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Evaluation and obstacle analysis of high-quality development in Yellow River Basin and Yangtze River Economic Belt, China

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Based on China's new development philosophy, and following the idea of "assessing the overall levels firstly, then anchoring the subsystems contributions and finally identifying the obstacle factors", an evaluation system of high-quality development (HQD) levels is constructed from five subsystems of innovative development (ID), coordinated development (CD), green development (GD), open development (OD) and shared development (SD). In this paper, the entropy weight TOPSIS model is used to measure the HQD levels of 19 provincial units located in the Yellow River Basin (YRB) and the Yangtze River Economic Belt (YREB) in 2010–2019, and with the assistance of the Obstacle Degree Model, the obstacle factors affecting the HQD of both are depicted. The results show that: (1) between 2010 and 2019, the HQD indices in YRB and YREB have been on an increasing trend, and the subsystems indices all show a trend of "GD > CD > SD > ID > OD", but the overall levels of HQD in both is not high, and there is still much room for improvement. (2) YREB has a significantly higher HQD level than YRB. From 2010 to 2019, the average values of the HQD indices in YRB and YREB were 0.2886 and 0.4073, respectively, but the index in YRB improves at a faster pace than YREB, and the gap of HQD levels between the two show a trend of continuous reduction towards regional balance and coordination. (3) The analysis of obstacle factors shows that while OD and ID are the main obstacles to HQD in both basins, the impact of both on the resistance to HQD in both basins is on a decreasing trend. GD is another bottleneck for the HQD of YRB, and the pressure on GD in the middle and upper reaches of the provincial units in the basin is increasing, and the obstacles are on a rising trend.

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Introduction

Since the Second Industrial Revolution, human civilization has experienced profound advancements, predominantly evident within the realms of social and economic spheres, such as remarkable economic expansion, rapid increase in urbanization rate, and technological progress. Concurrently, parallel to these advancements, issues of substantial resource consumption and escalating environmental degradation have garnered escalating public scrutiny (Wan et al., 2023). How to achieve sustainable development has become a common concern for all countries in the world.

In 2015, the United Nations introduced the 2030 Agenda, wherein the 17 Sustainable Development Goals (SDGs) were presented as a framework including economy, society, environment, and ecology for global pursuits towards sustainable development. This necessitates a comprehensive examination of economic advancement, environmental preservation, and societal welfare, thus reflecting the overarching trajectory of contemporary global sustainable development endeavors (Kroll et al., 2019; Pan et al., 2021a). However, since the framework mainly focuses on the worldwide issues, it is difficult to conduct a targeted analysis of different countries. Hence, constructing a development framework that aligns with the unique developmental attributes of a given region, in accordance with its specific circumstances, emerges as an exceedingly crucial undertaking for the prospective trajectory of regional development (Jiang et al., 2021a). To make the global goals and targets relevant at the local level, a process of SDG 'localization' has emerged, acknowledging that 'local-level indicators must be included in any future development framework (Garima and Jessica, 2022). Accordingly, several nations and regions have proffered distinctive sustainable development objectives and pragmatic trajectories, rooted in their individual contextual realities. Illustratively, the United States formulated The America 2050 Strategy in 2006, furnishing a directive framework aimed at fostering comprehensive investments in the domains of mobility, environment, and economic progress (Georgeson and Maslin, 2019). At the end of 2019, the European Union unveiled the European Green Deal, a pivotal initiative centered on attaining carbon neutrality by 2050, signifying the cornerstone strategic objective geared towards advancing sustainable development (Sany´e-Mengual et al., 2019).

In October 2017, China made an ambitious statement of high-quality development (HQD) in the report of China's 19th National Congress, marking a new era for China's economy (Pan et al., 2021a). In stark contrast to China's preceding high-speed economic growth paradigm, HQD aligns harmoniously with the principles underpinning sustainable development. Under the framework of China's new development philosophy, HQD includes innovative, coordinated, green, open, and shared development, which aspires to foster heightened sustainability in economic progress, cultivate a more ecologically conscious environment, and engender a more equitable social distribution. In essence, HQD serves as a "localized" framework that can better reflect the development situation of China. In 2022, the 20th report reiterated the imperative of diligently, accurately, and comprehensively enacting the new development philosophy. This approach prioritizes the pursuit of HQD and the resolution of challenges such as the deficiency in scientific and technological innovation capability, substantial disparities in regional urban-rural development, substantial demands in ecological and environmental safeguarding, and the pressing necessity to enhance the well-being of the populace. Meanwhile, against the backdrop of a sluggish global economic recovery and widespread inflation, as the world's second-largest economy, China steadfastly pursues an HQD path. This commitment not only exerts a positive impact on China's economic and social progress but also injects fresh impetus into safeguarding the stability of global industrial and supply chains, promoting global trade expansion, and propelling worldwide economic growth. Furthermore, China adheres to the principles of innovation, coordination, openness, green development, and shared prosperity, embodying a novel development ideology. This approach constructs an HQD model characterized by "greater sustainability in economic growth, greener ecological environment, and fairer social distribution," thereby offering novel development insights and a 'Chinese program' for the sustainable progress of the global economy and society.

The Yangtze River Economic Belt (YREB) and the Yellow River Basin (YRB) are important economic regions and ecological barriers in China, as well as important carriers of China's future high-quality development (Liu et al., 2023a). Spanning across 19 provincial units within the Eastern, Western, and Central regions of China, YRB and YREB collectively encompass approximately 53.33% of the nation's total land area, are home to 66.84% of its populace, and contribute to 66.62% of the country's regional GDP as of the year 2020 (Zhao and Fan, 2022). However, at present, both regions still have many problems such as large pollution emissions, a fragile ecological environment, and severe environmental risks (Feng and Guo, 2022; Liu et al., 2023a).

Commencing the 18th National Congress of the Communist Party of China, the two national strategies of "Development of the Yangtze River Economic Belt" and "Ecological Protection and High-quality Development of the Yellow River Basin" (collectively referred to as the "River Strategy") have inaugurated a new trajectory for the pursuit of HQD within YRB and YREB. As the most influential inland economic belt and ecological demonstration belt in China, YRB and YREB have systematic consistency and paths to learn from in terms of economic development, scientific and technological innovation, ecological governance and open development (Feng and Guo, 2022), while the two have different resource endowments, industrial conditions, driving forces for development and ecological environments, and their functional positioning, directions, paths, advantages and bottlenecks in the process of promoting HQD may also differ. Consequently, conducting rigorous scientific assessments and comprehensive comparative analyses of the levels of HQD within the two basins, alongside their influencing determinants, stands as a fundamental imperative. This endeavor not only serves as an intrinsic necessity to adjust the developmental trajectories of the two regions, but also an urgent need to promote the north-south linkage of the "River Strategy", narrow the gap between the north and the south, and foster the formation of a new pattern of regional coordinated development in China's New Era.

Literature review

The goal of HQD is to improve the quality and efficiency of development and to build a modern economic system. In addition, implementing HQD means changing economic development from quantity and scale to quality and efficiency, achieving more sustainable economic development, a greener ecological environment, and more equitable social distribution. In the past, scholars have mostly studied the issues of development quality in terms of the speed, efficiency, and balance of economic development (Mlachila et al., 2017; Woersching et al., 2016). For example, Wang (2017) studied the influence of factors such as technological progress, industrial structure, and population structure on the speed of regional economic development; Han et al. (2021) used kernel density function estimation and factor decomposition to analyze the spatial variation status and spatio-

temporal evolution characteristics of China's economic development. The report of the 19th National Congress made the important assertion that China's economy is transforming from high-speed growth to high-quality development, giving HQD a more contemporary connotation in terms of precise poverty alleviation, common prosperity, urban- rural coordinatd development, and ecological civilization, which goes beyond the traditional understanding of the economic development quality in the field of economics. In recent years, research on the quality of development has gradually expanded from an economic perspective to a social dimension. Currently, the studies on HQD have continued to evolve and can be roughly divided into the following three aspects: the study of the scientific connotation of HQD, the construction of HQD evaluation index systems, and the influencing factors of HQD.

The connotation of HQD. Theoretically, HQD constitutes an expansion and extension of the concept of sustainable development, based on the specific developmental context of China (Wan et al., 2023). Essentially, HQD epitomizes a novel developmental paradigm predicated upon values of quality and efficiency, seamlessly intertwined with the five-fold new development philosophy encompassing "innovation, coordination, greenness, openness and sharing", centrally oriented towards rectifying persistent issues of developmental imbalances and insufficiencies within the economic and social milieu and realizing the shift of the economic and social development mode. This shift entails a progression from an emphasis on quantity to a focus on enhancing efficiency, from scale expansion to structure optimization, from input & investment-driven to innovation-driven (Mohanty et al., 2018; Bain et al., 2019), and from treatment after pollution to green development (Geng et al., 2013; Schiller et al., 2018). The study of the connotation of HQD mainly centers around the principal contradiction of Chinese society, the new vision for development, the modernized economy, supply-side structural reform, and better quality, higher efficiency, and more robust drivers of economic growth through reform (Geng et al., 2013; Zhang et al., 2018). Thus, the rich connotation of HQD suggests the multidimensionality and complexity of its evaluation index systems.

The construction of HQD evaluation index systems. To date, there has been no unified indicator system yet. Based on the understanding of the connotation of HQD, scholars have constructed various evaluation systems along with standards and indicators according to their purposes and regions. Given the high operability of the establishment of an evaluation system and the availability of data, single-dimensional indicators are often used to measure the level of HQD, such as Total Factor Productivity (TFP) (Jahanger, 2021). However, due to the rich connotation of HQD, single-dimensional indicators may produce biased conclusions when used to reflect the actual circumstances of the multi-dimensional system (Wan et al., 2023). Therefore, scholars have also attempted to use multi-dimensional indicators to evaluate HQD. For example, Shi and Ren (2018) constructed an HQD evaluation index system from three aspects: the fundamentals of development, the social outcomes, and the ecological outcomes; Chen et al. (2022) constructed an HQD evaluation index system from three dimensions of environment, society, and economy. Although these indicators can effectively optimize the bias arising from evaluating the level of HQD based on single indicators, its indicators lack the representation of innovation, coordination, greenness, openness, and sharing, and it is insufficient to reflect the multi-dimensional connotation of HQD.

Therefore, a more complete evaluation system that can adequately reflect the five cores of HQD is necessary.

The influencing factors of HQD. The key to achieving HQD is to identify pivotal driving factors, and the optimization of influencing factors can potently improve the level of HQD. On the basis of constructing the HQD evaluation systems, scholars have done some research on the influencing factors of HQD. For example, Xu et al. (2020) conducted a study on the influencing factors of HQD in 30 provinces in China using spatial econometric models and concluded that expanding opening up to the outside world and improving TFP have obvious positive effects on China's HQD. In addition, scholars have also studied the influencing factors such as environmental regulation (Liu et al., 2021), technological innovation (Zhong et al., 2023), industrial upgrading (Li and Li, 2021), and educational development (Sang and Li, 2021) on HQD, and these studies have laid a certain foundation for exploring the influencing factors on HQD. Nevertheless, a majority of these investigations have predominantly encompassed qualitative methodologies and have been confined to a singular dimension, thus exhibiting limitations in terms of their lack of systematization and comprehensiveness. Furthermore, these studies slightly fall short in the exploration of the influencing factors of the entire HQD framework.

The Yangtze River and Yellow River hold profound significance as the nurturing lifelines of the Chinese nation. The development of YRB and YREB has garnered considerable scholarly attention, and a series of studies have been conducted on water-soil disasters and governance (Jiang et al., 2021b; Hu et al., 2022; Liu et al., 2023b), the impacts of climate change (Yang et al., 2023b; Zhang et al., 2023), the functions of ecological service (Pan et al., 2021b; Fang et al., 2021), education, healthcare and poverty alleviation and other livelihood issues (Zhou et al., 2022; Ren et al., 2023), etc. In recent years, the issue of HQD in both basins has progressively become a key focus of scholars, who have concentrated their efforts on formulating policies and delineating developmental trajectories aligned with the principles of HQD within the geographical regions (Chen et al., 2022), HQD of the economy and industries (Geng and Wang, 2023), HQD of construction, water conservancy, agriculture, transportation and other industries (Chen et al., 2023; Wang, 2022).

A review of previous studies reveals that the existing relevant results have enriched and improved the connotation of HQD and its research methods. This trend has been particularly pronounced since the formal establishment of the "River Strategy," which has thrust the matter of HQD within YRB and YREB into the forefront of scholarly interest. Nonetheless, it is noteworthy that certain limitations persist within the scope of relevant studies: (1) at present, the scholars' focus on the theory of "River Strategy" is somewhat insular. A majority of existing studies tend to examine the development of either YRB or YREB in isolation, thus neglecting the incorporation of both basins within a coherent analytical framework for comparative analysis. This deficiency hampers the assessment of the two regions' positions in the broader context of China's overarching comprehensive and regionally coordinated developmental paradigm. (2) Within the scope of assessing HQD level, the practice of undertaking quantitative diagnostic and comparative analyses of the obstacle factors to HQD within the basins remains relatively uncommon. Moreover, the principal strengths and constraints encountered by the two basins during the HQD journey have not been exhaustively elucidated from this perspective. This gap renders the endeavor of offering a theoretical underpinning for the coherent rationale and harmonized approaches to the simultaneous advancement of the "River Strategy" in the northern and

Fig. 1 Map of study area.

southern regions of China quite intricate. Therefore, in the linked perspective and following the research idea of "assessing the overall levels firstly, then anchoring the subsystems contributions and finally identifying the obstacle factors", this study will center on "the differences of the HQD levels between YRB and YREB". Through an exploration of the spatial and temporal heterogeneity in HQD levels within YRB and YREB between 2010 and 2019, the analysis will pinpoint key catalysts and challenges shaping HQD within the two regions. The objective is to establish a conceptual framework for delving into the comparative strengths and distinctive trajectories of HQD for the two basins.

Study area and data
Study area. This study takes YRB and YREB as the research targets and takes provinces (autonomous regions and municipalities directly under the Central Government) as the research units, among which for YREB, 11 provincial units, including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan and Guizhou, are identified as samples for YREB with reference to the Guidance Opinions of the State Council on Promoting the Development of the Yangtze River Economic Belt by Relying on the Golden Waterway; eight provincial units, including Qinghai, Ningxia, Gansu, Inner Mongolia, Shanxi, Shaanxi, Henan and Shandong, are identified as samples for YRB (Fig. 1).

Data sources and processing. In the year 2020, the global outbreak of the COVID-19 pandemic led to an economic standstill in numerous countries, including China. This phenomenon gave rise to substantial deviations between various categories of statistical data and initial projected targets. Consequently, taking into consideration both the trajectory of economic development and the accessibility of data, this research endeavor has chosen to utilize publicly available statistical data from the Chinese government prior to the onset of the pandemic. Simultaneously, owing to the Chinese government's practice of formulating developmental policies within coherent cycles of five years, we have elected to investigate two contiguous policy cycles for the purposes of this study. Hence, the time range of this study is from

2010 to 2019. The data were mainly obtained from the 2011–2020 China Statistical Yearbook, China Science and Technology Statistical Yearbook, China Energy Statistical Yearbook, and the statistical yearbooks of the provincial units in the basins. The data were processed and analyzed using Microsoft Excel 2018. The map was generated using ArcGIS 10.8 and Origin Pro 2022.

Methodology
Research framework. To compare the HQD levels of the 19 provincial units located in YRB and YREB in 2010–2019 and to explore the obstacles hindering the HQD of the two, this study is carried out in four steps. Firstly, based on China's new development philosophy and the "River Strategy", we begin with the analysis of the connotation of HQD from a multi-dimensional perspective of innovative development (ID), coordinated development (CD), green development (GD), open development (OD) and shared development (SD). Secondly, on the basis of the first step, we construct an evaluation index system of HQD and an HQD evaluation model with the assistance of the entropy weight TOPSIS model. Thirdly, we measure the HQD levels of the 19 provincial units in YRB and YREB in 2010–2019, both spatially and temporally. Fourthly, with the help of the Obstacle Degree Model, the obstacles hindering the HQD of the two regions are depicted. Finally, combined with the third and fourth findings of the above, the conclusions are made and the optimization strategies for the improvement of HQD in YRB and YREB are proposed. The overall research framework is shown in Fig. 2.

Evaluation index system and method for measuring HQD
Construction of evaluation index system. Based on the connotation of HQD and the new development philosophy, this paper constructs an HQD evaluation index system for YRB and YREB, including five subsystem layers, 11 element layers, and 21 indicator layers (Table 1), and carries out a comparative analysis of the HQD status of YRB and YREB and their respective internal provincial units based on the time-series panel data of the eight provincial units in YRB and 11 provincial units in YREB from 2010 to 2019. The specific indicators are as follows:
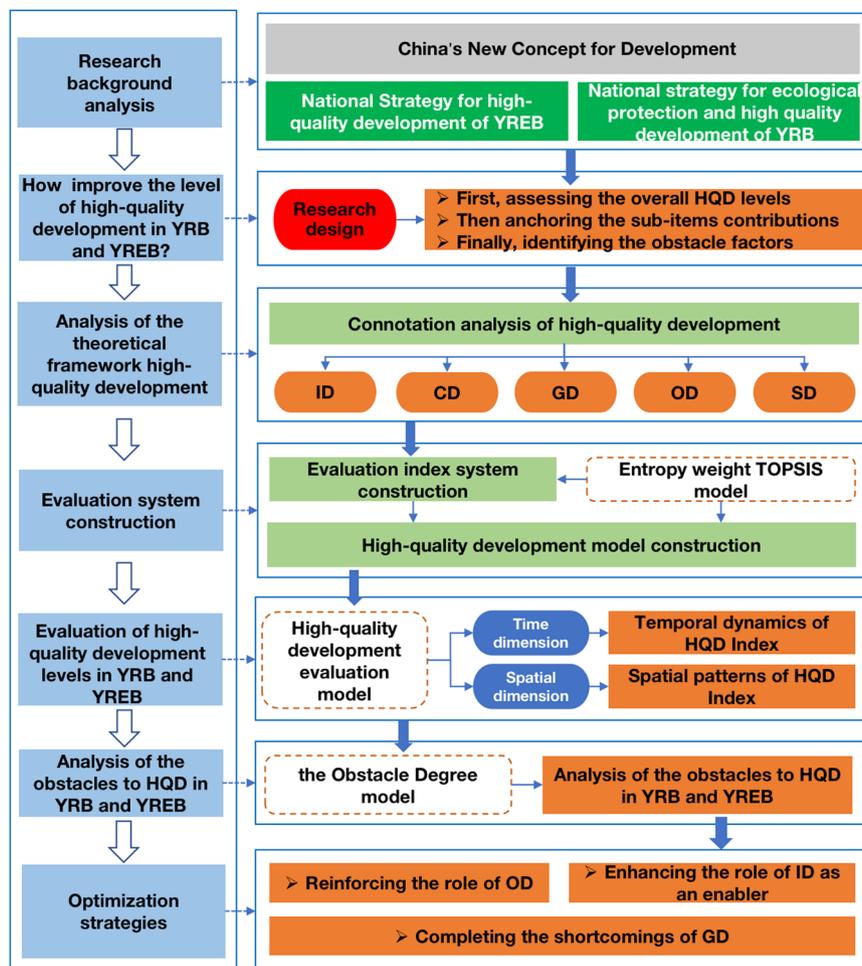
Fig. 2 Research framework.

Table 1 HQD evaluation index system.

Target layer	Subsystem layer	Element layer	Indicator layer	Effect
HQD level	ID	Innovation input	R&D expenditure as a share of GDP (C_1, %)	Positive
			Full-time equivalent of R&D personnel per 10,000 people (C_2, 10,000 man-year)	Positive
		Innovation output	Annual number of patents granted per 10,000 people (C_3, pieces/10,000 people)	Positive
			Technology market turnover as a share of GDP (C_4, %)	Positive
	CD	Urban-rural coordination	Ratio of urban to rural income (C_5, %)	Negative
		Regional coordination	Coefficient of variation of GDP per capita (C_6)	Negative
			Urbanization Rate (C_7, %)	Positive
	GD	Resource consumption	Energy consumption per 10,000 yuan GDP (C_8, t standard coal/ ¥10,000)	Negative
			Water consumption per 10,000 yuan GDP (C_9, m3 / ¥10,000)	Negative
		Environmental pollution	Wastewater emissions per 10,000 yuan GDP (C_{10}, t/¥10,000)	Negative
			Industrial SO_2 emissions per 10,000 yuan GDP (C_{11}, t/¥10,000)	Negative
			Solid waste generation per 10,000 yuan GDP (C_{12}, t/¥10,000)	Negative
	OD	Environmental Governance	Investment intensity in industrial pollution control (C_{13}, ¥10,000 /km^2)	Positive
			people employed in the aviation industry per 10,000 people (C_{14}, people/ 10,000 people)	Positive
			people employed in the rail industry per 10,000 people (C_{15}, people/ 10,000 people)	Positive
		Openness degree	Total foreign investment as a share of GDP (C_{16}, %)	Positive
			Total imports and exports as a share of GDP (C_{17}, %)	Positive
	SD	Social resource	Number of beds in health facilities per 10,000 people (C_{18}, beds/10,000 people)	Positive
			Investment in education as a share of GDP (C_{19}, %)	Positive
		Natural resource	PM2.5 concentration (C_{20}, μg/m^3)	Negative
			Water resources per capita (C_{21}, m^3/people)	Positive

(1) Innovative development (ID). ID is the "new engine" to promote HQD in YRB and YREB, which requires increasing investment in innovation such as human resources and research and development (R&D) funds to enhance the level of innovation output and cultivate and strengthen the new momentum of regional economic development. Therefore, the innovative development of YRB and YREB needs to continuously increase innovation investment such as human and financial resources to obtain more innovation output, achieve the replacement of old growth drivers with new ones, promote the quality and efficiency of traditional industries, cultivate emerging sectors of strategic importance actively, and build a modern industrial system that supports HQD. We selected R&D expenditure as a share of GDP and the Full-time equivalent of R&D personnel per 10,000 people to measure the innovation input of both regions. In addition, the annual number of patents granted per 10,000 people and technology market turnover as a share of GDP were used to evaluate the innovation output.

(2) Coordinated development (CD). The CD is an inherent requirement for promoting HQD in YRB and YREB, and the core meaning is to comprehensively coordinate urban and rural development and regional coordinated development. On the one hand, we should pay more attention to the development of the countryside, achieve comprehensive and integrated urban and rural development, and gradually narrow the development gap between urban and rural areas. On the other hand, comparative advantages of different regions in the basins should be given full play, in addition, to promoting integrated development patterns of upper, middle, and lower reaches and gradually reversing the trend of widening the development gap between different provincial units. Therefore, we measured urban-rural coordination with a ratio of urban to rural income and evaluated regional coordination with a coefficient of variation of GDP per capita and urbanization rate.

(3) Green development (GD). GD is the universal form of promoting HQD in YRB and YREB, the core meaning of which requires that based on ecological protection, the traditional rough and loose development mode should be changed, with green, low-carbon, and recycling as the core objectives, the industrial structure should be adjusted, the development mode should be changed, the consumption of resources and energy should be reduced, the emission of pollutants such as waste gas, sewage and solid wastes should be reduced, and the construction of ecological civilization should be taken as the grasp to increase the investment in environmental governance. In addition, we will take the construction of ecological civilization as a starting point, increase investment in environmental governance, and win the battle for "our skies blue, our waters clear, and our land pollution-free". The energy consumption per 10,000 yuan GDP and water consumption per 10,000 yuan GDP were used to reflect the resource consumption; the wastewater emissions per 10,000 yuan GDP, the industrial SO_2 emissions per 10,000 yuan GDP, and solid waste generation per 10,000 yuan GDP were used to reflect environmental pollution; while investment intensity in industrial pollution control was used to reflect environmental governance.

(4) Open development (OD). OD is the only way to promote HQD of YRB and YREB. The OD of YRB requires giving full play to their respective advantages of connecting roads to the sea, taking the main transport routes as the backbone, improving the open channels, expanding the open platform, and cultivating both inside and outside to build a new pattern of comprehensive opening to the outside world, and expanding and upgrading the level of opening to the outside world. We measured location advantage with people employed in the aviation industry per 10,000 people and people employed in the rail industry per 10,000 people. In addition, total foreign investment as a share of GDP and total imports and exports as a share of GDP were used to reflect the openness degree of both basins.

(5) Shared development (SD). SD is the fundamental purpose of HQD in YRB and YREB, the core of which is to better benefit the people's well-being by improving the quality and equalization of basic public services such as education, healthcare, employment and social security, while also allowing all people to share the green ecological well-being of blue sky and clear water. We used the indicators of social resources and natural resources to reflect the extent of SD, including the number of beds in health facilities per 10,000 people, investment in education as a share of GDP, PM2.5 concentration, and water resources per capita.

Measuring the HQD levels: the entropy weight TOPSIS model. Currently, the common methods used for the integrated multi-indicator assessment can be divided into two categories: subjective evaluation method and objective evaluation method. In order to reduce the influence of human subjective factors on the evaluation results, this paper adopts the objective evaluation method (entropy weight TOPSIS model) to measure the HQD levels of the 19 provincial units in YRB and YREB, which uses the method to determine the weights of different indicators first, and then the TOPSIS model to rank the objects (Wu and Zhu, 2015). The specific calculation process is as follows.

Construct the original matrix. Assuming that there are n measurement units and m measurement indicators, and x_{ij} represents the data value of the i-th indicator of the j-th measurement unit, among which, $i \in [1, m]$, $j \in [1, n]$, the evaluation raw data matrix can be constructed (Eq. (1)).

$$A = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \dots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \quad (1)$$

Determine the indicator weight. Step 1. Determine the ratio r_{ij} of the i-th indicator in the j-th cell.

$$r_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}} \quad (2)$$

Step 2. Calculate of entropy value for each indicator.

$$e_i = -\frac{\sum_{j=1}^{n} r_{ij} \times \ln r_{ij}}{\ln n} \quad (3)$$

where e_i is the entropy value of the i-th indicator.
Step 3. Calculate of weight for each indicator.

$$w_i = \frac{1 - e_i}{\sum_{i=1}^{m} (1 - e_i)} \quad (4)$$

where w_i is the weight of the i-th indicator.

Data standardization. As there are positive and negative indicators in the evaluation index system, this paper adopts the extreme value method, i.e., Eqs. (5) and (6) to standardize original data so

Provincial unit	2010	2015	2019	2010–2019	General trend	Ranking (2010/2015/2019)
Henan	0.1755	0.3484	0.4324	0.3132	↑	15/14/13
Shandong	0.2564	0.3817	0.4526	0.3531	↑	7/8/10
Shanxi	0.1526	0.2602	0.2973	0.2286	↑	18/18/18
Inner Mongolia	0.1673	0.3171	0.3174	0.2813	↑	17/16/16
Shaanxi	0.2152	0.4299	0.4716	0.3684	↑	11/4/5
Gansu	0.1686	0.3344	0.3932	0.2911	↑	16/15/15
Ningxia	0.1071	0.3042	0.3023	0.2611	↑	19/17/17
Qinghai	0.1991	0.2186	0.2253	0.2116	↑	13/19/19
Yunnan	0.2579	0.3779	0.4305	0.3406	↑	6/11/14
Guizhou	0.2077	0.3583	0.4342	0.3244	↑	12/13/12
Sichuan	0.2295	0.3867	0.4748	0.3420	↑	9/7/4
Chongqing	0.2663	0.3934	0.4672	0.3639	↑	5/6/7
Hubei	0.2816	0.4090	0.4582	0.3596	↑	4/5/8
Hunan	0.2251	0.3783	0.4545	0.3401	↑	10/10/9
Jiangxi	0.2451	0.3805	0.4707	0.3445	↑	8/9/6
Anhui	0.1875	0.3720	0.4478	0.3342	↑	14/12/11
Zhejiang	0.4815	0.5117	0.5564	0.4903	↑	2/2/2
Jiangsu	0.4776	0.4903	0.5311	0.4749	↑	3/3/3
Shanghai	0.7709	0.7382	0.7354	0.7654	↓	1/1/1
YRB	0.1802	0.3243	0.3615	0.2886	↑	-
YREB	0.3301	0.4360	0.4964	0.4073	↑	-

Table 2 Dynamics of the HQD indices of provincial units in YRB and YREB.

as to obtain the standardized data matrix $B = (x'_{ij})_{m \times n}$.

$$x'_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \qquad (5)$$

$$x'_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \qquad (6)$$

Establish a weighted decision matrix (WDM). Construct a weight vector matrix W using the weights of each indicator w_i and build a weighted decision matrix V by using Eq. (7).

$$V = B \times W = [v_{ij}]_{m \times n} \qquad (7)$$

Determine the ideal solutions. Determine the positive ideal solution V^+ and the negative ideal solution V^- for each indicator (Eqs. (8) and (9)).

$$V^+ = \left\{ \max v_{ij} \middle| i = 1, 2, \ldots, n \right\} = \left\{ V_1^+, V_2^+, \ldots, V_n^+ \right\} \qquad (8)$$

$$V^- = \left\{ \min v_{ij} \middle| i = 1, 2, \ldots, n \right\} = \left\{ V_1^-; V_2^-, \ldots, V_n^- \right\} \qquad (9)$$

Calculate the distances. Calculate the distances D_j^+ and D_j^- for each evaluation vector to V^+ and V^-, respectively (Eqs. (10) and (11)).

$$D_j^+ = \sqrt{\sum_{i=1}^{n} \left(V_i^+ - V_{ij} \right)^2} \qquad (10)$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} \left(V_i^- - V_{ij} \right)^2} \qquad (11)$$

Calculate the nearness degree. Calculate the HQD indices for different provincial units and their subsystems development indices (Eq. (12)).

$$T_j = \frac{D_j^-}{D_j^+ + D_j^-} \qquad (12)$$

where the value of T_j is in the range [0,1], and the higher the value, the higher the HQD level, and vice versa, the lower the level. This paper uses the "equally dividing method" to classify the HQD levels into five levels: low (0.00–0.20), relatively low

(0.20–0.40), medium (0.40–0.60), relatively high (0.60–0.80), and high (0.80–1.00).

Analysis of the obstacle factors impeding HQD: the Obstacle Degree Model. The evaluation of HQD focuses not only on judging the quality of development, but also, and more importantly, on identifying the most significant obstacles that limit the improvement of HQD, so that development strategies and measures can be tailored and adjusted. This paper introduces the Obstacle Degree Model (Lei et al., 2016) (Eq. (13)) to provide an in-depth analysis of the obstacle factors affecting the HQD of the two basins and different provincial units in two dimensions: the subsystems layers and the indicator layers.

$$O_i = I_i \times F_i / \left(\sum_{i=1}^{m} I_i \times F_i \right) \qquad (13)$$

where O_i denotes the obstacle degree for indicator i; I_i indicates the difference between the actual value and the optimal value, generally calculated as $I_i = 1 - x'_{ij}$; F_i denotes the contribution of indicator i to the target layer, i.e., the weight w_i of indicator i.

Results
Total HQD level
Temporal evolutionary characteristics of total HQD level. Table 2 shows the measured results of the HQD indices for each provincial unit in YRB and YREB in 2010, 2015, and 2019. In terms of the HQD indices, YRB and YREB had HQD indices of 0.1802, 0.3243, 0.3615, and 0.3301, 0.4360, 0.4964 in 2010, 2015, and 2019, respectively, and the average annual variation rate from 2010 to 2019 is 10.06 and 5.04%, respectively.

Further analysis shows that Shanghai consistently ranks first in the two basins in terms of HQD level, and its HQD index is much higher than that of other provincial units, while Zhejiang and Jiangsu rank more consistently, ranking second and third in the two basins, respectively. Henan, Shanxi, Inner Mongolia, Gansu, Ningxia, Qinghai, and some other provincial units have lower HQD levels and are ranked more backward. Temporal changes show that the ranking of Yunnan, Qinghai, Shaanxi, Shandong, Sichuan, Anhui, and Hubei in terms of HQD levels fluctuate more obviously, all of them are above three places, among them, Shaanxi, Sichuan, and Anhui have risen obviously in ranking,
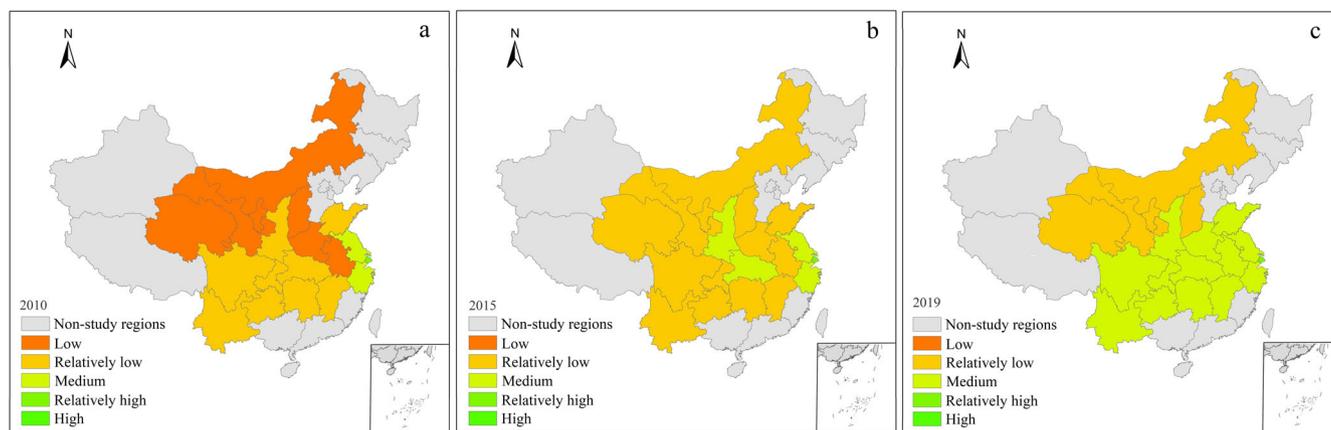
Fig. 3 Spatial heterogeneity of HQD level. a–c Represent the spatial heterogeneity of HQD level in 2010, 2015 and 2019 in YRB and YREB.

from 2010 to 2019, the ranking of HQD levels has improved by six, five and three places, respectively. The ranking of Shandong, Hubei, Qinghai, and Yunnan in terms of HQD levels are on a downward trend, dropping three, four, seven, and eight places, respectively, during the period 2010–2019. Other provincial units are relatively stable in the rankings, with little upward or downward fluctuation.

Spatial patterns of total HQD level. Based on the results of HQD indices of YRB and YREB, the HQD levels of each provincial unit were divided into five categories by using the "equally dividing method", and the spatial variation characteristics of the HQD levels of each provincial unit in 2010, 2015 and 2019 were visualized with the help of ArcGIS 10.8 (Fig. 3). In terms of spatial distributions, in 2010, YRB was at a low level, except for Shandong and Shaanxi, while YREB was at a low level, except for Shanghai, which was at a relatively high level, and Jiangsu and Zhejiang, which were at a medium level (Fig. 3a); In 2015, YRB was at a relatively low level except for Shaanxi, which was at a medium level, while YREB was at a relatively low level except for Shanghai, which was at a relatively high level, and Zhejiang, Jiangsu and Hubei, which were at a medium level (Fig. 3b); In 2019, Shandong, Henan and Shaanxi in YRB were at a medium level, while the remaining five provincial units were at a relatively low level, and Shanghai in YREB was at a relatively high level and the other 10 provincial units were at a medium level (Fig. 3c). Further analysis reveals that the only provincial unit with a relatively high HQD level in both basins is Shanghai, but the number of provincial units with a medium level increased from two in 2010 to four in 2015 and then to 13 in 2019, while the number of provincial units with low and relatively low levels decreased from 16 in 2010 to 14 in 2015 and then to five in 2019, indicating that under the leadership of the new development philosophy, the HQD levels of the two basins has continued to improve.

In addition, this paper adopts the coefficient of variation method to measure and analyze the evolutionary characteristics of regional differences of the HQD levels in the two basins, and characterizes the differences of HQD levels in the provincial units within the two basins by calculating the standard deviation rate of the HQD indices for each provincial unit in YRB and YREB (Fig. 4). The results show that: (1) the coefficient of variation of the HQD indices in YRB shows a fluctuating trend, indicating that the spatial variation of the HQD levels among provincial units within the basin has not varied much during the study period; (2) The coefficient of variation of the HQD indices in YREB is decreasing from 0.5371 in 2010 to 0.1775 in 2019,
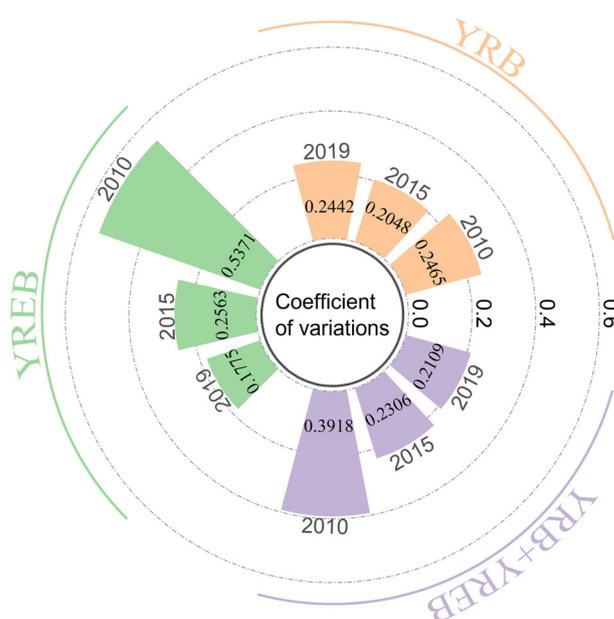

Fig. 4 Coefficient of variations of the HQD levels in YRB and YREB.

indicating that the spatial "polarization" of the HQD indices of each provincial unit within the basin is decreasing, i.e., the gap in the HQD levels of each provincial unit within the basin is decreasing; (3) The mean values of the coefficients of variation of the two basins' HQD indices in 2010, 2015 and 2019 were 0.3918, 0.2306 and 0.2109, respectively, also indicating that the overall differences in the HQD levels among provincial units within the two basins have been narrowing and improving in the direction of spatial balance.

Development level of the subsystems

Temporal dynamics of the subsystems. As can be seen from Fig. 5, the mean values of the indices of ID, CD, GD, OD, and SD in YRB and YREB from 2010 to 2019 were 0.1637, 0.4357, 0.5684, 0.1470, 0.2480, and 0.2692, 0.6176, 0.8015, 0.1911, 0.5457, respectively, and the HQD subsystems indices all show a decreasing pattern of "GD > CD > SD > ID > OD", indicating that the dynamic contribution of each subsystem to HQD of the basin varies significantly. Among them, the level of GD and OD in YRB increased faster from 2010 to 2019, with the average annual rate of change of the GD index and OD index being 6.14 and 5.19%, respectively, while YREB had a higher average annual growth rate
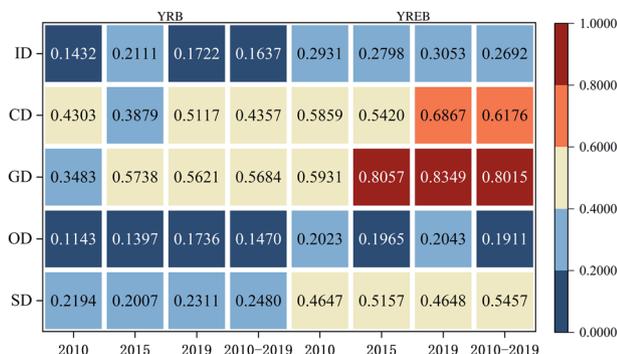
Fig. 5 The HQD subsystems indices in YRB and YREB, 2010–2019.

Fig. 6 Changes in HQD subsystems indices for provincial units in YRB and YREB.

of 4.08% in the GD index from 2010 to 2019, with smaller changes in the other subsystems indices. The results show that the contribution of GD in both basins has increased significantly under the development concept of " to step up conservation of the Yangtze River and the Yellow River", but the growth rate of the OD index in YREB is much lower than that of YRB, which also indicates that although the overall OD level of YREB is higher than that of YRB, the pace of OD in YRB has been greater in recent years, and YREB needs to further take advantage of the "Belt and Road" strategy to improve the level and quality of its OD.

Spatial patterns of the subsystems. The study shows that the spatial patterns of the five subsystems are as follows:

(1) The overall level of ID is not high in both basins, and there is a polarization pattern. As shown in Fig. 5, the ID indices of YRB and YREB from 2010 to 2019 were 0.1637 and 0.2692, respectively. In terms of spatial differences, from 2010 to 2019, Shaanxi and Shandong ranked among the top two provinces in YRB in terms of ID, with the mean values of the ID indices of 0.3845 and 0.2461, respectively. From 2010 to 2019, the ID indices of Shanghai, Zhejiang, and Jiangsu were 0.7714, 0.5617, and 0.5469, respectively, ranking among the top three in ID in YREB and becoming the leader of ID in YREB, while the ID indices of other regions were generally low. The results indicate that there is an insufficient diffusion and leading effect of ID from the more advanced regions in both YRB and YREB. There is also a pronounced polarization in ID levels. For instance, Anhui in YREB had an ID index of only 0.2237 in 2019, highlighting a significant gap compared to Shanghai, Zhejiang, and Jiangsu within the same area (Fig. 6).

(2) The overall disparity in the level of CD is small, except for the upper reaches of YRB, which shows a "collapse" pattern. As shown in Fig. 5, the CD indices of YRB and YREB from 2010 to 2019 were 0.4357 and 0.6176, respectively, indicating that YREB has a better level of CD than YRB. From 2010 to 2019, the CD index of Zhejiang was 0.7898, ranking first among the 19 provincial units in YRB and YREB. The level of CD in the middle and lower reaches of YRB is less different from that of YREB, but the level of CD in Gansu, Qinghai and Ningxia in the upper reaches of YRB is much lower than that of other provincial units in YRB and YREB, with a CD index of 0.0137, 0.1542 and 0.4908, respectively, in 2010–2019, forming a spatially collapsed pattern in the upper reaches of YRB (Fig. 6).

(3) The shortcomings of OD are prominent, and the role of "model students" in taking the lead needs to be enhanced. As shown in Fig. 5, the OD indices of YRB and YREB from
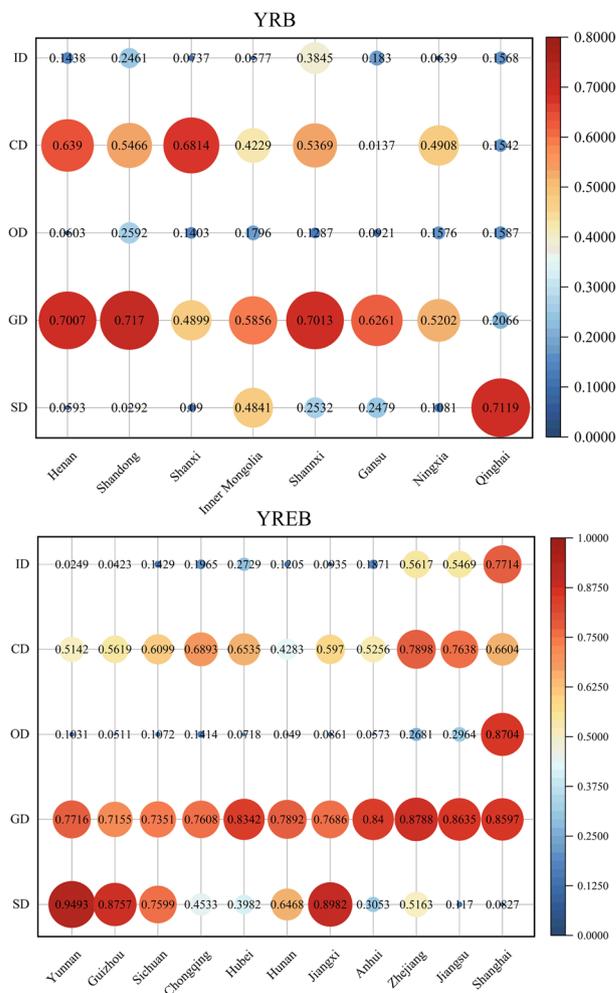
2010 to 2019 were 0.1346 and 0.1911, respectively. Although the OD level of YREB is better than that of YRB, the lack of OD is still a prominent shortcoming of HQD for both. For YRB, relying on the opportunity of "Belt and Road" construction and its special location advantage of connecting land to the sea (Ma et al., 2021), Shandong has become the "leader" of the OD of YRB, while its OD index is only 0.2592. For YREB, the Yangtze River Delta region has always been the window and frontline of China's opening up to the outside world, while the OD level of Shanghai (0.8704) was much better than that of Jiangsu (0.2964) and Zhejiang (0.2681) during the study period, making it the only 'model student' of the OD of YREB (Fig. 6).

(4) The overall level of GD is gradually improving, and the phenomenon of "backwardness" in the middle and upper reaches of YRB is obvious. As shown in Fig. 5, the GD indices of YRB and YREB from 2010 to 2019 were 0.5684 and 0.8015, respectively, and both GD indices showed a gradual increase in general, indicating that the level of GD in YRB and YREB has been improving in recent years. In terms of spatial differences, the spatial differences in the GD level between YRB and YREB are relatively small, with the mean values of GD level in different provincial units within YRB (except Qinghai) and YREB ranging between 0.4899–0.7170 and 0.7155–0.8788, respectively, from 2010 to 2019. Further analysis reveals that in the period from
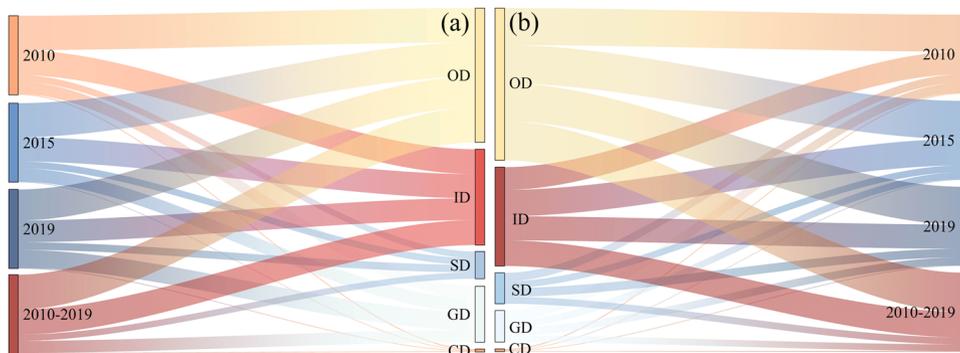
Fig. 7 The obstacle degrees (%) of the five subsystems. a, b Represent the obstacle degrees of the five subsystems in YRB and YREB.

2015 to 2019, the GD index in the upper and middle reaches of YRB, including Inner Mongolia, Qinghai, and Ningxia, exhibited a declining trend. For instance, the GD index for these regions in 2015 was 0.6119, 0.1794, and 0.5757, respectively, but it decreased to 0.4720, 0.1707, and 0.4461 by 2019 (Fig. 6). This indicates that these provincial units in the upper and middle reaches of the basin are facing significant pressure in terms of GD in the future.

(5) The pressure to SD is outstanding, and the "divergence effect" between economic development and people's well-being is noticeable. The mean value of the SD index for YRB and YREB from 2010 to 2019 was 0.2480 and 0.5457, respectively (Fig. 5). Interestingly, despite the relative economic development of the downstream regions in both basins, the SD level is notably low. In the case of YRB, the downstream provinces of Shandong and Henan, despite their relatively developed economies, have notably low SD indices, standing at only 0.0292 and 0.0593, respectively. On the other hand, the upstream provincial units of Qinghai and Inner Mongolia, with lower levels of economic development, exhibit higher SD indices at 0.7119 and 0.4841, respectively. Similarly, within YREB, Shanghai and Jiangsu, as the most economically developed regions, have relatively low SD indices at 0.0827 and 0.1170, respectively. Meanwhile, economically less-developed areas like Yunnan, Jiangxi, and Guizhou have relatively higher SD indices, with mean values of 0.9493, 0.8982, and 0.8757, respectively, from 2010 to 2019 (Fig. 6).

Analysis of obstacles to HQD Level
The obstacles to the subsystems. Figure 7 shows the differences in the degree of obstacles to HQD in YRB and YREB from the five subsystems. The results indicate that from 2010 to 2019, the obstacles to ID, CD, OD, GD, and SD were 31.66, 0.91, 44.08, 15.38 and 7.97% in YRB, and 32.44, 0.82, 49.57, 8.38 and 8.78% in YREB. The results highlight that OD and ID are the primary obstacles limiting HQD of both regions. From a developmental trend perspective, different subsystems have varying impacts on YRB and YREB. Notably, the obstacles to the subsystems, ID and OD, showed an overall decreasing trend. For instance, in YRB, the obstacles to ID and OD have decreased from 30.50 and 43.21% in 2015 to 27.56 and 39.21% in 2019, respectively. In YREB, the obstacles to ID and OD have decreased from 33.31 and 48.39% in 2015 to 30.54 and 47.89% in 2019, respectively. This trend may be closely related to the vigorous implementation of the innovation-driven development strategy and active promotion of the "Belt and Road Initiative" in recent years.

While GD is not the primary obstacle affecting both basins at present, it's worth noting that the obstacle level for GD in YRB is nearly twice that of YREB, and it is on an upward trajectory. This
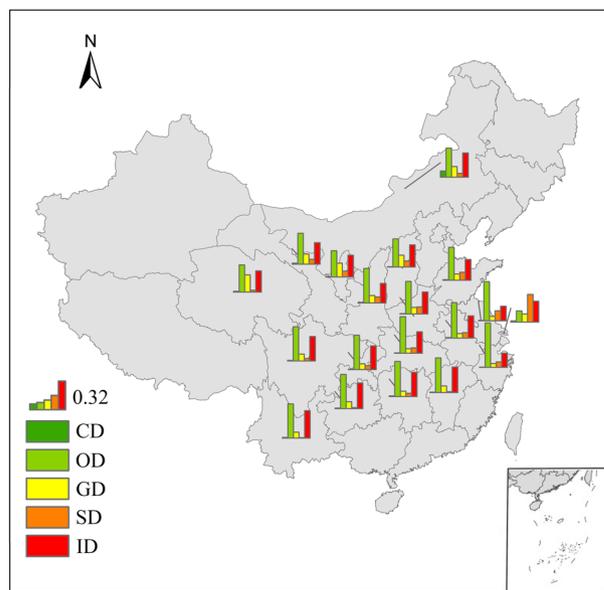

Fig. 8 The obstacle degrees to HQD in the five subsystems of the provincial units.

could be attributed to some provincial units in the upper and middle reaches of the Yellow River, such as Inner Mongolia, Qinghai, and Ningxia, facing challenges due to their weaker development foundations and the influx of middle and low-end industry transfers.

In terms of regional differences (Fig. 8), the obstacle degree of the subsystem, ID, was relatively small in Zhejiang and Jiangsu from 2010 to 2019, with 20.87 and 21.24%, respectively, followed by Shandong and Shanghai with 30.34 and 30.38%, respectively. For the subsystem, OD, Shanghai is the region with the lowest obstacle level in both basins, much lower than other provincial units in YREB during the same period, at 16.11%, less than 1/3 of the average obstacle level in other provincial units (48.99%). The obstacle degree of the subsystem GD has a large regional disparity, and the obstacle degree of the middle and upper reaches of YRB is generally higher and is on a rising trend, among which, Qinghai, Ningxia, and Shanxi ranked the top three in the two basins in terms of the obstacle degree of the subsystem GD, with 25.22, 20.29 and 17.31%, respectively. The obstacle degrees in the subsystems, SD and CD, are low overall and there is little inter-provincial variation.

The obstacles to the indicators. Figure 9 shows the main obstacle factors affecting the HQD of YRB and YREB. The results show that the obstacle factors in YRB are mainly reflected in the
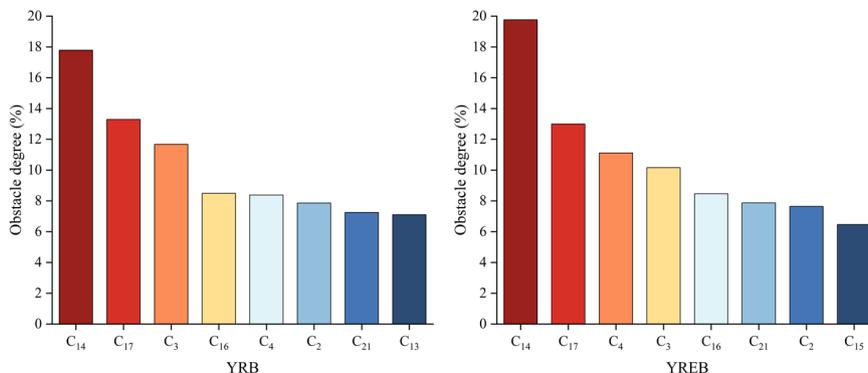
Fig. 9 The top eight obstacle factors and their obstacle degrees (%) in the indicator layers of YRB and YREB.

number of people employed in the aviation industry per 10,000 people (C_{14},17.79%), total imports and exports (C_{17},13.29%), annual number of patents granted per 10,000 people (C_3,11.67%), total foreign investment as a share of GDP(C_{16},8.49%), technology market turnover as a share of GDP (C_4,8.38%), full-time equivalent of R&D personnel per 10,000 people (C_2,7.86%), water resources per capita (C_{21},7.25%), and the investment density in industrial pollution control (C_{13},7.10%), the sum of the top eight obstacle factors in terms of obstacle degrees is 81.82%. The main obstacle factors for YREB are the number of people employed in the aviation industry per 10,000 people (C_{14},19.76%), total imports and exports as a share of GDP (C_{17},12.99%), technology market turnover as a share of GDP (C_4,11.11%), annual number of patents granted per 10,000 people (C_3,10.16%), total foreign investment as a share of GDP (C_{16},8.46%), water resources per capita (C_{21},7.87%), full-time equivalent of R&D personnel per 10,000 people (C_2,7.64%), and the number of people employed in the rail industry per 10,000 people (C_{15},6.46%), the sum of the top eight obstacle factors in terms of obstacle degree is 84.45%. The results show that although there are differences in the ranking of the main obstacle factors in the two basins, they both focus on the two subsystems, ID and OD.

Discussion
Total HQD level in YRB and YREB. In the early stage of China's reform and opening up, China implemented the idea of "unbalanced development", in which "the rich first pushing those being rich later", thus the regional imbalance of the economic geography of the "South is strong and the North is weak, and the East is high and the West is low" was gradually formed. After China's economy entered the "new normal", the regional economic pattern of "strong in the south and weak in the north" has been further highlighted, and has become a major problem plaguing the sustainable development of China's economy. Since then, regional coordinated development has become the focus of China's regional development strategy in the new era. The HQD of YRB and YREB carries the vital task of narrowing the development gap between China's north and south and realizing HQD of China's economy, society, and environment (Liu et al., 2023a). This study shows that the average value of the HQD index of YRB and YREB in 2010–2019 is 0.2886 and 0.4073, respectively. It can be seen that, on the one hand, the HQD level of YREB is significantly better than that of YRB, which is also consistent with the results of previous comparisons between YRB and YREB in terms of economic development (Wang and Tang, 2021), resource environment (Zhao et al., 2022), and green development efficiency (Liu et al., 2023a). Meanwhile, during the study period, the coefficients of variation of the HQD index of both regions show a decreasing trend, which also indicates that the gap in

HQD level between YRB and YREB is decreasing. On the other hand, the long-standing mode of extensive economic development is the main reason for the overall low-quality development of both regions. Simultaneously, the HQD index of both basins exhibits an increasing trend. It also indicates that with the construction of ecological civilization and green development on the agenda in China, the HQD level in the basins has been continuously improved, which is also consistent with the findings of Jiang et al. (2021a) on the temporal characteristics of HQD level in YRB.

HQD level of the subsystems in YRB and YREB. In terms of different subsystems of HQD, the average values of the indices of ID, CD, GD, OD, and SD of YRB and YREB in 2010–2019 were 0.1637, 0.4357, 0.5684, 0.1470, 0.2480, and 0.2692, 0.6176, 0.8015, 0.1911, 0.5457, respectively. This indicates that the contribution of the subsystems to HQD of the basins varies significantly. Further analysis revealed that:

(1) The level of ID in YREB is higher than that in YRB, but the overall level of both is still not high, which is consistent with the findings of Yang and Zhang (2020). During the study period, Shaanxi and Shandong ranked in the top two in terms of ID level in YRB, of which Shaanxi has a leading advantage in high-tech industries such as transport equipment, electronics and aerospace, agriculture and forestry science and technology in terms of scientific research foundation and human resources in colleges and universities among the provinces in YRB (Zhang et al., 2020b), while Shandong province relies on the large-scale innovation and R&D capacity of the "three core cities" of Jinan, Qingdao, and Yantai (Ma et al., 2021), and has a better foundation for innovation as a whole. Shanghai, Zhejiang, and Jiangsu are the leading regions in YREB in terms of the ID level. As of 2019, the number of patents granted per 10,000 people was 41.50, 48.78, and 38.86, respectively, much higher than the national average (17.54 per 10,000 people). However, it is worth noting that both regions are characterized by obvious polarization in ID level, and that the radiation diffusion effect of regions with higher ID levels is insufficient.

(2) The results of our study show that in 2010–2019, the CD indices of YRB and YREB were 0.4357 and 0.6176, respectively, and the CD level of YREB is still better than that of YRB. Among them, Zhejiang has the highest CD level in both regions, indicating that the urban-rural and internal regional gaps in economic and social development in the province are relatively small, which is also an important basis for the province to build a high-quality developmental common prosperity demonstration area. In

contrast, the CD levels of Gansu, Qinghai, and Ningxia in the upper reaches of the Yellow River are considerably lower than those of other provincial units within YRB and YREB. This discrepancy is attributed to the fact that many of these provincial units are situated in areas where multiple ethnicities coexist, poverty is prevalent, and ecological fragility is pronounced (Wang et al., 2008). Consequently, this has resulted in substantial disparities in urban-rural development, regional imbalances in development, and a limited degree of urbanization, severely constraining the enhancement of their CD levels.

(3) Examining the economic and social development trajectories of countries worldwide, it becomes evident that open development is an inevitable choice for promoting and achieving sustained, healthy regional economic and social development. It is also a necessary path for a nation's prosperity (Schminke and Van Biesebroeck, 2013). China's rapid economic growth and its continuous expansion of openness are closely intertwined with active participation in international economic co-operation. However, the findings of this study indicate that the insufficiency in the OD level remains a prominent weakness constraining HQD of YRB and YREB. As a pioneer and vanguard in China's comprehensive deepening of reforms and opening-up, Shanghai boasts the world's second-largest cargo throughput at Shanghai Port and the world's largest container port. Shanghai's array of open initiatives, including the Shanghai Free Trade Zone, the Pudong New Area, the China International Import Expo (CIIE), and the "Shanghai 100 Measures for Expanding Opening-up," has established it as one of the most globally open cities. Shanghai serves as the exclusive leading force for open development among the 19 provincial units within YRB and YREB, with a significant disparity in OD level compared to other provincial units. Hence, it is imperative for both regions to steadfastly uphold a higher level of openness. Accelerating the establishment of a new development paradigm with domestic circulation being the mainstay and the two circulations reinforcing each other, is paramount. Under the overarching guidance of the "Belt and Road Initiative," and utilizing transportation arteries as the backbone, it is crucial to enhance open channels, expand open platforms, and, in broader domains and at higher levels, facilitate the coordinated open development of provincial units along these rivers. This will ultimately elevate the overall OD level.

(4) The GD level within YRB and YREB has been gradually improving. This is evident in the continuous reduction in resource consumption (Cao et al., 2020), the increasing investment in environmental governance (Wang et al., 2024), and the ongoing amelioration of environmental pollution (Jiang et al., 2021b). These trends indicate that regional development, under the guiding concept of "Ecological Protection and High-Quality Development," is gradually moving away from the traditional single economy-oriented model, with more emphasis on green, which aligns with the findings of Liu et al., (2023a). However, it is worth noting that in the upper and middle reaches of the Yellow River, Inner Mongolia, Qinghai, and Ningxia experienced a continuous decline in GD indices from 2015 to 2019, with a growing disparity compared to other provincial units. This decline may be attributed to the fact that these areas are still in the early stages of industrialization, with the majority of their industries remaining traditional, primarily focusing on energy, raw materials, and sectors like chemicals, metallurgy, power,

and construction materials (Yang et al., 2020). Moreover, in the context of pollution control and the inland shift of national industries, these regions have absorbed mainly mid-end and low-end industries from more developed eastern areas (Li et al., 2021). This is reflected in high unit GDP energy and water consumption, relatively small but high-intensity emissions of pollutants, consistent with the findings of Zhong et al. (2020) regarding the existence of a "pollution refuge" effect in the upper and middle reaches of the Yellow River.

(5) The fundamental aim of HQD is to achieve SD, where the fruits of economic growth are better distributed to enhance people's well-being. This entails continually elevating the quality and equity of basic public services while ensuring that ecological well-being is enjoyed by all (Zhao et al., 2019). However, this study reveals a clear "divergence effect" between economic development and people's well-being in YRB and YREB, i.e., regions with relatively higher economic development exhibit lower SD levels. This phenomenon may be attributed to less-developed provincial units enjoying increasing material support and policy incentives from the central government, thereby rapidly improving the effective supply of their basic public services. Conversely, many developed provincial units have struggled to keep pace with the demands of high-density populations, leading to a "city disease" characterized by shortages in public services (Zhang et al., 2020a).

Furthermore, historical emphasis on pursuing total GDP growth in regional development, often at the expense of improving living standards, has been a persistent issue. This is especially true when following an extensive economic growth model characterized by "high investment, high pollution, high consumption," which has resulted in an ecological system under "overcapacity", particularly evident in ecological fragility and severe environmental pollution (Shen and Zhang, 2023). This has significantly hindered improvements in ecological well-being for the populace. For instance, the rapid industrial development and high population density in YREB have led to prominent water pollution (Wang et al., 2023), with a severe scarcity of water resources. Shanghai, in particular, experiences a per capita water resource level of less than 200 m^3, making it one of China's most typical cities suffering from water quality-type water scarcity (Fan et al., 2020). At the same time, in YRB, the more economically developed regions in the middle and lower reaches, such as Shandong, Henan, and Shanxi, are marked by high levels of atmospheric pollution (Yang et al., 2023a). Air pollution is also a significant factor limiting the well-being of the populace in YRB.

The obstacles to HQD in YRB and YREB. The new development philosophy posits that HQD entails making innovation the primary driving force, achieving coordination as an inherent characteristic, adopting green practices as the common form, embracing openness as the inevitable path, and ensuring shared development as the fundamental goal. In other words, HQD represents an integrated approach that encompasses ID, CD, GD, OD, and SD (Xia et al., 2022).

The results of the diagnostic analysis of obstacles to HQD reveal that insufficient openness is the primary constraint hindering HQD of both YRB and YREB. Additionally, a lack of innovation represents a major impediment to HQD of these two regions. While the specific ranking of obstacles varies between the two regions, the key hindrances are predominantly centered around indicators related to the openness system, such as the number of people employed in the aviation industry per 10,000 people (C_{14}), total imports and exports as a share of GDP (C_{17}),

annual number of patents granted per 10,000 people (C_3), total foreign investment as a share of GDP (C_{16}), technology market turnover as a share of GDP (C_4), full-time equivalent of R&D personnel per 10,000 people (C_2), etc. Therefore, the future HQD of these two regions needs to take OD and ID as the general grips, drum up the energy of innovation, open the door, stimulate the potential of the high level of innovation through the expansion of opening up, and lead the all-round opening up of internal and external affairs through innovation, so as to promote the integration of openness and innovation development of both regions.

Conclusions

Main findings. Guided by the new development philosophy, and based on the idea of "assessing the overall levels firstly, then anchoring the subsystems contributions and finally identifying the obstacle factors", this study constructs an HQD evaluation system, measures the HQD indices and subsystems indices of YRB and YREB from 2010 to 2019, and identifies the hindering effects of different factors on the HQD of the two basins based on the Obstacle Degree Model. The main conclusions are as follows:

(1) During the period 2010–2019, the HQD indices of YRB and YREB showed a rising trend, with the average values of the HQD indices of the two basins from 2010 to 2019 being 0.2886 and 0.4073 respectively, indicating that the overall level of HQD in both is not high and there is still much room for improvement. Additionally, in terms of HQD levels, YREB is significantly better than YRB, while the HQD index of YRB is improving faster than that of YREB, indicating that the gap between the two basins' HQD levels is trending towards regional balance.

(2) In terms of HQD subsystems indices of YRB and YREB, both showed a trend of "GD > CD > SD > ID > OD", and under the development concept of "to step up conservation of the Yangtze River and the Yellow River", the GD indices of the two basins have increased faster, and the contribution to the HQD of the basins has increased significantly.

(3) OD and ID are the main obstacles or barriers to HQD in the two basins, but the overall impact of both on HQD is decreasing, which also indicates that the innovation-driven development strategy and the "Belt and Road" initiative, both internal and external, are playing an increasingly important role in supporting the HQD of the two basins. In addition, GD is an important bottleneck for the HQD of YRB, and the increasing trend of obstacle degrees of GD in the middle and upper reaches of the provincial units in YRB indicates that the pressure on GD in the middle and upper reaches of the basin is increasing and should be given more attention.

Policy recommendations. Based on the research conclusions above, we offer some policy recommendations to governments and policymakers for improving the HQD levels in YRB and YREB.

(1) The study shows that both YRB and YREB exhibit relatively low overall HQD levels and significant regional disparities. Consequently, the future path must prioritize strengthening ecological civilization construction and avoiding the conventional approach of "treatment after pollution, and sacrificing resources and the environment in exchange for economic growth." It is imperative to steadfastly implement the development policy of "to step up conservation and stop its over development." Instead, the focus should be on the "ecological priority and green development" pathway to elevate the overall HQD level in the two regions. Simultaneously, future efforts should also concentrate on enhancing economic connectivity and collaboration between YRB and YREB in order to narrow the gap between the two in terms of the HQD levels. Leveraging the advantages of YREB in terms of technology, talent, education, and market, while harnessing the strengths of YRB in terms of labor force, land, and resources, is essential. Exploring co-operation modes of co-operation between the two basins such as industrial transfer, industrial nurturing, and industrial division of labor is crucial. This will promote the differentiated and integrated development of various cities within YRB and YREB, thereby narrowing the economic development disparities among them.

(2) The study has identified that OD and ID are the primary obstacles affecting HQD for both regions. Therefore, under the overarching framework of the "Belt and Road Initiative" and using transportation arteries as the backbone, it's essential to refine open channels and expand open platforms at higher levels and broader domains. This will foster collaborative open development among provincial units along these rivers, ultimately elevating the overall OD level. At the same time, both regions should intensively implement the strategy of innovation-driven development, which involves promoting deep integration between innovation chains and industrial chains, strengthening industrial division and co-operation, optimizing the layout of emerging industries, increasing investment in technological innovation, and expediting the construction of a green industrial system. These measures are crucial to address the prominent weaknesses in HQD.

(3) To leverage the resource endowments of the two basins and account for the differences between their upper, middle, and lower reaches, it is imperative to formulate differentiated and distinctive development strategies. In the upper reaches of YRB, provincial units should prioritize areas like the Source Region of the Three Rivers, the Qilian Mountains, and the water source conservation areas in Gannan. They should promote and implement major ecological protection, restoration, and construction projects to enhance water source conservation capabilities. In the middle reaches of YRB, provincial units should focus on soil and water conservation and pollution control. Simultaneously, the downstream provincial units should emphasize wetland conservation, restoration, and biodiversity protection projects.

In YREB, provincial units should solidly advance water pollution governance, aquatic ecosystem restoration, and water resource protection. This includes intensifying pollution reduction measures for industrial enterprises and tackling agricultural non-point source pollution. Additionally, efforts should be made to enhance the construction of sewage treatment facilities and supporting networks in towns and villages, elevating the scientific, precise, and integrated levels of pollution prevention and control.

Limitations and further directions. Although this study has made a significant contribution to the evaluation of HQD levels in YRB and YREB, it also has limitations and needs further research. First of all, given the data availability, we took the YRB and YREB as the research targets and the provincial units as the research units, and the research scale is relatively macro. However, there may be some differences in the status quo of small-scale HQD research such as prefecture-level cities, county-level cities, etc. Therefore, in the future, the HQD level of different administrative units can be

assessed on smaller scales. Secondly, whether it is from the provincial, prefecture, or country scale, these are also based on the perspective of the administrative unit. In the future, the differences in the impact of conditions and shortcomings, such as physical geography and economy and society, on the HQD of the two basins can be studied comparatively based on the perspective of the geographical unit of the two basins. What's more, it can take the comparative advantages as the starting point and the differentiated functional positioning as the basis to discuss the characteristic industrial system, energy system, ecological governance system, and open system of YRB and YREB, so as to provide theoretical support for the construction of the modern economic system.

Data availability

All data analyzed in this study are included in the supplementary information files.

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Author contributions

All authors contributed significantly to an article and approved the submitted version. Contributed to the concept or design of the article: XY. Contributed to analysis and interpretation of data for the study: XY, ZF. Drafting work or critically revising it for important intellectual content: XY, ZF. Substantial contributions to the conception or design of the work: YC. Final approval of the version to be published: XY. Agreement to be responsible for all aspects of work in ensuring that questions regarding the accuracy or completeness of any part of work are properly investigated and resolved: XY.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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