Influencing factors and improvement paths of green water use efficiency in the Yellow River Basin: a new perspective based on ecogeographical division

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Influencing factors and improvement paths of green water use efficiency in the Yellow River Basin: a new perspective based on ecogeographical division

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Abstract

It is very important for the protection and utilization of water resources in the Yellow River Basin to explore the influencing factors and improvement paths of green water use efficiency based on different regions. The dynamic evolution characteristics, regional differences and internal inefficiencies of green water use efficiency for 48 cities in the Yellow River Basin from 2008 to 2018 are analyzed, based on their ecological geographical divisions, with the use of a DEA-SBM model, GML index decomposition and kernel density estimation. We further use the panel Tobit model to analyze the external influencing factors of green water use efficiency and propose ways to improve the utilization of water resources in different regions from both internal and external perspectives. The results are as follows: (1) During the study period, the green water use efficiency fluctuated between 0.58-0.67 and showed a trend of improving in arid areas and falling in ones. (2) Exploring the sources of inefficiency from the inside reveals that labor, capital, and wastewater redundancy in the semihumid area is higher, the energy redundancy in the semiarid area is higher, and the economic output in the arid area is insufficient. (3) From the GML point of view, the absolute difference in the green water efficiency of the cities in the Yellow River Basin is expanding. In terms of EC (technical efficiency index), the technical efficiency of the semiarid area has a convergence effect. In terms of TC (technical progress index), the gap in the arid area has been widening, and technology in the semihumid and semiarid areas is converging backward. (4) There are significant differences in the external factors affecting green water use efficiency in different ecogeographical regions. This study helps the government to consider eco-geographical factors when formulating water resources-related policies, and provides a scientific reference for how to better utilize water resources in different regions of the Yellow River Basin from both internal and external aspects.

Keywords: Yellow River Basin; green water use efficiency; DEA-SBM; influencing Factors; ecogeographical division; improvement paths
1. Introduction

Water is an important strategic basic resource, not only as a necessary factor for human existence but also for its significant role in ecological environment construction and sustainable economic development (Qin et al., 2020). To ensure the sustainable development of human society, it is necessary to continuously improve the utilization efficiency of water resources (Adom et al., 2021). Green water use efficiency is an important indicator for sustaining water resources (Worthington, 2014; Zhang et al., 2020). As to its measurement and calculation, scholars mostly use stochastic frontier analysis (SFA) (Kaneko, 2000), index system evaluation (Hu et al., 2006) and various forms of data envelopment analysis (DEA), including Malmquist index model, two-stage DEA, three-stage DEA, Slack Based Model (SBM), Directional Distance Function (DDF) and super efficiency DEA, etc (Zhou et al., 2018; Zhao et al., 2017; Song et al., 2018; Hu et al., 2018). Comparing to the other two measurement methods, DEA is easier and more objective for evaluating efficiency for several reasons: restrictive assumptions about the correlation function between multiple input-output variables are not needed; price information of input-output elements also are not needed; and, problems related to subjective weighting are avoided (Zhao et
Therefore, DEA has become a primary technical tool for assessing efficiency. In September 2019, the ecological protection and high-quality development of the Yellow River Basin (YRB) was listed as a major national strategy in China. The YRB is an important ecological barrier and economic zone for undertaking industrial transfer in China. In 2018, the GDP of the YRB was approximately 23.9 trillion CNY. Compared with 9 trillion CNY a decade ago, the GDP of the YRB has grown rapidly (Liu et al., 2021). However, with the rapid development of urbanization and industrialization, the YRB is challenged by overexploitation of natural resources and fragile ecological environments (Ma et al., 2019) of which the contradiction between water supply and demand and pollution of the water environment have become increasingly prominent. In 2019, 10% of the Yellow River was inferior to Category V, which was higher than the national average, and the utilization rate of water resources was as high as 80%, far exceeding the ecological warning line of 40%. Protecting the ecological environment is an important guarantee for the high-quality development of the river basin (Xu et al., 2020). The YRB is an important water source in Northwest and North China, and studying the regional green water use efficiency of the YRB is critical for its protection.

To explore influencing factors, both internal and external aspects should be considered (Guo et al., 2020). The internal factor input can act on green water use efficiency from three aspects: scale effect, agglomeration effect and technological endogenous effect (He et al., 2021). First, the increase in the scale of the input of production function elements produces a scale effect, which can increase the economic output of water resources per unit of city and promote the intensive use of water resources (Zhang et al., 2020). However, when the scale exceeds the threshold, the constraints between the various input elements will lead to diseconomies of scale and have a negative effect on water use efficiency (Liu & Gong, 2018). Second, the increase in the scale of factor input will have an effect on the efficiency of resource utilization through the positive and negative externalities generated by the agglomeration effect (Rosenthal & Strange, 2003). Finally, Romer (1990) proposed new growth theory and believed that the technical efficiency and technological progress decomposed after the endogenous effect of technology had a great impact on resource utilization. External influences can act on green water use efficiency in three ways: structural upgrading, scale expansion, and industrial innovation (Qian & He, 2011; Li & Xu, 2018). Existing researches on the selection of external influencing factors basically focus on factor endowment, FDI (foreign direct investment), economic development, technological level (Wang et al., 2017; Li et al., 2018; Jin et al., 2019; Ma et al., 2021). Through the above articles, it can be found that there are few studies considered internal and external influencing factors at the same time. This study is not only giving the internal cause of green water use efficiency based on invalidity decomposition, but also integrating the research of the former studies, from the perspective of economic, social, and resources, exploiting external factors affecting the water efficiency of green in the YRB.

With the deepening of research, many scholars have found that the spatial differences and unbalanced development of regional water resources pose a threat to the sustainable and coordinated development of river basin resources (Sun & Tang, 2020; Wang et al., 2021; Gao et al.,
With regard to the spatial difference study of water efficiency, some scholars are launched from the national perspective, for example, He et al. (2020) explored the spatial characteristics of China's urban water resources utilization efficiency. Other scholars have launched research in a certain region in China, including South China (Liu & Chen, 2021), Yangtze River Economic Zone (Zhang et al., 2018) and Yangtze River Delta City Group (Sun et al., 2018). There are only a few papers in the YRB as research objects (Yue & Lei, 2022; Yue et al., 2021). The Yellow River flows through a wide area and spans across the three major ecological geographic regions of China. Actually, the heterogeneity of ecological conditions, element endowments, and resource consumption in different regions will lead to different characteristics of green water use efficiency (Ren et al., 2020). However, existing studies have not considered ecological geographical factors on partitioning methods. Therefore, it is necessary to explore the spatial heterogeneity of the improvement path of green water use efficiency in the YRB from a perspective of ecological geography.

To narrow the above gaps, this study uses 48 cities of the YRB from 2008 to 2018, to explore the characteristics, influencing factors and improvement paths of the green water use efficiency of the YRB based on different ecological geographical divisions. First, this study used DEA to calculate the green water use efficiency, and show the time trend of green water use efficiency and the dynamic evolution characteristics of GML decomposition in the YRB under different ecological geographic regions. Then, this study explained the reasons why green water use efficiency is not optimal from an internal perspective and explored the influencing factors of green water use efficiency from an external perspective. Finally, suggestions were proposed to improve the green water use efficiency in different regions from both internal and external perspectives. The results of this study could provide references for improving water efficiency in different regions and promoting the coordinated development of green water resources in river basins.

2. Methodology and variable selection

2.1 Study area

The Yellow River originates from the Bayan Har Mountains and flows through the 9 provinces of Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, and Shandong with the Qinling Mountains as the boundary. The total length of the basin is 5464 km, with a total area of 2.55 million km². This study combines cities with data from the "Chinese Rivers and Lakes Dadian-Yellow River Volume" compiled by the Yellow River Conservancy Commission and existing research (Hu et al., 2021; Zhang et al., 2019). Based on the availability of data, we select 48 prefecture-level cities. Due to differences in the climate and ecological conditions, ecological geographical zoning was carried out before the evaluation of water resources in the river basin. According to the recommendations of UNESCO and the World Meteorological Organization, China can be divided into four categories: humid, semihumid, semiarid, and arid; the cities in the YRB are unevenly distributed in the three major ecological geographies of semihumid, semiarid, and arid. The semihumid area includes nearly 70% of the cities of the entire basin, the semiarid area includes 3 cities, and the arid area includes 11 cities
2.2 Variable selection and data source

Green water use efficiency research indicators include input indicators, expected output and undesired output indicators. Among the input indicators, human input represents the annual average number of employees, capital input represents fixed capital calculated by the perpetual inventory method, and water input represents total water consumption. Economic output is the expected output of water use efficiency, which is expressed as the actual GDP that is deflated based on the 2006 base period. Water pollution discharge is an undesired output. All pollution must be eliminated due to water pollution discharge. Including chemical oxygen demand (chemical oxygen demand emissions, ammonia nitrogen emissions, petroleum, lead mercury, etc.), so it is characterized by the wastewater emissions of each city.

This paper explores the influencing factors on green water use efficiency in the YRB from external factors. It mainly reflects the influence of economic and social activities on water use efficiency. After considering city applicability and existing research (Guo et al., 2015; Yin&Zhao, 2018; Ren&Lu, 2019), this paper selects the following indicators as external factors:

1. Opening up (FDI): FDI can rely on the "technology spillover effect" to promote industrial innovation. In contrast, it may also change the industrial layout due to the "pollution paradise
effect", thereby affecting the efficiency of resource utilization (Gray, 2004; Choe, 2003). It is expressed as logarithmic value of foreign direct investment amount.

2. The level of economic development (GDP): The rapid development of the economy will increase the scale and intensity of resource utilization. At the same time, a better level of social and economic development can also drive knowledge innovation (Zhang, 2003) and improve the water use efficiency from the perspective of technology substitution and pollution control. It is expressed as real per capita GDP.

3. Population density (POP): Population agglomeration is an important cause of pressure on the water environment. The age and spatial structure of the population can promote upgrading the consumption structure, thereby affecting green water use efficiency (Yang et al., 2020). It is expressed as the number of people per unit of land area.

4. Industrial structure (IS): The adjustment of industrial structure can influence the water use structure by stimulating structural dividends. At the same time, the industrial structure is conducive to causing changes in the structure of consumer demand to drive enterprise management innovation, enhance interindustry innovation and cooperation, and have an impact on the improvement of resource utilization efficiency (Ren & Yang, 2020). It is expressed as the proportion of secondary and tertiary industries in GDP.

5. Urbanization rate (UR): The process of urbanization has greatly changed economic structures and lifestyle. By affecting the supply, demand and employment structure of labor, urbanization has led to the reallocation of production factors, resulting in changes in water use efficiency (Ma et al., 2014). It is expressed as the proportion of urban population in the total population.

6. Water resources endowment (WATER): Lin & Sun (2003) proposed the theory of dynamic comparative advantage. They believed that the factor endowment structure determines the choice of industries and the direction of technological progress, which in turn affects the utilization of resources. It is expressed as the logarithm of per capita water consumption.

7. Technological innovation (RD): The level of technological innovation is one of the important factors affecting water use efficiency. It can rely on optimizing the allocation effect, market demand effect and network synergy effect to promote the upgrading of industrial structure, expand economic scale efficiency, and promote the improvement of green water use efficiency (Yan et al., 2019). It is expressed as the proportion of scientific and technological expenditures in fiscal expenditures.

8. Environmental governance (ET): Environmental governance has an impact on the production activities of enterprises through the effects of "following costs" and "innovation compensation" and plays an important role in pollution control and emission reduction (Liu et al., 2021). It is expressed as domestic sewage treatment rate.

In 2007, China began pollution prevention and control of the four major river basins. In 2019,
it focused on the high-quality development of the YRB. Therefore, the data available in the past 10 years are used as the research period. Economic indicators are derived from the "2009-2019 China City Statistical Yearbook" and the National Economic and Social Development Bulletin. Water resource-related indicators are derived from the provincial water resource bulletins and the websites of the Ministry of Water Resources of China and the provincial water resource departments. Some indicators have inconsistent statistical standards: The total water consumption statistics are calculated by adding up agricultural, industrial, domestic and ecological water consumption. Some cities have no agricultural water consumption indicators, so we replace them with forest, animal husbandry and fishery water consumption. Some cities have no ecological water consumption indicators. Because the proportion of ecological water is extremely low, it has almost no effect on the results, so it is ignored. For indicators with inconsistent units before and after, conversion is carried out according to the latest statistical unit, and some missing data in the data source are estimated and supplemented by the moving average method.

Table 1 Indicators Definition, Unit and Data Source

<table>
<thead>
<tr>
<th>Influencing factors</th>
<th>Variable</th>
<th>Unit</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal influencing factors</td>
<td>Human input</td>
<td>Annual average number</td>
<td>Ten thousand people</td>
</tr>
<tr>
<td></td>
<td>employees</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Capital input</td>
<td>Fixed capital stock</td>
<td>Ten thousand yuan</td>
</tr>
<tr>
<td></td>
<td>Water input</td>
<td>Total water consumption</td>
<td>One hundred million m³</td>
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<tr>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Economic output</td>
<td>Actual GDP</td>
<td>Ten thousand yuan</td>
</tr>
<tr>
<td></td>
<td>Water pollution</td>
<td>Total wastewater</td>
<td>Ten thousand tons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>emissions volume</td>
<td></td>
</tr>
<tr>
<td>External influencing factors</td>
<td>Opening up(FDI)</td>
<td>logarithmic value of</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td></td>
<td>foreign direct</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The level of economic</td>
<td>real per capita GDP</td>
<td>Yuan</td>
</tr>
<tr>
<td></td>
<td>development(GDP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Population density(POP)</td>
<td>the number of people</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>per unit of land area</td>
<td></td>
</tr>
<tr>
<td>Indicator</td>
<td>Description</td>
<td>Source</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>--------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Industrial structure (IS)</td>
<td>the proportion of secondary and tertiary industries in GDP</td>
<td>China Statistical Yearbook</td>
<td></td>
</tr>
<tr>
<td>Urbanization rate (UR)</td>
<td>the proportion of urban population in the total population</td>
<td>China Statistical Yearbook</td>
<td></td>
</tr>
<tr>
<td>Water resources endowment (WATER)</td>
<td>the logarithm of per capita water consumption</td>
<td>provincial water resource bulletins, websites</td>
<td></td>
</tr>
<tr>
<td>Technological innovation (RD)</td>
<td>the proportion of scientific and technological expenditures in fiscal expenditures</td>
<td>China Statistical Yearbook</td>
<td></td>
</tr>
<tr>
<td>Environmental governance (ET)</td>
<td>domestic sewage treatment rate</td>
<td>China Statistical Yearbook, National Economic</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>and Social Development Bulletin</td>
<td></td>
</tr>
</tbody>
</table>

2.3 DEA-SBM model

Water use efficiency is defined as the ratio of the optimal water consumption of an economic unit to the actual water consumption (Wang et al., 2020). The existing measurement of water efficiency does not consider wastewater discharge, which makes the measurement results have a certain deviation. To solve this problem, this study incorporates wastewater discharge into the total factor water efficiency measurement framework and uses the slack-based measure (SBM) model (Tone, 2001) to measure the green water use efficiency of cities in the YRB.

Suppose there are n design-making units (DMUs) in the research area. Each unit has m kinds of inputs, q1 kinds of desirable outputs and q2 kinds of undesirable outputs. Then, the green water efficiency model of the n-th decision-making unit is as follows:

\[
\text{Min} \rho_n = \frac{1 - \frac{1}{m} \sum_{i=1}^{m} s_i^- / R_{ik}}{1 + \frac{1}{q_1 + q_2} \left( \frac{1}{q_1} \sum_{r=1}^{q_1} s_r^{g^+} / R_{rk} + \frac{1}{q_2} \sum_{r=q_1+1}^{q_1+q_2} s_r^{b^+} / R_{rk} \right)}
\]

\[
\sum_{j=1}^{n} \lambda_{jk}^{-} x_{ij} + s_i^- = x_{ik}, i = 1, 2, ..., m
\]

s.t.

\[
\sum_{j=1}^{n} \lambda_{jk}^{g} y_{ik}^{g} - s_r^{g^+} = y_{rk}^{g}, r = 1, 2, ..., q_1
\]

\[
\sum_{j=1}^{n} \lambda_{jk}^{b} y_{ik}^{b} + s_r^{b^+} = y_{rk}^{b}, r = 1, 2, ..., q_2
\]

\[
\lambda_{jk} \geq 0, \quad s_i^- \geq 0, \quad s_r^{g^+} \geq 0, \quad s_r^{b^+} \geq 0
\]
where \((s_i^- , s_i^{g+} , s_i^{b+})\) are the slack variables of input variables, desirable output, and undesirable output, respectively. The objective function \(\rho^*\) is strictly decreasing. When \(s_i^- = s_i^{g+} = s_i^{b+} = 0\), the function has an optimal solution. If \(\rho^* = 1\), the decision-making unit is efficient. If \(0 \leq \rho^* \leq 1\), it means that the decision-making unit has a loss of efficiency and has not been fully effective. When the DMU has not been fully effective, it can be improved through the adjustment of input and output, and the extent of improvement is determined by the proportion of slack variables in their respective inputs and outputs. Green water use inefficiency can be decomposed into input inefficiency and output inefficiency. The calculation is shown in formulas (2)-(4):

Input inefficiency (input redundancy rate): 
\[
IE_x = \frac{1}{m} \sum_{i=1}^{m} s_i^x
\]  

Expected output inefficiency (desired output insufficiency rate): 
\[
IE_{y_i} = \frac{1}{q_i} \sum_{i=1}^{q_i} \frac{s_i^{b+}}{y_{ik}}
\]  

Unexpected output inefficiency (unexpected output redundancy rate): 
\[
IE_{y_i} = \frac{1}{q_2} \sum_{i=1}^{q_2} \frac{s_i^{b+}}{y_{ik}}
\]  

2.4 Global Malmquist (GML) index

According to the GML method (Oh, 2010), the interannual change value of green water use efficiency in the basin is measured, and it is decomposed into the technical efficiency index (EC) for measuring changes in technical efficiency and the technical progress index (TC) for measuring technological progress.

\[
GML_{i+1} (x', y', b', x'^{t+1}, y'^{t+1}, b'^{t+1}) = \frac{1 + D^G(x'^{t+1}, y'^{t+1}, b'^{t+1})}{1 + D^G(x', y', b')}
\]

\[
= \frac{1 + D'(x'^{t+1}, y'^{t+1}, b'^{t+1})}{1 + D'(x', y', b')} \times \frac{1 + D^G(x', y', b')}{1 + D^G(x'^{t+1}, y'^{t+1}, b'^{t+1})} \times \frac{1 + D'^{t+1}(x'^{t+1}, y'^{t+1}, b'^{t+1})}{1 + D'(x', y', b')}
\]

\[
= EC_{i+1} \times TC_{i+1}
\]

where \(D^G(x, y, b)\) is the global directional distance function, \(x\) is the input, \(y\) is the desired output, and \(b\) is the undesired output.
2.5 Kernel density estimation

The kernel density estimation method can use a continuous density curve to describe the
distribution position, distribution pattern and polarization trend of random variables, and in this
paper, the commonly used Gauss kernel function is used to estimate the green water use efficiency
of the city in the YRB (Chen et al., 2019). The model is as follows:

\[
f(x) = \frac{1}{Nh} \sum_{i=1}^{N} K\left(\frac{X_i - x}{h}\right)
\]

(6)

\[
k(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right)
\]

(7)

where \(X_i\) represents the green water use efficiency in each city, \(x\) is the average value of green
water use efficiency, \(N\) is the total number of samples, \(h\) is the bandwidth, and \(K\) is the kernel
function.

2.6 Tobit regression model

In the regression of this article, green water use efficiency is an explained variable with a
value of 0-1, so the Tobit model is used for regression analysis, and the model is set as follows:

\[Eff_i = \beta_0 + \beta_1FDI_i + \beta_2GDP_i + \beta_3POP_i + \beta_4IS_i + \beta_5UR_i + \beta_6RWater_i + \beta_7RD_i + \beta_8ET_i + \epsilon_i\]

(8)

where \(Eff\) represents the green water use efficiency; \(\beta_0\) is the intercept term, and \(\beta_1\) to \(\beta_8\) are the
parameters to be estimated; \(\epsilon_i\) is the random error term of the i-th city that obeys the normal
distribution in year t. After the LR test, the results strongly reject the null hypothesis that there is
no individual effect, so this article uses the random effects Tobit model to conduct an empirical
analysis of external influencing factors.

This study measures the regional green water use efficiency based on the DEA-SBM model.
Then, GML index decomposition and its kernel density curve are used to characterize the dynamic
evolution characteristics of green water efficiency. Furthermore, we use the internal
decomposition of efficiency to explore the internal reasons why water use efficiency has not
reached the optimal value and proposed internal improvement paths in different areas. Finally,
through the Tobit model, we explored the external influencing factors of green water use
efficiency and proposed external improvement paths in different areas.

3. Result

3.1 Time trend analysis of green water use efficiency

From 2008 to 2018, the green water use efficiency changes in the YRB were relatively stable,
fluctuating between 0.58 and 0.67, but there was still a gap from the optimal frontier, so there was
room for improvement in the allocation of water resources. From a regional perspective, a trend of
"arid areas are improving and humid area is falling" is shown. During the study period, the
efficiency values of the semiarid area and arid area increased by 18.96% and 15.14%, respectively, while the efficiency values of the semi-humid area decreased by 7.79% (Fig. 2).

Figure 2  Green water use efficiency of cities in the Yellow River Basin and its subregions

3.2 Dynamic evolution of GML decomposition of green water efficiency in the Yellow River Basin

We continued to characterize the endogenous driving factors of green water use efficiency in the YRB and its ecological districts and used GML index decomposition combined with nuclear density estimation to show the dynamic evolution of green water use efficiency (Table 1).

From a distribution perspective, the main peak positions of the GML nuclear density curve all show a changing trend from left to right, indicating that the level of urban green water efficiency
is rising. The semiarid area has the largest shift to the right, with obvious latecomer advantages, and the semihumid area has a relatively small shift to the right, with a relatively slow efficiency level. In terms of distribution situation, the peak heights of all regions have been decreasing year by year, and the width of all of the regions except the semihumid one has expanded, indicating that the absolute difference in water use efficiency is showing an expanding trend. In terms of the polarization trend, all regions maintain a single peak state from beginning to end, without gradient effects, and the efficiency values are relatively concentrated. In terms of malleability, only in arid regions does a right-tailed tail and a broadening trend show. In regard to EC, the location of the semiarid area remains unchanged, the peak value is decreased, the width is enlarged, and there is no tailing phenomenon, indicating that the technical efficiency of this area has a convergence effect and that the interval difference is decreasing year by year. The position of the main peak in the semihumid and arid areas shifted to the right, the peak value decreased and the width widened, indicating that the gap technical efficiency in the two regions has been expanding, and low-efficiency cities have insufficient power to catch up with cities in high-efficiency provinces. In 2018, the two regions exhibited double peaks and showed a trend of trailing right and extension and widening, indicating that the technical efficiency of subhumid and arid regions has significantly improved and accumulated. From the perspective of TC, the evolution trends of the semihumid and semiarid areas are the same. The center of the curve shifts to the left, the peak rises, the width shrinks, and the left-tailing change shows that the regional technology has not improved during the study period. The location of the arid area remained unchanged, and the peak value decreased, indicating that the technological gap between cities in the arid area gradually expanded during the study period.

Table 2 Dynamic evolution of GML decomposition of green water efficiency in the Yellow River Basin and its subregions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Region</th>
<th>Distribution location</th>
<th>Distribution situation</th>
<th>Polarization trend</th>
<th>Malleability</th>
</tr>
</thead>
<tbody>
<tr>
<td>GML</td>
<td>Semihumid</td>
<td>From left to right</td>
<td>Peak drop, width shrink</td>
<td>Single peak</td>
<td>None</td>
</tr>
<tr>
<td>arid</td>
<td>From left to right</td>
<td>Peak drop, width expand</td>
<td>Single peak</td>
<td>Tail right, extend and widen</td>
<td></td>
</tr>
<tr>
<td>Semiarid</td>
<td>From left to right</td>
<td>Peak drop, width expand</td>
<td>Single peak</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>YRB</td>
<td>From left to right</td>
<td>Peak drop, width expand</td>
<td>Single peak</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>EC</td>
<td>Semihumid</td>
<td>From left to right</td>
<td>Peak drop, width expand</td>
<td>Twin peaks</td>
<td>Tail right, extend and widen</td>
</tr>
<tr>
<td>arid</td>
<td>From left to right</td>
<td>Peak drop, width expand</td>
<td>Twin peaks</td>
<td>Tail right, extend and widen</td>
<td></td>
</tr>
<tr>
<td>Semiarid</td>
<td>Unchanged</td>
<td>Peak drop, width expand</td>
<td>Single peak</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>YRB</td>
<td>Unchanged</td>
<td>Peak rise, width shrink</td>
<td>Single peak</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>TC</td>
<td>Semihumid</td>
<td>From right to left</td>
<td>Peak rise, width shrink</td>
<td>Single peak</td>
<td>Tail left, extend and widen</td>
</tr>
<tr>
<td>arid</td>
<td>Unchanged</td>
<td>Peak drop, unchanged width</td>
<td>Single peak</td>
<td>Tail right, extend and widen</td>
<td></td>
</tr>
</tbody>
</table>
### 3.3 Internal causes of green water use inefficiency

To further explore the reasons for the inefficiency of green water use in the various regions of the YRB, this paper measures the redundancy rate and insufficient rate of input-output factors in each region (Table 2).

<table>
<thead>
<tr>
<th>region</th>
<th>time</th>
<th>Labor redundancy rate(%)</th>
<th>Capital redundancy rate(%)</th>
<th>Resources redundancy rate(%)</th>
<th>Insufficient economic output rate(%)</th>
<th>Waste water redundancy rate(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semihumid</td>
<td>2008</td>
<td>20.23</td>
<td>9.58</td>
<td>43.00</td>
<td>0.00</td>
<td>36.08</td>
</tr>
<tr>
<td>arid</td>
<td></td>
<td>12.73</td>
<td>0.22</td>
<td>26.60</td>
<td>1.26</td>
<td>26.81</td>
</tr>
<tr>
<td>Semiarid</td>
<td></td>
<td>20.36</td>
<td>9.08</td>
<td>54.10</td>
<td>0.00</td>
<td>41.84</td>
</tr>
<tr>
<td>YRB</td>
<td></td>
<td>19.79</td>
<td>8.88</td>
<td>44.52</td>
<td>0.12</td>
<td>36.82</td>
</tr>
<tr>
<td>Semihumid</td>
<td>2012</td>
<td>26.31</td>
<td>21.30</td>
<td>38.78</td>
<td>0.00</td>
<td>51.27</td>
</tr>
<tr>
<td>arid</td>
<td></td>
<td>17.17</td>
<td>12.62</td>
<td>39.42</td>
<td>1.07</td>
<td>34.98</td>
</tr>
<tr>
<td>Semiarid</td>
<td></td>
<td>7.79</td>
<td>18.85</td>
<td>56.34</td>
<td>0.00</td>
<td>40.50</td>
</tr>
<tr>
<td>YRB</td>
<td></td>
<td>21.49</td>
<td>20.20</td>
<td>42.85</td>
<td>0.09</td>
<td>47.78</td>
</tr>
<tr>
<td>Semihumid</td>
<td>2015</td>
<td>30.86</td>
<td>28.06</td>
<td>32.13</td>
<td>0.00</td>
<td>44.93</td>
</tr>
<tr>
<td>arid</td>
<td></td>
<td>15.26</td>
<td>17.94</td>
<td>26.96</td>
<td>0.88</td>
<td>19.36</td>
</tr>
<tr>
<td>Semiarid</td>
<td></td>
<td>16.30</td>
<td>16.32</td>
<td>43.01</td>
<td>0.00</td>
<td>25.94</td>
</tr>
<tr>
<td>YRB</td>
<td></td>
<td>26.55</td>
<td>24.74</td>
<td>34.30</td>
<td>0.02</td>
<td>38.98</td>
</tr>
<tr>
<td>Semihumid</td>
<td>2018</td>
<td>23.50</td>
<td>21.30</td>
<td>45.43</td>
<td>0.00</td>
<td>36.18</td>
</tr>
<tr>
<td>arid</td>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Semiarid</td>
<td></td>
<td>12.33</td>
<td>11.04</td>
<td>37.71</td>
<td>0.00</td>
<td>29.67</td>
</tr>
<tr>
<td>YRB</td>
<td></td>
<td>19.47</td>
<td>17.62</td>
<td>40.82</td>
<td>0.00</td>
<td>32.43</td>
</tr>
<tr>
<td>Semihumid</td>
<td>mean</td>
<td>27.74</td>
<td>20.75</td>
<td>39.20</td>
<td>0.00</td>
<td>44.13</td>
</tr>
</tbody>
</table>
Throughout the entire river basin, there is a huge gap in the inefficiency of the use of green water resources caused by the five elements. The inefficiency of each element is in the order of wastewater redundancy > resource redundancy > labor redundancy > capital redundancy > insufficient economic output. Excessive wastewater discharge is the main factor restricting the improvement of regional green water efficiency. However, the demand for water resources and pollution emissions declined during the study period, which shows that the region has focused on green development in recent years. From the perspective of expected output, the rate of insufficient economic output is small and declines year by year. By 2018, the insufficient economic output rate of all regions was zero, indicating that the level of economic development in the YRB had been continuously improving. In subregions, the labor, capital, and wastewater redundancy in the subhumid area ranks at the top and is significantly higher than the regional average. In the arid area, the redundancy rates for economic output and for other factors were low, indicating its primacy in restricting insufficient economic output. The semiarid area has the most resource redundancy, indicating that the area is facing the dual ecological pressure of resource waste and environmental pollution. From the average value of the coefficient of variation, the imbalanced characteristics of the regional economic development level are significant, and the redundancy of water resources and wastewater is a common problem that restricts green water use efficiency. This is because the semihumid area covers cities with a large population and investment scale in the YRB, and it has many high-energy-consuming and high-polluting industries, resulting in more industrial wastewater discharge. The cities in the arid area are all located in western China, their economic development level is lagging, and their industrial advantages are not prominent. Therefore, relying on resources produces little economic benefit. Cities in the semiarid area are all resource-based cities. They possess an underdeveloped economy, backward technology, and excessive dependence on resources, characteristics which make them fall into the disadvantageous situation of a “resource curse”.

3.4 External influencing factors of green water use efficiency in the Yellow River Basin

The regression results are shown in Table 3. The influence coefficients of foreign investment (FDI) on the YRB as a whole and subregions are all positive. However, the semihumid and arid areas are not significantly impacted. The economic development level (GDP) has significant positive impacts in the semihumid and semiarid areas but has significant negative impacts overall the whole and on all arid areas. The population density (POP) has a significant negative impact on the entire YRB and semihumid and semiarid areas and has no significant impact on arid areas. The industrial structure (IS) has a significant positive impact on the green water use efficiency of the
whole district and subhumid areas. The urbanization level (\textit{UR}) has a significant positive impact on the whole district, subhumid area and arid area. The water resource endowment (\textit{WATER}) has a significant inhibitory effect on water use efficiency in the arid area. The effect of technological innovation (\textit{RD}) and environmental governance (\textit{ET}) is not significant.

Table 4 Regression results of influencing factors of green water use efficiency in the Yellow River Basin and subregions

<table>
<thead>
<tr>
<th>Variable</th>
<th>YRB</th>
<th>Semi-humid</th>
<th>Semi-arid</th>
<th>Arid</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDI</td>
<td>-0.0141**</td>
<td>-0.0140</td>
<td>-1.1321***</td>
<td>-0.0368</td>
</tr>
<tr>
<td></td>
<td>(-2.01)</td>
<td>(-0.84)</td>
<td>(-4.13)</td>
<td>(-0.72)</td>
</tr>
<tr>
<td>GDP</td>
<td>-0.1739***</td>
<td>0.1138***</td>
<td>-0.2882**</td>
<td>-0.7130***</td>
</tr>
<tr>
<td></td>
<td>(-3.97)</td>
<td>(2.98)</td>
<td>(-3.69)</td>
<td>(-2.24)</td>
</tr>
<tr>
<td>POP</td>
<td>-0.0633**</td>
<td>-0.0796*</td>
<td>-0.3077***</td>
<td>-0.0424</td>
</tr>
<tr>
<td></td>
<td>(-2.18)</td>
<td>(-1.68)</td>
<td>(-2.62)</td>
<td>(-0.27)</td>
</tr>
<tr>
<td>IS</td>
<td>0.0052**</td>
<td>0.0139***</td>
<td>0.0058</td>
<td>-0.0015</td>
</tr>
<tr>
<td></td>
<td>(2.09)</td>
<td>(2.85)</td>
<td>(0.68)</td>
<td>(-0.15)</td>
</tr>
<tr>
<td>UR</td>
<td>0.0032*</td>
<td>-0.0059*</td>
<td>0.0038</td>
<td>0.0331*</td>
</tr>
<tr>
<td></td>
<td>(1.86)</td>
<td>(-1.89)</td>
<td>(0.58)</td>
<td>(1.66)</td>
</tr>
<tr>
<td>WATER</td>
<td>0.0057</td>
<td>-0.0134</td>
<td>0.0550</td>
<td>-0.0685**</td>
</tr>
<tr>
<td></td>
<td>(0.33)</td>
<td>(-0.34)</td>
<td>(0.89)</td>
<td>(-2.14)</td>
</tr>
<tr>
<td>RD</td>
<td>0.0035</td>
<td>-0.0284</td>
<td>-0.0075</td>
<td>-0.0386</td>
</tr>
<tr>
<td></td>
<td>(0.34)</td>
<td>(-1.10)</td>
<td>(-0.34)</td>
<td>(-0.35)</td>
</tr>
<tr>
<td>ET</td>
<td>0.0922</td>
<td>0.1035</td>
<td>0.0022</td>
<td>0.0006</td>
</tr>
<tr>
<td></td>
<td>(1.48)</td>
<td>(1.48)</td>
<td>(0.75)</td>
<td>(0.19)</td>
</tr>
<tr>
<td>Cons</td>
<td>1.2242***</td>
<td>0.5931*</td>
<td>-1.4976</td>
<td>3.8378**</td>
</tr>
<tr>
<td></td>
<td>(4.16)</td>
<td>(1.87)</td>
<td>(-1.59)</td>
<td>(2.39)</td>
</tr>
<tr>
<td>LR test</td>
<td>P = 0.000</td>
<td>P = 0.000</td>
<td>P = 0.000</td>
<td>P = 0.000</td>
</tr>
<tr>
<td>Sample</td>
<td>528</td>
<td>374</td>
<td>33</td>
<td>121</td>
</tr>
</tbody>
</table>

Note: Values in parentheses are Z statistics; *, **, *** are the 1%, 5%, and 10% significance levels, respectively

3.5 Robust test
To prove the reliability of the regression results, this study first replaced the panel model after the Hausman test for regression, then replaced the explained variables, and used DDF-DEA to recalculate the green water efficiency. The results show that the direction and significance level of all influencing factors on green water efficiency are basically the same as those in the previous regression results, which proves that the evaluation methods and indicators have a consistent and stable interpretation of the above regression results (Table 4).

Table 5 Robust test

<table>
<thead>
<tr>
<th>Variable</th>
<th>YRB</th>
<th>Semihumid</th>
<th>Semiarid</th>
<th>Arid</th>
<th>YRB</th>
<th>Semihumid</th>
<th>Semiarid</th>
<th>Arid</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDI</td>
<td>-0.0134*</td>
<td>-0.0112</td>
<td>-1.1142***</td>
<td>-0.0389</td>
<td>-0.0142**</td>
<td>-0.0091</td>
<td>-1.1313***</td>
<td>-0.0056</td>
</tr>
<tr>
<td>GDP</td>
<td>-0.1196***</td>
<td>0.0928***</td>
<td>-0.1126*</td>
<td>-0.2861*</td>
<td>-0.0663***</td>
<td>0.1028***</td>
<td>-0.1925***</td>
<td>-0.4185*</td>
</tr>
<tr>
<td>POP</td>
<td>-0.0693**</td>
<td>-0.0744**</td>
<td>-0.2701***</td>
<td>-0.0538</td>
<td>-0.0667**</td>
<td>-0.0796*</td>
<td>-0.3072***</td>
<td>-0.0322</td>
</tr>
<tr>
<td>IS</td>
<td>0.0059**</td>
<td>0.0082**</td>
<td>0.0037</td>
<td>-0.0017</td>
<td>0.0028*</td>
<td>0.0040*</td>
<td>0.0006</td>
<td>-0.0051</td>
</tr>
<tr>
<td>UR</td>
<td>0.0030*</td>
<td>-0.0091*</td>
<td>0.0038</td>
<td>0.0342*</td>
<td>0.0061*</td>
<td>-0.0025**</td>
<td>-0.0005</td>
<td>0.0333*</td>
</tr>
<tr>
<td>WATER</td>
<td>0.0048</td>
<td>-0.0122</td>
<td>0.0367</td>
<td>-0.0825***</td>
<td>0.0061</td>
<td>-0.0034</td>
<td>0.0456</td>
<td>-0.0025**</td>
</tr>
<tr>
<td>RD</td>
<td>0.0024</td>
<td>0.0270</td>
<td>-0.0112</td>
<td>-0.0366</td>
<td>0.0028</td>
<td>0.0204</td>
<td>-0.0088</td>
<td>-0.0251</td>
</tr>
<tr>
<td>ET</td>
<td>0.0007</td>
<td>0.0009</td>
<td>0.0011</td>
<td>0.0005</td>
<td>0.0003</td>
<td>0.0007</td>
<td>0.0009</td>
<td>0.0001</td>
</tr>
<tr>
<td>Cons</td>
<td>1.2317***</td>
<td>1.3766***</td>
<td>-0.7816</td>
<td>3.6181**</td>
<td>1.3233***</td>
<td>1.4337***</td>
<td>1.0575**</td>
<td>5.3059**</td>
</tr>
<tr>
<td>LR test</td>
<td>P = 0.000</td>
<td>P = 0.000</td>
<td>P = 0.000</td>
<td>P = 0.000</td>
<td>P = 0.000</td>
<td>P = 0.000</td>
<td>P = 0.000</td>
<td>P = 0.000</td>
</tr>
<tr>
<td>Sample</td>
<td>528</td>
<td>374</td>
<td>33</td>
<td>121</td>
<td>528</td>
<td>374</td>
<td>33</td>
<td>121</td>
</tr>
</tbody>
</table>
4. Discussion

Our study found that: First, the green water use efficiency of the YRB has not reached the optimal frontier, which is consistent with Gao’s research (2020), indicating that it is necessary to explore the path to improve green water efficiency. From the perspective of time trends, it shows a trend of first falling, then rising and then falling, which is consistent with Yue’s (2021) research. The reason is that the pressure of the global economic crisis in 2008 caused the central and local governments to invest a large amount of bailout funds in infrastructure and heavy chemical industries. This seriously distorted allocation of resources caused the water efficiency of the river basin to decline year by year until it bottomed out in 2011; 2011 was the beginning of "The Yellow River Basin Water Conservancy Development Plan in the Twelfth Five-Year Plan", and the start of the project played a central role in promoting the economic development, ecological management and water resource protection of the YRB. However, with the transfer of polluting industries, the speed and structure of industrial development in the river basin do not match the use of water resources, resulting in an unsustainable upward trend. Zoning result shows that green water use efficiency in arid areas are improving and humid area is falling. The reason for these results is that there are few water resources in semiarid and arid areas, and so local governments will focus on cultivating residents’ awareness of saving water and strengthening public water saving actions (Wang et al., 2019). At the same time, with the construction of the hydropower base on the upper reaches of the Yellow River and the implementation of the South-to-North Water Diversion Project, the water use efficiency in the semi-arid and arid areas has been continuously improved. However, most cities included in the semi-humid area have relatively extensive economic development methods, and the large population of this area causes large domestic water consumption. Therefore, the improvement of green water use efficiency is restricted to a certain extent in the semihumid area (Ren et al., 2020).

Second, based on GML decomposition and inefficiency decomposition of green water use efficiency, the urban positioning and improvement paths of different ecological regions are analyzed. Cities in the semihumid area are positioned as technology driven. Efforts should be made to improve the technical level of the city in the region, coordinate the proportional relationship of input elements, and replace the redundancy of capital and labor input with technology. At the same time, technology should be relied on to improve wastewater discharge, carry out clean production and increase recycling. Zhu et al. (2022) also proposed that technological progress in the urban agglomeration in the YRB is the leading factor in improving water use efficiency, but they did not subdivide the research into eco-geographical divisions. Cities in the semiarid area are positioned as resource-dependent. The redundant input of urban resources in the region is the main reason for inefficiency. Regional energy consumption is too large, so the focus of future transformation is resource conservation. This area can rely on foreign investment to play the technological spillover effect and rely on resource advantages to deploy green industries to improve water resource utilization efficiency. Cities in the arid area are positioned as economically contracting. The key direction of the improvement path is to expand regional economic benefits. Ren et al. (2016) and Ma et al. (2021) also believed that economic
output is important for water efficiency, but in fact, not all cities should focus on expanding economic benefits. This study concludes that the reason why arid areas need to increase economic benefits is that, cities in arid area lack of pillar industries and the large outflow of population have led to poor economic development. Cities in this area are possible to increase the added value of water resource utilization through an introduction of talent, an increase in infrastructure construction, a higher level of innovation, and a diversification of the industrial layout.

Third, according to the external influencing factors, the current technical spillover effect of FDI on river basin water resource utilization is stronger than the pollution paradise effect, indicating that expanding the scale of foreign investment and improving the quality of foreign investment have a positive effect on resource utilization. Although there is little literature on FDI promoting water efficiency, FDI can significantly lead to technological innovation spillovers that can have a positive impact on the environment. (Ye et al., 2018; Zhang et al., 2019). The subhumid area has a sound economic foundation and focuses on economic green development. Therefore, economic improvement will drive the improvement of water use efficiency. However, the economy in the arid area is relatively backward, and the economic development model focusing on growth is contrary to the conservation of resource utilization, which has a negative impact on water use efficiency. The conclusion that the level of economic development is negatively correlated with green water efficiency is inconsistency with the research of Yue et al. (2021) and Ren et al. (2020), The possible reason is that the level of economic development generally has a nonlinear relationship with resource utilization, and regions with different levels of development are not necessarily on the same side of the U-shaped curve. (Ma&Yan, 2016) Population density has the obvious inhibitory effect on green water use efficiency, which is as same as Gao’s research (2020). Actually, YRB has a large population but poor water resources, which makes the population density negatively affect water use efficiency. The conclusion that industrial structure is positively related to green water use efficiency is consistent with the research of Wang et al. (2017). However, the industrial structure only affects the subhumid area. That is because compared with the arid area, the subhumid area has a good economic development foundation, innovation and the accumulation of human resources, which promotes the optimization and upgrading of the industrial structure and promotes water use efficiency. Urbanization can promote green water use efficiency in YRB (Yue et al., 2021) but have a negative effect in semihumid area (Ren et al., 2020). Urbanization is the foundation of industrialization. Most cities in the semihumid area have a good degree of industrialization. High water-consuming industries such as metallurgy and thermal power have increased water pollution emissions. The average water consumption in the semiarid area is large, and water waste is serious. Therefore, the endowment of water resources has an inhibitory effect on efficiency. We get the same correlation with Ma et al. (2021). The coefficient of technological innovation has a certain "Matthew effect" on efficiency, possibly because the innovation foundation is good in humid area, while innovation ability in arid area is insufficient. However, the coefficient is not significant, which may be because the current government funding support for scientific research is insufficient (Huang et al., 2021). The coefficient of environmental governance can promote water efficiency (Wang et al., 2020), but it does not significantly indicate that regional environmental
protection awareness and pollution treatment technologies need to be improved.

Based on the regional differences of influencing factors, an external improvement path is proposed: All cities in the YRB should accelerate the transformation of economic development models and increase environmental protection awareness and scientific research funding support. For the sub-humid area: (1) In addition to high-tech talent attraction policies, population inflows must be reasonably controlled. (2) Cities should continue to transform and upgrade the industrial structure, deploy high-tech industries and high-end green industries based on resource endowments, and release the dividends of industrial transformation. (3) The number of cities in the semihumid area is large, and the total water consumption far exceeds that of other areas. Preferential policies can be used to encourage residents to save water. For the semiarid area: (1) The economic development level and technological level are low, and relatively backward infrastructure construction is characteristic of the cities in this region. It is necessary to further increase investment promotion and opening up to the outside world and promote development with trade and foreign investment. (2) Compared with the arid area, the semiarid area has relatively more water resources and a smaller population. The improvement path is to change residents' water consumption habits, strengthen the cultivation of water-saving awareness, and increase the promotion of water-saving technology. The purpose is to increase the amount of water available and save water consumption to improve the green water use efficiency. For the arid area: (1) The relatively backward pressure of regional employment, infrastructure, and capital makes it difficult for cities to absorb foreign investment and introduce technology. Therefore, the arid area should increase investment in education, cultivate high-quality talent, and improve the level of regional scientific and technological innovation. (2) Cities in the arid area are in the early stages of urbanization. The problems of "urban diseases" at this stage have not yet been highlighted. This area must strive to coordinate the relationship between urbanization levels and resource utilization.

5. Conclusion and policy recommendations

This study uses DEA-SBM model, GML index decomposition and its kernel density curve, inefficiency source decomposition and Tobit model to explore the internal and external factors affecting urban green water efficiency in the Yellow River Basin, and draw meaningful conclusions.

First, the green water use efficiency fluctuated between 0.58-0.67 and showed a trend of improving in arid areas and falling in ones. From the GML point of view, the absolute difference in the green water efficiency of the cities in the Yellow River Basin is expanding. In terms of EC, the technical efficiency of the semiarid area has a convergence effect. In terms of TC, the gap in the arid area has been widening, and technology in the semihumid and semiarid areas is converging backward. Second, we conclude that wastewater and resource redundancy are the main factors that inhibit the improvement of regional green water efficiency. The labor, capital, and wastewater redundancy in the semihumid area are relatively high, the resource redundancy in the semiarid area is relatively high, and the economic output in the arid area is insufficient. Third,
there are significant differences in the external factors affecting green water use efficiency in different ecogeographical regions.

To improve green water use efficiency in the YRB and promote the coordinated development of efficiency in the whole region, we further analyzed the deep-seated reasons based on the results obtained and proposed an improvement path. According to the results and the improvement path, the following suggestions are made. First, on the basis of the actual conditions and typical characteristics of water resource development in various regions, a green water efficiency improvement strategy tailored to local conditions is implemented. The transformation direction of the semiarid area is resource conservation. The semihumid area should focus on replacing redundant inputs with technology and reducing pollution emissions, while the primary task of the arid area is economic development.

Second, there are large differences in the economic and social development of regional cities. The semihumid area should start from the perspectives of controlling population inflows, optimizing industrial structure, and implementing preferential policies. The promotion path of the semiarid area is to increase the attractiveness of foreign investment, strengthen the cultivation of water-saving awareness and promote water-saving technology. The arid area relies on improving the quality of human capital and coordinating the relationship between urbanization and resource conservation to boost water use efficiency.

Third, narrowing the regional gap is the primary task for achieving coordinated improvement in the utilization of green water resources in cities in the YRB. First, a collaborative innovation network is created to break down barriers to the flow of factors between regions. Then, the water requirements of various regions should be ordinated, water resource planning should be formulated rationally, and the spatial imbalance of efficiency should be alleviated. Finally, the water use structure should be adjusted based on regional comparative advantages and water resource endowments, water-poor areas should be benefited through pipe network water delivery and other projects, and the coordination of the overall water resource utilization of the YRB should be improved.

Our study is not without limitations. This paper focuses on the influencing factors of green water use efficiency. In fact, water resources have the characteristics of spatial overflow and are easily affected by neighboring areas. Therefore, by determining the spatial characteristics of water resources in each regional city, there is still room for further research. In future research, we can increase space exploration and explore the spatial correlation between influencing factors and urban green water efficiency in the YRB.

Acknowledgment

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Data Availability Statement

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Compliance with Ethical Standards

Competing interests: We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature of kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled Influencing factors and improvement paths of green water use efficiency in the Yellow River Basin: a new perspective based on ecogeographical division.

Ethical approval: The work does not involve any hazards, such as the use of animal or human subjects’ issue. There is no plagiarism in our research, any data, articles or theories of others.

Consent to participate: All of the authors of the paper have participated in certain substantive aspects of this study, and they are acknowledged or listed as contributors.

Consent to publish: The paper has not been and will not be submitted simultaneously to other journals. The paper is entirely original works conducted by us without copying or plagiarism issues. The information reported in the paper is accurate according to our best knowledge. A single study do not be split up into several parts to increase the quantity of submissions and submitted to various journals or to one journal over time. We consent to publish.

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