Research on water resources pricing model under the water resources-economic high-quality development coupling system: a case study of Hubei Province, China

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ABSTRACT

Achieving high-quality economic development under the new development pattern has become an inevitable requirement for China’s economic development. Correctly calculating the value of water resources and optimizing the price mechanism of water resources is one of the important guarantees for promoting the high-quality development of the regional economy. Based on this fact, this paper takes Hubei Province as an example to construct a coupling relationship model between water resources and economic high-quality development and to evaluate the coupling coordination between the two. And then, the fuzzy comprehensive evaluation model is used to evaluate the value of water resources in Hubei Province, and recalculate its water price. The results show that Hubei province now is a lagging development of water resources, and the current water price is far lower than assessed. The government should improve the mechanism of water price which should be driven by innovation to adjust the water use structure, finally achieve high-quality economic development of Hubei Province.

Key words: Coupling relationship, Fuzzy comprehensive evaluation, High-quality economic development, Hubei Province, Water resources value

HIGHLIGHTS

• High-quality economic development requires a correct assessment of the value of water resources.
• Optimizing water price mechanisms is one of the important guarantees for promoting high-quality regional economic development.
• Hubei Province is currently lagging in the development of water resources, and the current water price is much lower than the assessed water price.
• Governments can innovate to drive the restructuring of water use by appropriately raising water prices.

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1. INTRODUCTION

Since the reform and opening-up, China’s economic and social development conditions and trends have undergone great changes. After more than 30 years of rapid growth, the growth rate gradually slowed down. In the face of the transformation of basic social contradictions in China and the complex and changeable international environment, economic development particularly needs to promote economic growth from speed to quality at this stage. The government work report (Keqiang, 2018) clearly stated that achieving high-quality economic development is not only a new strategy for China’s economic development but also a development idea for a long period time in the future. High-quality economic development is an economic development policy based on the concept of sustainable development that conforms to China’s basic national conditions. It is an economic development that provides high-quality output for the whole society sustainably and equitably with high efficiency and efficiency (Research Group of Economic Research Institute of National Development and Reform Commission, 2019). As a basic resource for social and economic development, water resources have a mutual promotion effect with high-quality economic development. Speeding up the improvement of water resources-related laws and regulations, improving watershed management and ecological compensation system, promoting smart water conservancy construction, and establishing and improving water-saving policy systems are all the concrete manifestations of high-quality economic development policies in water resources management (Opinions of the State Council, 2021). These measures enable water resources to better adapt to high-quality economic development. Correctly accounting for the value of water resources and optimizing the price mechanism of water resources are the key links to establish and improve the water-saving policy system, which can largely promote the green and sustainable development of the economy and provide strong support for the high-quality development of the economy. On the one hand, the rapid development of the social economy puts forward new requirements for the demand and utilization of water resources. Based on correctly calculating the value of water resources, water price can coordinate the balance of water use, and promote the high-quality development of the economy through the improvement of the water price mechanism. On the other hand, value determines the price. Price is the monetary embodiment of value. A reasonable and perfect price mechanism can fully reflect the value of water resources. Generally speaking, water price includes resource water price, engineering water price, and environmental water price (Yan-ping & Jin, 2021). Resource water price represents the value of water resources and reflects the relative scarcity of water resources. The engineering water price reflects the cost and some profits of natural water resources transforming into usable water resources. Environmental water price is the cost of environmental damage caused by sewage, which is manifested in the cost of wastewater treatment. High-quality economic development requires paying attention to the scarcity of water resources, protecting the
ecological environment, and achieving green and sustainable development; at the same time, high-quality economic development involves the coordinated high-quality development of multiple industries such as the agricultural industry. Therefore, when calculating the value of water resources, it is necessary to comprehensively consider these factors to calculate a benchmark water price that accurately reflects the value of water resources.

China’s National Development and Reform Commission and other departments have also called for accelerating the establishment and improvement of price mechanisms conducive to stimulating the improvement of water supply quality and promoting water conservation to support high-quality economic development. Since the implementation of the strategy of promoting the rise of the central region, the economic and social development of the central region has made significant achievements and played an important supporting role in the national economic and social development. Hubei, as the representative and focus of high-quality development in the central region, needs to make greater efforts to improve economic quality and people’s livelihood in the post-epidemic era. However, China’s current water price is low, which cannot reflect the value of water resources and is not conducive to the implementation of a high-quality development strategy. Therefore, it is of great significance to judge the coupling relationship between water resource value and high-quality economic development and recalculate water price based on water resource value for high-quality economic development.

2. LITERATURE REVIEW

In 1987, the Prime Minister of Norway, Mrs Brundiland, and others in the ‘Our Common Future’ report put forward the ‘sustainable development’, clearly the development of economy and environmental protection and resources are inter-related causal relationship. To realize the sustainable utilization of water resources, scholars and research institutions in various countries have researched the aspects of water resources development and utilization, water resources protection, and water resources planning, and put the water resources system into the socio-economic–ecological environment system for unified examination. Noel & Howitt (1982) organically integrated the economic model and the hydrological model, providing a new direction for the study of sustainable utilization of water resources. Lefkoff & Gorelick (1990) established agricultural production function and long series optimization model and used mathematical methods to transmit information between economic and hydrological models. Faisal et al. (1997) introduced economic objectives in the study of groundwater, linking groundwater management with economy and enriching the content of groundwater management research. At present, the research on the relationship between water resources management and economic development mainly focuses on the integration of water resources and the mechanism of water resources. Hassan & Thurlow et al. (2015) used the general equilibrium model to analyze the impact of water resources policies on the optimal allocation of water resources, rural domestic water use, and economy under a given economic scenario because of the severe water resources situation in South Africa, and found that the reduction of water supply can make water resources transfer from high water-consuming agricultural products to low-use aquatic products. Maria & Xavier (2012) studied the advantages and disadvantages of different policies in water resources management in Catalonia, Spain, based on the CGE model from the perspective of water supply and demand. Wei et al. (2017) studied the social value of water resources for economic development in Australia from 1843 to 2011 and found that before the 1970s, the value of water resources was mainly reflected in the economic focus, and changed into environmental focus after the 1970s. Bromley et al. (2018) studied the institutional aspects of water resources management in developing countries, introducing the important role of water resources management in agricultural production and its impact on economic development. Rezaee et al. (2021), by developing a system dynamics model framework, combines economic, social, and environmental aspects, and uses the TOPSIS method to reallocate water resources in East Azerbaijan Province of Iran to adapt to the economic and environmental development of the region.
For China, the economic development under the new pattern should be high-quality development based on the concept of sustainable development in line with the actual situation of China’s development. At present, scholars’ evaluation of high-quality economic development mainly has two starting points (Xiao-ling et al., 2019). One is based on five development concepts, namely innovation, coordination, green, openness, and sharing (Yi-zhen et al. 2018a). The second is based on the basic contradiction of Chinese society, namely people’s needs for a better life and unbalanced and inadequate development. High-quality development is inseparable from the support of water resources. Both starting points consider the close relationship between high-quality economic development and water resources. In terms of theoretical research, Wen-lai (2021) puts forward the strategic choice of high-quality development of water conservancy from the perspective of intensive and safe utilization of water resources and expounds on the relationship between water resources and high-quality development. Xiao-dong & Bei (2019) put forward that in the high-quality development of the Yellow River Basin, water resources should be taken as the largest rigid constraint, and focus on solving the problem of water resources in the whole basin. Dong et al. (2021) focused on the Yangtze River Basin, expounded its existing problems in the price reform of water environment resources, and proposed to innovate the price mechanism of water environment resources to boost the high-quality development of the Yangtze River Basin. In empirical research, Jian-hua & Liang-chao (2020) used the Copulas function and grey correlation analysis to quantitatively evaluate the correlation between water resources utilization and high-quality development in the lower reaches of the Yellow River. The coupling relationship between water resources and high-quality development under the new pattern of economic development also marks the sustainable development of the regional economy. Taking Shaanxi Province as an example, Wang et al. (2021) studied the coordination relationship between the utilization of water resources and high-quality development by using the coupling coordination degree model and found that the utilization of water resources had an important impact on the high-quality development of the economy, and accordingly put forward suggestions to coordinate the relationship between the two. Dong-ling & Yue (2021) used the coupling coordination degree model to quantitatively calculate the water resources utilization efficiency and economic coordination degree in the Yellow River Basin and analyzed the coupling relationship between water resources and economic coordination degree.

The water price mechanism based on the value of water resources is an important part of high-quality economic development. The accurate evaluation of water resources value and the formulation of a reasonable price mechanism has a significant impact on the high-quality development of the regional economy. At present, there are three types of models for water resource pricing: the market-based model, the resource-based optimal allocation model, and the water price determination model based on comprehensive indicators (Yong-bin & Ya-juan, 2018). Taking Ohio as an example, Schneider & Whitlatch (1991) constructs the pricing model of water supply and demand and sets water prices based on the price elasticity coefficient of water demand. Nieswiadomy (1992) uses the marginal cost model and the price collection management model to calculate the water price and water price elasticity index in the eastern and northern regions of the United States. Taking Beijing as an example, Wen-lai (1998) calculated the price of water resources in Beijing by using the method of a fuzzy comprehensive evaluation and found that the calculated water price was in line with the actual situation. Yi-zhen et al. (2018b) improved the fuzzy mathematics model according to the actual situation of the region through the three aspects of water resources, water resources quality, and social and economic development, and evaluated and priced the water resources in Nanjing. Yong-bin & Ya-juan (2018) calculated the weight of each criterion layer and index by AHP and entropy weight method and studied the value and pricing of water resources in major cities of China. This model comprehensively incorporates various factors affecting the value of water resources into the water resources value model and comprehensively evaluates the value of water resources.
Reviewing previous studies, most scholars use the coupling method to study the relationship between water resources utilization efficiency and high-quality development. Part of them only expounds on the significance of water price mechanism for high-quality development from a macro perspective, and the research on the relationship between price mechanism and high-quality development is relatively lacking. Water pricing based on market mechanism and optimal allocation of resources have the defects of focusing on demand. Based on the water price model of comprehensive indicators, the demand and supply are considered simultaneously by using the method of fuzzy mathematics, which is highly dynamic and can relatively accurately evaluate the value of water resources and calculate the water price. However, there is no unified and complete index system, and there is no unified standard for determining the weight. Therefore, this paper takes Hubei Province as an example, calculates the value of water resources based on the perspective of high-quality development, fully considers the natural factors, socio-economic factors and environmental factors of water resources value, and constructs the index system of water resources value and high-quality economic development to construct the coupling coordination model of water resources and high-quality economic development, and analyzes the relationship between water resources value and high-quality economic development.

3. METHODS

3.1. Determination of weight by the entropy method

There are many methods of weight calculation, such as analytic hierarchy process, experience method, and so on, but these methods are too subjective. As an objective and comprehensive evaluation method, the entropy weight method can eliminate the influence of subjective factors and determine the weight by calculating the discrete degree of data, which can be more in line with the objective situation. Therefore, this paper uses the entropy method as the weight determination method, the specific calculation process is as follows:

First, the indicators are normalized.

Positive indicators:

\[ x_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \]  

(1)

Negative indicators:

\[ x_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \]  

(2)

For \( n \) samples, \( m \) indicators, then \( x_{ij} \) is the number of the \( j \) indicators for the \( i \) sample \((i = 1, \ldots, n; j = 1, \ldots, m)\).

For convenience, the normalized data \( x'_{ij} \) is still denoted as \( x_{ij} \).

Second, calculate the proportion of sample \( i \) under indicator \( j \) to that indicator

\[ p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, \quad i = 1, \ldots, n, \quad j = 1, \ldots, m \]  

(3)
Third, calculate the entropy of item $j$

$$e_j = -k \sum_{i=1}^{n} p_{ij} \ln (p_{ij}), \quad j = 1, \ldots, m$$  \hspace{1cm} (4)

where $k = 1/\ln (n) > 0$ meets the $e_j \geq 0$.

Fourth, calculate information entropy redundancy (difference)

$$d_j = 1 - e_j, \quad j = 1, \ldots, m$$  \hspace{1cm} (5)

Fifth, calculate the weight of each index

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j}, \quad j = 1, \ldots, m$$  \hspace{1cm} (6)

### 3.2. Coupling relationship model between water resources system and high-quality development

Coupling is initially used in the field of electronics, and its measurement standard coupling degree is used to measure the correlation between the two systems. This paper takes water resources and high-quality economic development as two systems and establishes a coupling model of water resources and high-quality economic development.

Firstly, the comprehensive evaluation function of the two systems is established according to the obtained data and indicators, reflecting the overall level:

$$f(x) = \sum_{i=1}^{n} w_{1i} \cdot x_i$$  \hspace{1cm} (7)

$$g(y) = \sum_{i=1}^{n} w_{2i} \cdot y_i$$  \hspace{1cm} (8)

where $w_{1i}$ and $w_{2i}$ are the weights of each index of water resources and high-quality economic development, respectively. $x_i$ and $y_i$ are the evaluation indexes of high-quality economic development. $f(x)$ is the comprehensive evaluation function of the water resources system. $g(y)$ is the comprehensive evaluation function of the high-quality economic development system. Then, the coupling model is constructed according to the comprehensive evaluation function of the water resources system and the high-quality economic development system:

$$C = 2 \frac{\sqrt{f(x) \cdot g(y)}}{f(x) + g(y)}$$ \hspace{1cm} (9)

In this paper, only water resources system and high-quality economic development system are two systems, so the coefficient is 2, $C$ is the coupling degree of water resources and high-quality economic development, and $0 \leq C \leq 1$. The coordination of the two systems is expressed by $D$. The formula is

$$D = \sqrt{C \cdot T}$$  \hspace{1cm} (10)

$$T = \alpha f(x) + \beta g(y)$$  \hspace{1cm} (11)
where \( C \) is the coupling degree between the two systems. \( D \) is for coupling coordination. \( T \) is the comprehensive evaluation function of the high-quality development level of water resources and economy, and \( \alpha \) and \( \beta \) are the weights to be determined. Since the two systems are equally important, they are both 0.5. According to the above formula, the coupling and coordinated development of water resources and high-quality economic development can be obtained. In order to facilitate comparison, according to the relevant literature research, this paper divides the coupling coordination degree into five levels: serious imbalance, low coordination, moderate coordination, high coordination, and extreme coordination, and analyzes the lag under the comparison of the two evaluation functions.

### 3.3. Water resources valuation and price model

The water resources system is a complex, multi-factor-affected compliance system. Influencing factors of this system mainly include quantity and quality of water resources and socio-economic factors.

The expression of the water resources value model is

\[
WLJ = f(X_1, X_2, \ldots, X_n)
\]

(12)

where \( WLJ \) is the value of water resources, and \( X_1, X_2, \ldots, X_n \) is various influencing factors, such as water resources amount, per capita available water resources, average rainfall, and water production modulus. The model will be embodied as below.

Assuming domain \( N \) is the value factor of water resources, the expression is

\[
N = \{X_1, X_2, \ldots, X_n\}
\]

(13)

The expression of evaluation vector \( M \) is

\[
M = [\text{High} \quad \text{Relatively High} \quad \text{Common} \quad \text{Relatively Low} \quad \text{Low}]
\]

(14)

The fuzzy comprehensive evaluation model of water resources value is

\[
V = A \cdot R
\]

(15)

Among them, \( V \) is the fuzzy comprehensive evaluation matrix of water resources value. \( A \) is the weight vector of a fuzzy comprehensive evaluation of water resources value. \( \cdot \) is the composite operation symbol of the fuzzy matrix, and the weighted average operator is needed in the fuzzy comprehensive evaluation of water resources value. \( R \) is a composite matrix composed of a single factor evaluation matrix \( X_1, X_2, \ldots, X_n \).

\[
R = \begin{bmatrix}
    r_{1,1} & \cdots & r_{1,5} \\
    \vdots & \ddots & \vdots \\
    r_{i,1} & \cdots & r_{i,5}
\end{bmatrix}
\]

(16)

Among them, \( r_{ij} (i = 1, 2, \ldots, 16; j = 1, 2, \ldots, 5) \) is the \( j \)-level evaluation of the \( i \)-th element. In this paper, the ascending (descending) semi-step distribution is used to construct a linear membership function to determine \( r_{ij} \). The membership function expression is:
When $j = 1$,

$$r_{ij}(x) = \begin{cases} 
1, & x \leq x_{i1} \\
\frac{x - x_{i1}}{x_{i1} - x_{i2}}, & x_{i1} < x < x_{i2} \\
0, & x \geq x_{i2}
\end{cases} \quad (17)$$

When $j = 2, 3, 4$,

$$r_{ij}(x) = \begin{cases} 
\frac{x - x_{ij-1}}{x_{i1} - x_{i2}}, & x_{ij-1} \leq x \leq x_{ij} \\
\frac{x - x_{ij+1}}{x_{i,j+1} - x_{ij}}, & x_{ij} < x < x_{ij+1} \\
0, & x \leq x_{ij-1}, x \geq x_{ij+1}
\end{cases} \quad (18)$$

When $j = 5$,

$$r_{ij}(x) = \begin{cases} 
1, & x \geq x_{i5} \\
\frac{x - x_{i4}}{x_{i5} - x_{i4}}, & x_{i4} < x < x_{i5} \\
0, & x \leq x_{i4}
\end{cases} \quad (19)$$

In the formula, $x$ is the value of evaluation factors. $i$ is the number of evaluation factors. $j = 2, 3, \ldots, 5$ is the set level 5 evaluation criteria. $x_{ij}$ and $x_{i,j+1}$ are grade values adjacent to the evaluation factors, respectively. $r_{ij}(x)$ is the membership of evaluation factor $i$.

According to the water resources value model, the above evaluation result $V$ is a dimensionless vector. Since the fuzzy comprehensive evaluation result is a sequence and does not have continuity, we introduce the fuzzy comprehensive index of water resources value. The value of water resources is divided into five levels, representing different value levels, constructing vector $T$.

$$H = [1 \ 2 \ 3 \ 4 \ 5] \quad (20)$$

Then, we can calculate the fuzzy comprehensive index of water resources value $W$

$$W = V \cdot H \quad (21)$$

Among them, $T$ is the water resources value grade vector. $W$ is the fuzzy comprehensive index of water resources value. $V$ is water resources value fuzzy comprehensive evaluation results. Formula $WLJ = V \cdot S'$ is used to calculate the water price, $S'$ is the transpose of the vector of water resources price, which is determined by the residents' water price bearing index method.

In general, water price includes water resource value, water resource fee, sewage treatment fee, and reasonable cost and profit of water supply enterprises. The reasonable water price should be less than the residents’
maximum water cost index, and the calculation formula is:

$$P = \frac{BE}{K} - L - F - G$$  \hspace{1cm} (22)

where $P$ is the highest upper limit of water resource value, $B$ is the water rate affordability index, $K$ is the annual per capita water consumption, $E$ is the per capita disposable income, $L$ is the reasonable water supply cost and normal profit, $F$ is the sewage treatment fee, and $G$ is the tax fee. Using the method of the equal interval, the maximum upper limit of water resources value is divided into equal intervals, and the water resources price vector $S$ is obtained. The calculation formula is:

$$S = [P, 0.75P, 0.50P, 0.25P, 0]$$  \hspace{1cm} (23)

4. CASE ANALYSIS

Hubei Province is located in the central region of China, belonging to the Yangtze River system, surrounded by mountains on three sides, opening south, slightly incomplete basin. It belongs to subtropical monsoon humid climate, and a few alpine regions have an alpine climate. Generally speaking, there is abundant precipitation and the rain and heat are simultaneous. The average annual precipitation is 800–1,600 mm, decreasing from south to north. Precipitation distribution has obvious seasonal variation, generally the most in summer and the least in winter. In 2019, the total amount of water resources in the province was 61.370 billion cubic meters, which was 40.8% lower than that in 2018, and the total amount of water resources fluctuated greatly, which also led to the obvious impact of water resources on the high-quality economic development of Hubei Province. Therefore, it is particularly important to build a reasonable water price mechanism based on scientific water resources value assessment (Figure 1).

4.1. Selection of the evaluation index

4.1.1. Water resources system evaluation indicators

When selecting the evaluation index of water resources value, it is necessary to consider the uniqueness of water resources itself to ensure that the index can be representative and feasible. Referring to Davies & Simonovic (2011), De-zhi & Rui-cai (2015), Yu & Hui-ming (2018), Qi (2019), and Shu-ying (2020), and comprehensively considering the current situation of water resources in Hubei Province, this paper constructs an evaluation index system from the perspectives of natural factors, social and economic factors, and ecological environment factors that affect the value of water resources from the perspective of high-quality development.

1. Natural factors. Water resources amount can most intuitively reflect the amount of water resources, which has an important impact on the accounting of water resources value. At the same time, many natural factors such as precipitation and inflow are also influencing factors of water resources value. Therefore, this paper selects the indicators of total water resources, per capita water resources, average precipitation, water production modulus, water production coefficient, runoff coefficient, and inflow coefficient on the related indicators of natural factors to comprehensively reflect the impact of natural factors on water resources value.

2. Socio-economic factors. Among the social factors, population density is the most prominent, and the increase or decrease of the population will affect the use of water resources and other aspects. Since water resources play an important role in the process of economic and social development, economic development cannot be separated from the support of water resources, and the development of all walks of life cannot be separated...
from the water. From the perspective of high-quality development and economic factors, this chapter selects per capita GDP, per capita GDP water consumption, per capita water consumption, total water supply, water resources development and utilization rate, groundwater exploitation ratio, and water consumption ratio to reflect the influence of economic factors. When selecting specific indicators, it is necessary to take into account the uniqueness of the region and select different measurement indicators for the industrial structure and comprehensive location of different provinces. Considering that Hubei’s geographical location conditions enable its agriculture, industry, and so on to develop comprehensively, and these industries have a large demand for water resources, agricultural water consumption, industrial water consumption, ecological water consumption, domestic water consumption, effective utilization coefficient of farmland irrigation water and average water consumption per mu of farmland irrigation are also included in the index range.

3. Ecological environment factors. High-quality economic development needs to change the concept of development, and pay more attention to environmental factors such as water quality. In this paper, the water quality compliance rate, urban sewage treatment capacity, and per capita effective irrigation area of water function area under two factors are selected as the influence of environmental factors on the value of water resources.

To establish a relatively perfect index system, this paper selects 16 evaluation indexes to construct the evaluation system of water resources value in Hubei Province and uses the entropy method with strong objectivity to determine the weight of each index. The data are derived from the water resources bulletin of Hubei Province 2015–2019 and the statistical yearbook of Hubei Province. Each index and its actual data are listed in Table 1.

4.1.2. Economic system evaluation indicators

According to the research (Jiao et al. 2018), the evaluation system of high-quality economic development is constructed on the basis of the five development concepts. It is roughly divided into six aspects: the quality of
economic growth, the level of innovation and development, the level of coordinated development, the level of green development, the level of open development, and the level of shared development. According to the reality of Hubei Province, 12 indicators are selected to construct the evaluation system of high-quality economic development in Hubei Province. The entropy method with strong objectivity is used to determine the weight of each indicator. The indicators and their actual data are given in Table 2.

### Table 1 | Evaluation index and actual value of water resources value in Hubei Province.

<table>
<thead>
<tr>
<th>Evaluating index</th>
<th>Unit</th>
<th>Actual number</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical</strong></td>
<td></td>
<td>2015</td>
<td>2016</td>
</tr>
<tr>
<td>Water resources amount</td>
<td>$1 \times 10^8$ m$^3$</td>
<td>1,015.63</td>
<td>1,498</td>
</tr>
<tr>
<td>Per capita available water resources</td>
<td>m$^3$</td>
<td>1,740.9</td>
<td>2,552.6</td>
</tr>
<tr>
<td>Average rainfall</td>
<td>ml</td>
<td>1,177</td>
<td>1,423.4</td>
</tr>
<tr>
<td>Water production modulus</td>
<td>$1 \times 10^4$ m$^3$ km$^{-2}$</td>
<td>54.63</td>
<td>80.58</td>
</tr>
<tr>
<td>Runoff coefficient</td>
<td>–</td>
<td>0.838</td>
<td>1.0315</td>
</tr>
<tr>
<td><strong>Socioeconomic</strong></td>
<td></td>
<td>2015</td>
<td>2016</td>
</tr>
<tr>
<td>The average water consumption per ten thousand yuan GDP</td>
<td>m$^3$</td>
<td>102</td>
<td>87</td>
</tr>
<tr>
<td>Water consumption per capita</td>
<td>m$^3$</td>
<td>515</td>
<td>479</td>
</tr>
<tr>
<td>Total water supply</td>
<td>$1 \times 10^8$ m$^3$</td>
<td>301.27</td>
<td>281.97</td>
</tr>
<tr>
<td>Agriculture water consumption</td>
<td>$1 \times 10^8$ m$^3$</td>
<td>151.94</td>
<td>133.7</td>
</tr>
<tr>
<td>Industrial water consumption</td>
<td>$1 \times 10^8$ m$^3$</td>
<td>93.26</td>
<td>91.41</td>
</tr>
<tr>
<td>Domestic water consumption</td>
<td>$1 \times 10^8$ m$^3$</td>
<td>56.07</td>
<td>56.86</td>
</tr>
<tr>
<td><strong>Ecological environment</strong></td>
<td></td>
<td>2015</td>
<td>2016</td>
</tr>
<tr>
<td>Water resources utilization ratio</td>
<td>–</td>
<td>0.2966</td>
<td>0.1882</td>
</tr>
<tr>
<td>Proportion of groundwater utilization</td>
<td>–</td>
<td>0.0302</td>
<td>0.0313</td>
</tr>
<tr>
<td>Rate of water quality compliance</td>
<td>%</td>
<td>81.5</td>
<td>84</td>
</tr>
<tr>
<td>Daily municipal wastewater treatment capacity</td>
<td>$1 \times 10^4$ m$^3$</td>
<td>656</td>
<td>687.7</td>
</tr>
<tr>
<td>Ecological water consumption</td>
<td>$1 \times 10^8$ m$^3$</td>
<td>0.8</td>
<td>1.1</td>
</tr>
</tbody>
</table>

*Data source: The data are derived from the water resources bulletin of Hubei Province 2015–2019 and the statistical yearbook of Hubei Province.

4.2. Coupling results of water resources system and high-quality economic development system

According to the time series, the actual value of the evaluation index of Hubei Province from 2015 to 2019 is brought into the above coupling model, and the comprehensive evaluation function, coupling degree, and coupling coordination degree of water resources value and high-quality economic development in Hubei Province are obtained.
It can be seen from Figure 2 that from the perspective of time series, the comprehensive evaluation index of water resources and economy fluctuated tortuously, especially in 2016, which declined rapidly and then gradually increased, and the overall development was obviously and optimized. The degree of coupling has maintained a high level in 5 years, but the degree of coordination has suddenly declined from high coupling in 2015 to moderate coupling. Comparing the indicators of the two systems, it can be found that the rapid economic development is significantly higher than the support of the water resources system, and the low degree of coordination is caused by the lag of water resources. However, in the following 3 years, the government has adjusted the water price and put forward relevant policies for the green and coordinated development of economic development. Through these adjustments, it has continued to recover and reached extreme coordination by 2019.

Table 2 | Evaluation index and actual value of high-quality economic development in Hubei Province.

<table>
<thead>
<tr>
<th>Evaluating index</th>
<th>Unit</th>
<th>Actual number</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of economic growth</td>
<td>GDP growth rate</td>
<td>0.0696, 0.0927, 0.1116, 0.1255, 0.0883</td>
<td>0.0638</td>
</tr>
<tr>
<td></td>
<td>Economic vigor</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>54.8, 55.1, 55.5, 55.7, 54.6</td>
<td>0.0754</td>
</tr>
<tr>
<td>Innovative development level</td>
<td>Technical market contract turnover</td>
<td>Billion yuan</td>
<td>789.34, 903.84, 1,033.08, 1,204.09, 1,429.84</td>
</tr>
<tr>
<td></td>
<td>Enterprise R&amp;D expenditure intensity</td>
<td>–</td>
<td>0.0134, 0.0134, 0.0126, 0.0125, 0.0129</td>
</tr>
<tr>
<td>Coordinated development level</td>
<td>Proportion of added value of the tertiary industry to GDP</td>
<td>%</td>
<td>43.1, 43.94, 46.53, 47.6, 50</td>
</tr>
<tr>
<td></td>
<td>Urban-rural income ratio</td>
<td>–</td>
<td>2.2839, 2.3093, 2.3088, 2.3004, 2.294</td>
</tr>
<tr>
<td>Green development level</td>
<td>Industrial wastewater treatment</td>
<td>10,000 tons/day</td>
<td>1,052.22, 565.6, 624.78, 629.45, 640</td>
</tr>
<tr>
<td></td>
<td>Ten thousand yuan GDP wastewater discharge</td>
<td>Tons ten thousand yuan^{-1}</td>
<td>5.283, 6.1872, 7.5198, 8.9947, 10.5457</td>
</tr>
<tr>
<td>Level of open development</td>
<td>Total value of foreign trade import and export</td>
<td>Thousands of USD</td>
<td>45,552,580, 39,388,773, 46,337,190, 52,781,547, 57,160,602</td>
</tr>
<tr>
<td></td>
<td>Total investment of foreign-invested enterprises</td>
<td>Millions of dollars</td>
<td>89,231, 99,316, 115,103, 142,275, 186,438</td>
</tr>
<tr>
<td>Shared development level</td>
<td>Financial intensity of social security and employment</td>
<td>–</td>
<td>0.14, 0.1524, 0.1606, 0.1615, 0.159</td>
</tr>
<tr>
<td></td>
<td>General public service expenditure intensity</td>
<td>–</td>
<td>0.1008, 0.0996, 0.1013, 0.1018, 0.0998</td>
</tr>
</tbody>
</table>
water resources system can well match the rapid economic development. At this time, the water resources system has a positive impact on the high-quality development of the economy. In order to achieve the coordinated development of the two, the government should make policy adjustments according to the degree of coordination between the two to avoid the imbalance caused by the negative impact of the water resources system on the high-quality economic development.

Based on the calculated coupling coordination degree from 2015 to 2019 and according to the classification criteria, the coupling coordination types and development types of high-quality development of water resources and economy in Hubei Province from 2015 to 2019 are divided as follows:

From Table 3, it can be seen that the coupling coordination degree of the two systems was low in 2016 and 2017, when only the coordinated development of the economy was proposed, and the overall coordination degree of the water resources system and the high-quality development system of the economy was not high. Coupled with the abundant water resources in 2016 and 2017, the development types of the 2 years were economic lag. In 2018, the State Council put forward the requirements of high-quality economic development in the government work report. Hubei actively responds to the strategy of the Yangtze River Economic Belt, and constantly adjusts the industrial layout. The speed of economic development is fast, and the coordination between the two is gradually increasing. However, due to the rapid economic development, the performance of the water resources system is relatively lagging, which requires the government to take some policy responses. Because

**Table 3 | Types of coupling coordination between water resources and high-quality economic development.**

<table>
<thead>
<tr>
<th>Time</th>
<th>Coupling coordination D</th>
<th>( f(x) ) vs. ( g(y) )</th>
<th>Type of coupling coordination</th>
<th>Type of development</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>0.7434</td>
<td>( g(y) &gt; f(x) )</td>
<td>High coupling coordination type</td>
<td>Water resources lag</td>
</tr>
<tr>
<td>2016</td>
<td>0.5005</td>
<td>( g(y) &lt; f(x) )</td>
<td>Moderate coupling coordination type</td>
<td>Economic lag</td>
</tr>
<tr>
<td>2017</td>
<td>0.5978</td>
<td>( g(y) &lt; f(x) )</td>
<td>Moderate coupling coordination type</td>
<td>Economic lag</td>
</tr>
<tr>
<td>2018</td>
<td>0.7439</td>
<td>( g(y) &gt; f(x) )</td>
<td>High coupling coordination type</td>
<td>Water resources lag</td>
</tr>
<tr>
<td>2019</td>
<td>0.8789</td>
<td>( g(y) &gt; f(x) )</td>
<td>Extreme coupling coordination type</td>
<td>Water resources lag</td>
</tr>
</tbody>
</table>

**Fig. 2 | Comprehensive evaluation function, coupling degree, and coupling coordination degree of high quality development of water resources and economy.**
the value of water resources can be expressed through water price, it is necessary to evaluate the value of water resources accurately and establish a water price mechanism that matches it.

4.3. Fuzzy comprehensive evaluation of water resources value

In this paper, the evaluation criteria are divided into five levels: high, relatively high, common, relatively low, and low, and the standards of each evaluation index are determined based on the average of 31 provinces in China in 5 years and the actual situation of Hubei Province. The specific evaluation criteria are shown in Table 4.

According to the evaluation standard of water resources value in Hubei Province, combined with the actual data of each index in 2015–2019 and the membership calculation formula, the single factor membership matrix of each index in 2015–2019 is determined. Taking 2015 as an example, the single factor membership matrix is as follows:

$$R_{2015} = \begin{bmatrix}
   r_1 & 0 & 0.4609 & 0.5391 & 0 & 0 \\
   r_2 & 0 & 0 & 0.3259 & 0.6761 & 0 \\
   r_3 & 0 & 0 & 0.7433 & 0.2567 & 0 \\
   r_4 & 0.2685 & 0.7315 & 0 & 0 & 0 \\
   r_5 & 0 & 0 & 0 & 0 & 1 \\
   r_6 & 1 & 0 & 0 & 0 & 0 \\
   r_7 & 0 & 0 & 0 & 1.5000 & 0.8500 & 0 \\
   r_8 & 0 & 0.9873 & 0.0127 & 0 & 0 \\
   r_9 & 0 & 0.7985 & 0.2015 & 0 & 0 \\
   r_{10} & 0.1630 & 0.8370 & 0 & 0 & 0 \\
   r_{11} & 0.6070 & 0.3950 & 0 & 0 & 0 \\
   r_{12} & 0 & 0 & 0 & 0.4663 & 0.5367 \\
   r_{13} & 0 & 0 & 0 & 0 & 1 \\
   r_{14} & 0.0750 & 0.9250 & 0 & 0 & 0 \\
   r_{15} & 0 & 0.5600 & 0.4400 & 0 & 0 \\
   r_{16} & 0 & 0 & 0 & 0 & 1
\end{bmatrix}$$

The results of fuzzy comprehensive evaluation of water resources in Hubei Province from 2015 to 2019 are as follows:

$$V_{2015} = A \cdot R_{2015} = \begin{bmatrix}
   0.1345 & 0.3751 & 0.1541 & 0.1355 & 0.2009 \\
   0.1381 & 0.2961 & 0.1324 & 0.1548 & 0.2785 \\
   0.1409 & 0.3412 & 0.1234 & 0.1583 & 0.2362 \\
   0.1772 & 0.3812 & 0.1356 & 0.1605 & 0.1455 \\
   0.3123 & 0.3678 & 0.1132 & 0.0867 & 0.1199
\end{bmatrix}$$

The fuzzy evaluation index of water resources from 2015 to 2019 is:

$$W_{2015} = 2.8932, \quad W_{2016} = 3.1396, \quad W_{2017} = 3.0078, \quad W_{2018} = 2.7159, \quad W_{2019} = 2.3341$$

The closer the value of $W$ is to 5, the greater the value of water resources. Through the calculation results, it is found that the fuzzy evaluation index of water resources has decreased year by year since 2016, but it has remained at a relatively high level. Combined with the current situation of social and economic development in Hubei Province, it can be found that this is the index decline caused by the improvement of water resources efficiency brought about by scientific and technological progress.
4.4. Calculation of water resources price

The corresponding price of water resources needs to be obtained by formula $\text{WLJ} = V \cdot S'$, where $\text{WLJ}$ is the value of water resources and $S'$ is the price vector of water resources.

According to the study of the World Bank, the residents’ water affordability index is generally in the range of 3–5% (Chica-Olmo et al., 2013). As a reasonable indicator of developing countries, this paper comprehensively considers the impact of the reality of Hubei Province and the change of water price on the residents’ water psychology and affordability. Ring choose 1.5% as residents’ water affordability index. Referring to the study of urban water supply cost and water price, taking into account the special situation of Hubei Province, the average value of the three-level water supply price in Hubei Province is calculated by 68% (Yi-zhen et al., 2018b). The upper limit of water resources price is calculated as shown in Table 5.

From this, the price vector of water resources in Hubei Province from 2015 to 2019 is obtained:

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{2015}'$</td>
<td>$\begin{bmatrix} 4.7534 \ 5.7389 \ 6.1717 \ 6.6450 \ 7.2341 \end{bmatrix}$</td>
<td>$\begin{bmatrix} 3.5650 \ 4.3041 \ 4.6287 \ 4.9838 \ 5.4256 \end{bmatrix}$</td>
<td>$\begin{bmatrix} 2.3767 \ 2.8694 \ 3.0858 \ 3.3225 \ 3.6170 \end{bmatrix}$</td>
<td>$\begin{bmatrix} 1.1883 \ 1.4347 \ 1.5429 \ 1.6613 \ 1.8085 \end{bmatrix}$</td>
<td>$\begin{bmatrix} 0 \ 0 \ 0 \ 0 \ 0 \end{bmatrix}$</td>
</tr>
</tbody>
</table>
Finally, according to the formula $WLJ = V \cdot S^0$, the water price of residents in Hubei Province from 2015 to 2019 is evaluated, and the actual water price of residents in Hubei Province and the water price of residents are calculated as follows:

It can be seen from Table 6 that the average residential water price ladder price has dropped by 10.09% from 2.28 yuan m$^{-3}$ in 2015 to 2.05 yuan m$^{-3}$ in 2016. This is because the Hubei Province ladder water price policy standards have been adjusted, in the water price ladder price accounting, Hubei Province, the first level of water coverage of 80% of household users monthly average water consumption adjustment. At the same time, with the development of the social economy, technological progress related to water supply in Hubei Province has led to a decline in water supply costs, resulting in a decline in water prices. Comparing the simulated water price calculated by the water resources price evaluation model with the actual water price in Hubei Province, it is found that the actual water price is much lower than the estimated water price, and the gap between it and the estimated water price is expanding year by year. This is because Hubei Province only considers the water end when adjusting the water price, and ignores the value of water resources, which is not conducive to the sustainable development of the economy and the awareness of water-saving. At the same time, for Hubei Province, the water price has remained unchanged from 2016 to 2019, while the per capita disposable income has increased, and the water expenditure as per capita disposable income has become smaller and smaller, so it is more necessary to adjust the water price.

### 5. CONCLUSIONS AND SUGGESTIONS

#### 5.1. Conclusion

Based on the coupling method, this paper analyzes the coupling relationship between water resources value and high-quality economic development in Hubei Province from 2015 to 2019 and calculates the value and price of water resources in Hubei Province from 2015 to 2019 by the fuzzy comprehensive evaluation method. The conclusions are as follows:

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Price ceiling of water resources for Hubei residents.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>Unit</td>
</tr>
<tr>
<td>Price cap</td>
<td>yuan·m$^{-3}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Results of water resources price assessment for Hubei residents.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>Unit</td>
</tr>
<tr>
<td>Average residential water price ladder price</td>
<td>yuan·m$^{-3}$</td>
</tr>
<tr>
<td>Annual per capita disposable income</td>
<td>yuan</td>
</tr>
<tr>
<td>Water expenditure as per capita disposable income</td>
<td>%</td>
</tr>
<tr>
<td>Annual water consumption per person</td>
<td>m$^3$</td>
</tr>
<tr>
<td>Cost and profit of water supply</td>
<td>yuan·m$^{-3}$</td>
</tr>
<tr>
<td>Taxes fee</td>
<td>yuan·m$^{-3}$</td>
</tr>
<tr>
<td>Sewage treatment fee</td>
<td>yuan·m$^{-3}$</td>
</tr>
<tr>
<td>Re-estimated water price of residents</td>
<td>yuan·m$^{-3}$</td>
</tr>
</tbody>
</table>
1. According to the coupling results, it is found that the coupling degree and coupling coordination degree between water resources and high-quality economic development in Hubei Province is generally on the rise. Due to the reduction of water prices in 2016, the coupling coordination degree has changed from high coupling in 2015 to moderate coupling, and then steadily from moderate coupling to extreme coupling. Due to prominent economic development and active corresponding national strategies, its economic form has gradually improved to a high-quality development model. However, with the increase of economic development speed, the carrying capacity of water resources on economic development is facing pressure. In 2017, the development type of Hubei Province changed from economic lag to water lag, which shows that the water resources system cannot effectively coordinate economic growth at this time and has a negative impact on economic development. Although Hubei Province is rich in water, due to its climate reasons, the spatial and temporal distribution of precipitation is uneven, and the water use efficiency is low. Therefore, it is necessary to improve the carrying capacity of water resources for economic development, improve the utilization efficiency of water resources, and take green development as an important aspect of economic development.

2. According to the water use situation in Hubei Province from 2015 to 2019, it is found that due to the decrease in water supply cost, the current water price has not been adjusted after a downward adjustment in 2016, but the calculated water price increases year by year and the water resource value in each year is far lower than the current price. Due to the implementation of ladder water price in Hubei Province, according to the average comparison of water consumption and water price at present, the water cost of residents is too low, and the proportion of GDP is small, which cannot reflect the role of water resources value in the economy, and is not conducive to the formation of social water-saving consciousness. Compared with the level of economic development, the current water price has great development space. Therefore, it is necessary to gradually improve the water price, form a green water price mechanism that matches the high-quality development, improve the policy system of high-quality development strategy, improve the awareness of water-saving and the utilization efficiency of water resources, and steadily promote the high-quality development of economy in Hubei Province.

5.2. Recommendation

In order to solve the problem of lagging development of water resources between the two systems, it is necessary to improve the carrying capacity of water resources for high-quality economic development in order to achieve high-quality sustainable development. Suggestions are as follows:

1. Implementing innovation-driven development. Hubei Province needs to actively adjust its industrial structure and increase R&D investment. In the case of lagging development of water resources, on the one hand, it is necessary to optimize the industrial structure and reduce the proportion of high water consumption industries. On the other hand, technological innovation should be strengthened to improve the utilization efficiency of water resources and realize the coordinated and high-quality development of the economy and water environment.

2. Optimizing water price mechanism. According to the fuzzy comprehensive evaluation results, the gap between the current water price and the estimated water price is too large. Hubei Province should appropriately increase the water price according to the actual situation of the province and improve the proportion of water price in per capita GDP, so as to improve the awareness of water-saving and adapt to the high-quality and rapid economic development trend. At the same time, differentiated price management should be implemented, and the water price should be meticulously managed. Different charging standards should be formulated according to the water demand conditions of different industries, and the water fee gap should
be widened by taking the required water quantity of the industry as the boundary to promote the adjustment of industrial structure and the high-quality development of the Hubei economy.

**ACKNOWLEDGEMENTS**

We would like to acknowledge the support of the National Social Science Fund Project (Grant No. 19FJYB029) and the Special Fund for Basic Research Funds in Central Universities (Grant No. B200207011). We also acknowledge the editors and reviewers for their valuable comments.

**DATA AVAILABILITY STATEMENT**

All relevant data are included in the paper or its Supplementary Information.

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Opinions of the State Council (2021). *Opinions on Promoting High Quality Development in the Central Region in the New Era*.


First received 9 August 2021; accepted in revised form 20 December 2021. Available online 21 January 2022.