Study on the Development and Utilization Model of Water Resources in Yihe River Basin

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Abstract. The problem of water resource shortage has made many countries in the world face severe challenges. The reasonable water resource development and utilization model has increasingly become the research focus of each country. In this study, the Yihe river basin is taken as the research area. Based on the current water utilization status from 2001 to 2016, the fuzzy comprehensive evaluation model is used. Selecting five evaluation factors, including urbanization rate, ecological environment water consumption rate, per capita water consumption, surface water supply ratio and groundwater supply ratio, to study the regional water resource development and utilization model. The results show that both Linyi city and Zibo city in the Yihe river basin are more suitable for the joint development model of surface water and groundwater.

1. Introduction
The development of national economy and society is increasingly dependent on water resources. Due to the shortage of water resources, economic development and production layout must adapt to water conditions [1]. 97.5% of the world's water resources are salty, fresh water including glaciers accounts for only 2.5%, among which the most accessible fresh water is only 0.3%, and the natural distribution is uneven [2]. Siamak Farrokhzadeh used the multi-objective optimization model to prove that if water resource management policies are not improved, at least one aspect of agriculture and environment will be in a state of tension [3]. M. Habibi Davijani used genetic algorithm (GA) and particle swarm optimization (PSO) to optimize the distribution of water in agriculture, industry and life, and found that economic and social benefits increased [4]. Peng Jing established a multi-objective dynamic water resource allocation model and found that the total satisfaction rate increased after optimization, thus achieving a dynamic balance in time and space of water resource allocation [5].

There are many factors that influence the total amount of water resources. In addition to the climatic factors under natural conditions, social and human factors also play a role. Yizhong Zhu found that urbanization level is a key factor affecting water resources carrying capacity [6]. Kaize Zhang used the improved coupled coordination model to find that social and spatial urbanization has a great obstacle to urbanization-water security system [7]. Wanbin Huang's research concluded that urbanization would bring negative effects on the underground hydrological situation, mainly including the reduction of infiltration by the impermeability of urban roads and the phenomenon of underground over-exploitation [8]. In addition, Mahdi Soleimani-Motlagh pointed out that both drought and over-exploitation would lead to a deficit in groundwater, and over-exploitation would lead to a higher
deficit to GDP ratio [9]. Mahdi Motagh mentioned that the over-extraction of groundwater causes a large amount of land subsidence, which reduces the water storage of underground aquifers [10]. Shengtong Di studied the land subsidence in Binzhou city, Shandong Province, and found that proper reduction of groundwater extraction could effectively prevent and control the land subsidence [11].

Adrian Morales-Torres concluded that decision support tools can provide advantages in terms of economy, energy conservation and environment [12]. Zijun Song found that the ratio of water supply and demand in Shandong province is still very low at present, which is very related to the basic situation of total water resources and population density in Shandong Province, and Shandong has to continue to intervene to alleviate the imbalance of water supply and demand in the future [13]. In view of the increasingly severe situation of water resources, in order to ensure the rational development and utilization of water resources, the development and utilization mode of water resources in the Yihe River basin of Shandong province will be studied, in order to put forward the best scheme which is more suitable for the local sustainable development.

2. Data Sources and Research Methods

2.1. Data Sources
The evaluation index system of this study mainly includes five evaluation factors, namely, urbanization rate, ecological environment water consumption rate, per capita water consumption, surface water supply ratio and groundwater supply ratio. The above evaluation indexes are based on the current situation of water resources development and utilization in Yihe River Basin from 2001 to 2016. Data are from Shandong Hydrology Bureau.

2.2. Research Methods
A fuzzy comprehensive evaluation model [14-17] was established. According to the basic principle of fuzzy comprehensive evaluation, two finite theoretical fields were set up, including the set \( U = \{ u_1, u_2, \ldots, u_n \} \) and comment set \( V = \{ v_1, v_2, \ldots, v_n \} \). Firstly, a single-factor evaluation was conducted on the evaluation factor \( u_i \), and then the membership degree \( R_{i1} \) function of the evaluation factor \( u_i \) on \( v_i \) was determined. The selection of evaluation criteria corresponds to the cost-type index of the smaller the better, which is opposite to the efficiency-based index of the larger the better [18]. In the membership function, "\( > \)" is opposite to "\( < \)", and "\( \geq \)" is opposite to "\( \leq \". The membership function [19,20] is as follows:

\[
\begin{align*}
    u_{v1}(x) &= \begin{cases} 
    1 & x < G_1 \\
    \frac{1}{G_1 - G_2}^{-} x - \frac{G_1}{G_1 - G_2} & 0 \leq x \leq G_2 \\
    0 & x \geq G_2
    \end{cases} \quad (1) \\
    u_{v2}(x) &= \begin{cases} 
    \frac{1}{G_2 - G_3}^{-} x - \frac{G_2}{G_2 - G_3} & x \leq G_2 \\
    1 & x = G_2 \\
    \frac{1}{G_2 - G_3}^{-} x - \frac{G_2}{G_2 - G_3} & G_2 \leq x < G_3
    \end{cases} \quad (2) \\
    u_{v3}(x) &= \begin{cases} 
    \frac{1}{G_3 - G_4}^{-} x - \frac{G_3}{G_3 - G_4} & x \leq G_3 \\
    1 & x = G_3 \\
    \frac{1}{G_3 - G_4}^{-} x - \frac{G_3}{G_3 - G_4} & G_3 \leq x < G_4
    \end{cases} \quad (3)
\end{align*}
\]
3. Case Analysis

3.1. Overview of the research area

Yihe River originates from the west of Yiyuan county in the south of Shandong province. It is 287 kilometers long in Shandong province and covers an area of 10,772 square kilometers. It flows through Linyi and Zibo cities. The upper reaches of the basin are hilly areas with sandy soil or loam soil. The lower reaches are plain and the soil is mostly loam. The basin has a temperate monsoon continental climate, with an average annual precipitation of over 800mm. Natural precipitation in the basin is the main supply of local runoff, and underground runoff is relatively small. The annual rainfall is mainly from May to October, and the flood season is mainly from July to September. Due to the uneven distribution of rainfall during the year, the flood season is prone to floods.

3.2. Model Establishment

Using fuzzy comprehensive evaluation method in Linyi and Zibo city in Yihe river basin development model for the accurate evaluation of water resources, establishing water resources quantitative evaluation index system, evaluation index system including urbanization rate, ecological environment water use ratio, per capita water consumption, the proportions of the surface water and groundwater water five evaluation factors. The above evaluation indexes are based on the current situation of water resources development and utilization in Yihe River Basin from 2001 to 2016. Statistical results of quantitative evaluation indicators of water resources are shown in Table 1.

Table 1. Statistical results of quantitative evaluation indexes of water resources in Linyi city and Zibo City, Yihe River Basin.

| Evaluation Index | urbanization rate(%) | environment water use ratio(%) | per capita water consumption (m³) | proportions of the surface water (%) | proportions of the groundwater water(%) |
|------------------|---------------------|-------------------------------|-----------------------------------|-------------------------------------|-------------------------------------|
| Linyi            | 53                  | 2                             | 45                                | 67                                  | 32                                  |
| Zibo             | 31                  | 5                             | 96                                | 15                                  | 57                                  |

Yihe river basin water resources development model can be divided into single development of groundwater(I), the development of groundwater (II), surface water and groundwater joint development (III) mainly, the development of surface water (IV) and the single development of surface water (V) five kinds of mode, put them as the comment set a water resources development pattern evaluation standard [21], as shown in Table 2.
Table 2. Evaluation criteria of water resources development model.

| Evaluation Index                              | I   | II  | III | IV  | V   |
|----------------------------------------------|-----|-----|-----|-----|-----|
| urbanization rate(%)                         | >70 | 50-70 | 35-50 | 20-35 | <20 |
| environment water use ratio(%)               | >4  | 3-4  | 2-3  | 1-2  | <1  |
| per capita water consumption(m^3)            | >250| 200-250 | 150-200 | 80-150 | <80 |
| proportions of the surface water (%)         | 100 | 80   | 60   | 40   | 20  |
| proportions of the groundwater water(%)      | 20  | 40   | 60   | 80   | 100 |

3.3. Results

3.3.1. Development and Utilization mode of water resources in Linyi City. According to the membership function, the evaluation set consisting of n evaluation factors constitutes the evaluation matrix $R_1$, which is as follows:

$$R_1 = \begin{bmatrix}
0 & 0.6111 & 0.3889 & 0 & 0 \\
0 & 0 & 0.5000 & 0.5000 & 0 \\
0 & 0 & 0 & 0 & 1 \\
0 & 0.3500 & 0.6500 & 0 & 0 \\
0.4000 & 0.6000 & 0 & 0 & 1
\end{bmatrix}$$

The modal operator [22] comparison method is adopted to determine the weight vector of the impact of each evaluation factor on the development and utilization of water resources in Linyi city. Scale structure consistency matrix to determine the importance of qualitative ordering, after the most important indicators and other indicators will be ordered qualitative one binary comparison (using the tone operators on the importance of relative membership degree in Table 3), be able to get a binary comparison matrix $C_1$, then use MATLAB to calculate the maximum eigenvalue lambda binary comparison matrix of $C_1$, the weight of its corresponding matrix eigenvector $A_1 = (a_1, a_2, ..., a_n)$, is the weight matrix vector of the desired value.

Table 3. Relation between mood operator and relative membership degree.

| Mood operator | Same | Marginal | Slight | Comparative | Clear | Full | Extraordinary | Most Extremes | Inapproachable |
|---------------|------|----------|--------|-------------|-------|-----|---------------|--------------|---------------|
| Relative membership degree | 1.000 | 0.818 | 0.667 | 0.538 | 0.429 | 0.250 | 0.176 | 0.111 | 0.053 | 0 |

$$C_1 = \begin{bmatrix}
1 & 0.6670 & 1.5 & 0.8180 & 0.8180 \\
1.5 & 1 & 0.5380 & 1 & 1 \\
0.6670 & 1.5857 & 1 & 1 & 1 \\
1.2225 & 1 & 1 & 1 & 0.5380 \\
1.2225 & 1 & 1 & 1.8587 & 1
\end{bmatrix}$$

The maximum eigenvalue $\lambda_1=5.1963$ and the maximum eigenvector $A_1 = (0.4146, 0.4264, 0.4724, 0.4007, 0.5125)$ are calculated.

The basic form of the fuzzy comprehensive evaluation mathematical model is $B = A_1 \ast R$, where $A = (a_1, a_2, ..., a_n)$ for n weight fuzzy comprehensive evaluation factors, $R$ for fuzzy comprehensive evaluation matrix, the calculation using main factors determine type $M$ ($\cap \lor$) principle of operation, can get the evaluation results in the water resources development and utilization mode of matrix $B_1 = (b_1, b_2, ..., b_m)$, is a synthetic operator, and the formula is as follows:

$$b_i = \max \{ (a_i \cap r_{ij}) \} \quad (i=1,2,\ldots,n, \quad j=1,2,\ldots,m) \quad (6)$$
In the process of fuzzy comprehensive evaluation results, the maximum membership principle is not adopted, but the model eigenvalue is used to determine the evaluation grade of regional water resources. This method not only emphasizes the decisive role of the maximum membership, but also considers the influence of other membership degrees on the evaluation results. The specific methods are as follows:

Firstly, the corresponding weight coefficient is assigned to m water resources development and utilization mode comments, and then the weight weight set formed by m weights is obtained: \( D = (d_1, d_2, \ldots, d_m) \), where the weight depends on the membership degree of each mode, namely:

\[
d_i = \frac{b_j^2}{\sum_{j=1}^{m} b_j^2} (j=1, 2, \ldots, m)
\] (7)

Then the characteristic value of the pattern is \( I = \sum_{i=1}^{m} d_i^* i \). If \( |I - i| < 0.5 \), then the final evaluation result is that the irrigated area belongs to the i comment.

According to the above formula, \( I = 3.118664984 \) and \( |I_1 - 3| < 0.5 \), then the final judgment result is that Linyi city belongs to the third comment, namely the joint development mode of groundwater surface water.

3.3.2. Validation of model results. Due to the complexity of water resources development and utilization in arid regions, it is easy to lead to deviation of correlation analysis results. Therefore, consistency [23] and randomness test are needed to test whether the weight matrix vector obtained is reasonable. The test formula is as follows:

\[
CR = \frac{CI}{RI}
\] (8)

\[
CI = \frac{\lambda_{\text{max}} - m}{m - 1}
\] (9)

Where, CR is the random consistency ratio of the judgment matrix; CI is the evaluation matrix consistency index; RI is the average random consistency index of the evaluation matrix (values obtained from a large number of experimental results are shown in Table 4). \( \lambda_{\text{max}} \) is the maximum eigenvalue; M is the order of the judgment matrix.

When CR < 0.10, the judgment matrix is considered to have satisfactory consistency, indicating that the weight distribution is reasonable; otherwise, the judgment matrix needs to be adjusted.

| m  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI | 0   | 0.58| 0.90| 1.12| 1.24| 1.32| 1.41| 1.45| 1.49|     |

After testing, CR_1 < 0.1, the evaluation matrix has satisfactory consistency.

3.3.3. Development and utilization mode of water resources in Zibo City. According to the membership function, the evaluation set consisting of n evaluation factors constitutes the evaluation matrix \( R_1 \), and the evaluation matrix \( R_2 \) is as follows:

\[
R_2 = \begin{bmatrix}
0 & 0 & 0.2667 & 0.7333 & 0 \\
1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0.4571 & 0.5429 \\
0 & 0 & 0 & 0 & 1 \\
0 & 0.1500 & 0.8500 & 0 & 0 
\end{bmatrix}
\]

The consistency scale matrix is constructed to determine the qualitative ranking of the importance of the indicators, and then the most important indicators of the qualitative ranking are binary compared
with other indicators one by one (using the relative membership relation of the modal operator to the importance in table 3). A binary comparison matrix $C_2$ can be obtained.

$$
C_2 = \begin{bmatrix}
1 & 0.667 & 1.5 & 0.818 & 0.818 \\
1.5 & 1 & 0.538 & 1 & 1 \\
0.667 & 1.8587 & 1 & 1 & 1 \\
1.2225 & 1 & 1 & 1.8587 & 1 \\
1.2225 & 1 & 1 & 0.538 & 1
\end{bmatrix}
$$

Maximum eigenvalue $\lambda_2=5.1963$, maximum eigenvector $A_2= (0.4146, 0.4264, 0.4724, 0.5125, 0.4007)$

The basic form of the fuzzy comprehensive evaluation mathematical model is $B = A_2 \circ R$. According to formula (6) (7), $I_2=3.425934259$ and $|I_2-3| < 0.5$, then the final evaluation result is that Zibo city belongs to the third comment, namely the groundwater surface water joint development model.

3.3.4 Validation of model results.

$$
CR = \frac{CI}{RI} \\
CI = \frac{\lambda_{max} - m}{m-1}
$$

After testing, $CR_2 < 0.1$, the evaluation matrix has satisfactory consistency.

4. Results and Discussion

4.1. Current water use in the region

The utilization rate of surface water development in Yihe River Basin is only 40%, and that of groundwater development is 44%. The utilization rate of comprehensive development of water resources in the basin is not high [24], indicating that there is great potential for rational utilization of water resources.

In the basin, there are industries with large water consumption and dense personnel in agriculture and industry, with large per capita cultivated land occupancy and low water resource occupancy. Therefore, it is extremely urgent to improve the utilization efficiency of local water resources.

4.2. Solutions and promotion

The improvement of water resource utilization efficiency depends on rational development and utilization. In terms of development, it is necessary to coordinate the utilization of surface water and groundwater. As studied by Haimin Shang, there is a good correlation between groundwater level and shallow ecological types, so that it can adapt to the development of economic structure without causing serious ecological and environmental problems [25]. In terms of utilization, efforts should be made to promote the popularization of water-saving industries, including high-efficiency water-saving irrigation agriculture.

China has a vast territory, complicated geological conditions, different types of water resources and different levels of economic development, so it is impossible to fully apply the development model of a certain basin. Just as Fi-John Chang pointed out the concept of "zonality", a sound water resource management should consider changes in time and space [26]. Under this idea, both domestic and foreign water resources development models suitable for the development of local natural society are put forward according to local conditions. Using the multi-layer fuzzy optimal selection method, Wenchuan Wang proposed that the best comprehensive benefit of water resources development and utilization measures in Tianjin should be sewage reuse measures, followed by south-to-North water diversion project and seawater desalination project [27]. Yuzhou Chen took Zhoushan Islands as the research area and found that island areas are more suitable for the AIU (All in Use) model of
comprehensive development and utilization for storage, exchange, adjustment and supply [28]. Xuelin Chen explored a flood resource development and utilization mode of diversion + flood diversion + engineering protection through the implementation of the comprehensive flood disaster management project in the Xitugou Basin, thus effectively controlling flood and desertification [29]. According to the balance of total water resources supply and demand, Si Lin established the monthly water supply optimization model and established a new watershed water resources development and utilization model of "on-site conversion of surface water and groundwater" in the coastal plain area of Cambodia [30]. All these will provide guidance for the improvement of water resource utilization efficiency and the economical utilization of fresh water resources in China and even in the world.

5. Conclusion
This study discusses the suitable and reasonable development and utilization of Yihe river basin water resources model, uses the fuzzy comprehensive evaluation model, choses 5 evaluation factors that is the urbanization rate, ecological environment water use ratio, per capita water consumption, the proportions of the surface water and groundwater water, the results show that Yihe basin of Linyi city and Zibo are more suitable for joint development of underground water resource utilization patterns.

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