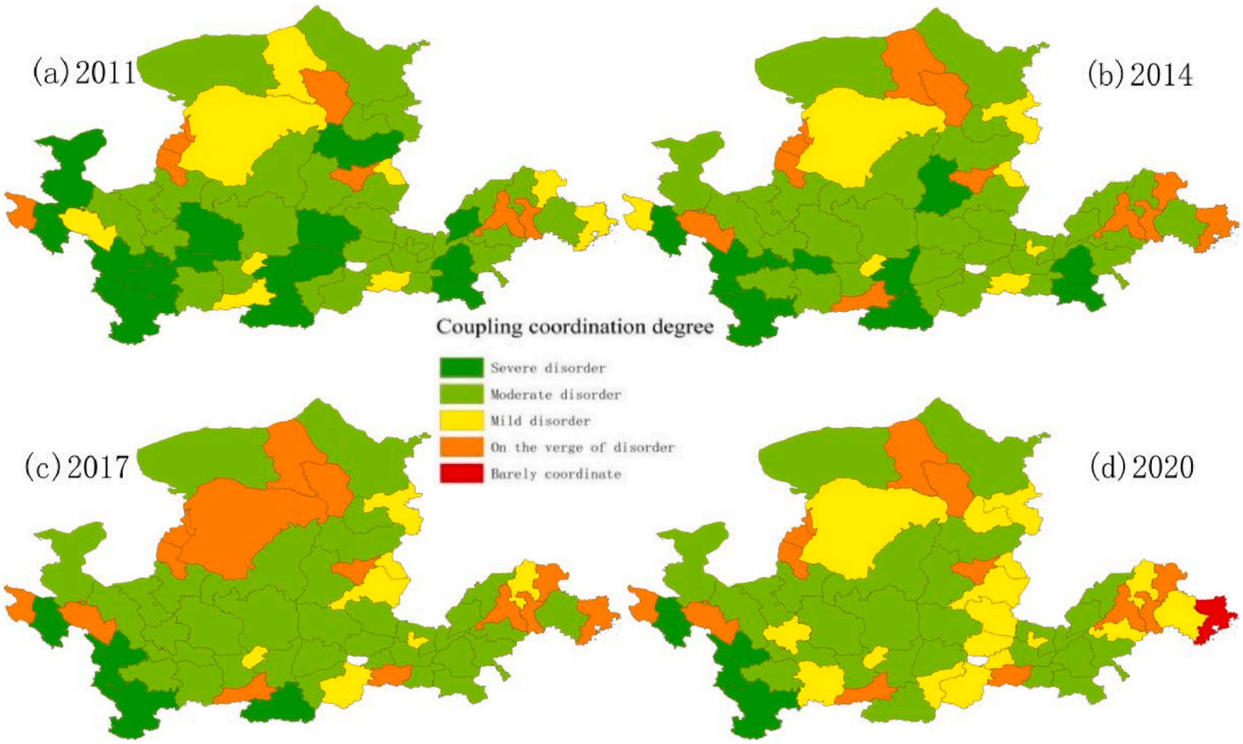


Fig. 6. Spatial variation of coupling coordination degree of cities in the Yellow River Basin.

River Basin, resulting in a great impact on ecology, production and living in most areas of the basin. Another part of the reason may lie in the difference of geographical topography in the upper, middle and lower reaches of the Yellow River Basin, which leads to differences in the coordinated development of ecology, production and living systems in different regions.

4. Conclusion

Based on the high-quality evaluation index system constructed by ecological-production- living system, the high-quality comprehensive development and the coupling coordination degree of the ecology-production-living system of 61 cities along the Yellow River Basin from 2011 to 2020 are respectively measured, and the corresponding visual analysis of the results is carried out, and the following conclusions are obtained:

(1) The high-quality development level of 61 cities in the Yellow River Basin showed an overall upward trend, but the development level was not high. The comprehensive score of the top ten cities in the comprehensive level was above 0.37, but the comprehensive score of most cities was below 0.2; The development level of cities varies greatly, and the comprehensive score of the top cities is much higher than that of the bottom cities.
(2) According to the comprehensive scores of high-quality development of 61 cities in the Yellow River Basin, their development trends can be divided into three categories: 44 cities with sustainable growth, 11 cities with fierce fluctuation and 6 cities with stable development. Sustainable growth cities of 61 cities accounted for 72 %, the absolute growth rate of top cities was more obvious, and the growth rate of high-quality development level of cities with lower development level was higher. However, some cities such as Taiyuan and Xi 'an showed a downward trend in individual years due to the impact of social security or the epidemic.
(3) There is a significant difference of high-quality development space in the upper, middle and lower reaches of the Yellow River Basin, and the upper and lower reaches are higher than the middle reaches. Due to proper ecological protection, the upper reaches showed a higher level of development than the middle and lower reaches before 2016; The level of high-quality development of downstream cities has steadily improved, especially after 2016, the development has reached the highest level of the three; The middle reaches are always at a lower level of development.
(4) The coupling coordination degree of ecological-production- living systems of the major cities in the Yellow River basin is at a low level, and shows an overall upward trend from 2011 to 2020, and the cities with high coupling coordination degree increase more; the cities with higher coupling coordination degree mainly appear in Shandong Peninsula and Inner Mongolia Autonomous region, except some provincial capital cities, the coupling coordination degree of cities in other areas is at a low level.

(5) Compared with the growth rate of the coupling coordination degree of 61 cities from 2011 to 2020, there are 19 cities with year-on-year growth greater than or equal to 30 %, 23 cities with growth between 20 % and 30 %, 11 cities with growth between 10 % and 20 %, and 8 cities with growth below 10 %. It's 61 cities showed an overall upward trend in 10 years, and most of the increase was large.
(6) From the perspective of spatial distribution characteristics, there are significant differences in the level of high-quality development in the Yellow River Basin, while the coupling coordination degree does not change greatly in the spatial layout.

5. Limitation and policy implications

5.1. Limitations of the study

There are still some points that can be improved and supplemented in this paper. First of all, through further analysis and exploration, it is found that the scope of cities in the Yellow River Basin in the study can be further expanded within a reasonable range to increase the channels of data acquisition. Secondly, the scientificity and rationality of variables in the index system can be further verified by robustness test in subsequent studies. Finally, relevant studies on the influence of neighboring cities on the overall development of the Yellow River Basin can be increased to further study the development of the Yellow River Basin from multiple perspectives.

5.2. Policy implications

According to the above conclusions, the overall development level and coupling coordination of cities in the Yellow River Basin are still at a low level. Therefore, the next step should be to formulate relevant measures for different cities, according to local conditions, to achieve the overall high-quality coupled and coordinated development of the Yellow River Basin. Specific suggestions are as follows:

(1) The spatial difference in the level of high-quality development shows that we should carry out differential development combing the regional advantages. The upper reach is rich in ecological resources and high quality of ecological environment, which is suitable to use all kinds of ecological products to create income while maintaining ecological balance and promoting ecological healthy development. Some cities in the middle reaches are rich in energy resources, so it is necessary to make use of their own resources to develop the economy, ensure ecological balance, develop water-saving industries, and effectively solve the problems of soil erosion and domestic water shortage. The distribution of lower reaches is more complex, we need to give full play to their own advantages, and make it clear that they prefer to provide industrial products, agricultural products or tourism services.
(2) Further improve the competitiveness of central urban agglomeration. Some cities along the Yellow River basin, such as Xi'an, Zhengzhou, Jinan, Qingdao and Lanzhou, have a high level of development. We should give full play to the leading role of these cities and vigorously develop urban agglomerations as the center. At present, the existing urban agglomerations in the Yellow River basin include Guanzhong Plain Urban agglomeration, Central Plains Urban agglomeration and Shandong Peninsula Urban agglomeration which are not competitive, so it is necessary to develop around the central cities in the basin, speed up the construction of urban agglomeration, accurately locate the development direction, and strengthen the development. Give full play to the leading role of central cities to the surrounding cities to promote the overall high-quality development of the Yellow River basin as a whole.
(3) Make full use of policy advantages. On the one hand, we should give full play to the advantages brought by the implementation of ecological protection and high-quality development strategy in the Yellow River Basin, vigorously develop modern agriculture. Big data, Internet and other technologies are used to transform traditional planting and animal husbandry to reduce pollution and protect ecology. For the situation of excessive pollution and waste of resources in industrial production, we should speed up technological upgrading and transformation. Improve energy-consuming industries, and put ecological protection in the first place. On the other hand, we should seize the opportunity of the construction of the Silk Road Economic Belt, improve the level of opening to the outside world, strengthen infrastructure construction, make use of all kinds of resources, technology, funds, etc., to build our own development system, optimize the allocation of resources, and seize the opportunity for rapid development.

Data availability statement

Data will be made available on request.

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Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Huili Wang: Data curation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Yujie Xu:** Data curation, Software, Visualization, Writing – original draft. **Chunnan Li:** Data curation, Software, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

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