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An Improved Fuzzy Analytic Hierarchy Process for the Allocation of Water Rights to Industries in Northeast China

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Abstract: To facilitate water management and efficient utilization of water resources, the allocation of water rights to individual industries must be underpinned by a rational and defensible process. This study aimed to develop an improved fuzzy analytic hierarchy process method of allocating water rights to different industries and focused on Qing'an County, northeast China as a case study. An evaluation index system for allocation of initial water rights was established, and incorporated physiographic, societal, economic, and ecological criteria. The system classifies four categories of second-level indices, 14 third-level indices, and 30 fourth-level indices. The order of priority of the evaluation index was determined and the total weight of initial water rights for different industries was calculated using the fuzzy analytic hierarchy process method. Results showed that the indices for the allocation of initial water rights ranked in descending order of their total weights coefficient were: (1) agricultural water rights: 0.9508; (2) residential water rights: 0.0240; (3) water rights for non-agricultural production: 0.0173; (4) environmental water rights: 0.0078. Agricultural water consumption accounted for the largest proportion of total water because the study area is a major grain production area. The study provides a theoretical basis for the allocation of water rights and water rights trading in northeast China.

Keywords: allocation of water rights to industries; fuzzy analytic hierarchy process; evaluation index system; fuzzy comprehensive evaluation method

1. Introduction

The rational allocation of water resources among industries plays an important role in promoting the coordinated development of the social economy. Although average yearly agricultural water consumption in China accounts for 70% of total water consumption, agriculture remains less state-of-the-art irrigations and full covered water conservancy infrastructure. The rapid acceleration of urbanization and industrialization has resulted in residential and industrial water needs being prioritized over those of agriculture and the environment. With the continuous year-by-year reduction in available water along with increases in water demand, a rational and defensible method of assigning water rights to individual industries is a priority. Therefore, there is value in conducting research related to developing relevant systems and mechanisms for the allocation of water rights to alleviate water shortages among different industries. The allocation of initial water rights to different industries is an important component of water rights trading and water management to achieve efficient use of water resources and to promote high agricultural yield through appropriate water diversion and distribution [1,2].

There have been many previous studies focusing on the allocation of initial water rights over the last 30 years. Early studies included research into water laws that were suitable for areas with different characteristics [3–5] and studies that defined water rights [6]. John [7] (2005) and Zhong [8] (2009) introduced the concept of the allocation of initial water rights based on equity and sustainability. Other studies proposed the allocation of water rights based on land area, funding, and priority of water resources utilization [9,10]. Walmsley [11] (1995) proposed two mechanisms for the allocation of water rights, with one based on a centralized mechanism and the other on a market-based mechanism. Jerson [12] (2002) proposed a water rights allocation model based on the opportunity cost of water for different users. Kreutzwiser [13] (2004) proposed a water permit system based on the priority of water use and a reasonable charge for water use to compensate for the shortcomings of the original agricultural management and water intake permit system. Marleen et al. [14] (2014) and Zachary [15] (2018) proposed a water rights allocation mechanism based on equitable apportionment that is better able to achieve a fairer apportionment of drought impacts among individual water users while meaningfully elevating the rights of future generations to water and increasing adaptive capacity. The Drought Water Rights Allocation Tool (DWRAT) and improved Python Water Rights Allocation Tool (PyWRAT) were developed for the allocation of water rights in drought conditions by linearizing nonlinear problems [16,17]. Zhong [8] (2009) proposed a multi-objective optimization model based on a genetic algorithm (GA) that can assist in the initial definition and allocation of water rights for different counties. Xiao [18] (2011) and Ge [19] (2017) proposed a method for allocating initial water rights at the provincial level which considers total water use and combines a dynamic projection pursuit technique with a self-adaptive chaotic optimization algorithm. Zhang et al. [20] (2020) developed an Interval-parameter Two-stage Stochastic Programming (ITSP) model for the allocation of water rights based on the conditional value-at-risk theory and Gini coefficient constraints and the assumption that optimized allocation of water rights can reduce the risk of inequitable localized water deficits. Wang et al. [21] (2018) and Zhang [22] (2013) proposed a hierarchical structural model for the allocation of water rights using the hierarchical analysis method, and investigated trades in water rights. However, despite these aforementioned studies, many shortcomings in the allocation of initial water rights remain. Current methods of allocating water rights across different industries do not sufficiently take into consideration population, irrigated agricultural area, and Gross Domestic Product (GDP). Many uncertainties continue to exist, such as the degree of annual population change, changes to the irrigated area due to soil erosion and yearly changes to GDP. In addition, the current system of allocating water rights to different industries does not take into account the market model and the concept of sustainable development as it does not consider policy fluctuations and interaction among multiple constraints. Finally, although methods proposed by previous studies such as an analytic hierarchy process, multi-objective genetic algorithms, and dynamic projection pursuit technique can solve the multi-objective and multi-level characteristics of the water rights allocation problem, each approach has both advantages and disadvantages. The advantages are the methods are more advanced, faster computing speed, and many complex factors are considered, whereas there's an important disadvantage is no individual method can completely address the uncertainty in the allocation process.

The analytic hierarchy process (AHP) was proposed by Saaty [23] in 1977 and is widely used in the calculation of weightings for an evaluation index system. AHP is a flexible and simple statistical method of multidimensional objective policy making and can transform qualitative indicators to quantitative indicators to address complex problems in a hierarchical and systematic way [24–27]. Some of the great advantages of the AHP include its ability to handle complex real-life problems and its ease of use [28]. Previous studies have demonstrated the potential and effectiveness of AHP when applied to a geographical information system (GIS) interface [29–31], ecological vulnerability assessment, evaluation of irrigation water quality, and the evaluation of agricultural water management in irrigation districts [32–34]. Other studies have suggested that AHP can solve complex problems of water allocation with multiple levels and objectives [21,22]. Nevertheless, previous studies that applied AHP highlighted deficiencies and limitations, including uncertainty and poor reliability of results of the original analytic hierarchy process in calculating the weights of evaluation indices; therefore, the potential remains for improvement of the AHP model for better allocation of initial water rights [35,36]. Accordingly, the present study improves the original analytic hierarchy process by combining the AHP model with fuzzy decision theory. The improved fuzzy analytic hierarchy process considers the hierarchy structure and the number of indicators, making the results more reasonable. Furthermore, the exponential scaling was adopted to convert the 1–9 scales and the membership function is fuzzified to obtain more accurate results [37]. This approach aims to develop a method that is easy to operate and that can solve the complex problem of allocating water rights considering multiple levels, multiple objectives, and multiple decisions.

The present study was conducted in Qing'an County of Northeast China and aimed to present an approach for allocating water rights in different industries in the county. The current study followed the approach of: (1) evaluation indices were screened and appropriate indices were identified by theoretical analysis and the Delphi method [38], following which the evaluation index system for allocation of water rights for different industries was established, and the hierarchical structure map was constructed; (2) by combining with fuzzy decision theory, the fuzzy assessment matrix was constructed and the consistency of the fuzzy assessment matrices were evaluated; (3) the total weight of each index in the index evaluation system for allocation of water rights to different industries was calculated through the improved fuzzy AHP method; (4) the priority order of the industries was evaluated and the comprehensive weight of each industry was obtained according to its position in the evaluation index; (5) the total available water rights in the county were allocated to agricultural, residential, non-agricultural production and environmental, and the results of water rights allocation to the different industries were obtained. The present study provides a theoretical basis for the allocation of water rights to industries and the establishment of a sustainable water resources management system in northeast China.

2. Materials and Methods

2.1. Study Area

Qing'an County is located in the middle of Heilongjiang Province, between latitude 46°30′–47°36′ N, longitude 127°14′–28°32′ E (Figure 1). The total area of the county is 5469 km^2, accounting for 15.53% and 1.16% of the total areas of the city and province, respectively. The region can be described as typically semi-arid and semi-humid, with obvious seasonal climate characteristics, long and cold winters, and short, warm and rainy summers. The average annual potential evaporation (measured with 20 cm evaporating dish) and average rainfall are 664.5 mm and 545.3 mm, respectively. The maximum depth of permafrost in this region is 1.8–2.1 m, and the region experiences freezing for approximately 6 months.

The county incorporates 14 townships and 93 administrative villages under its jurisdiction, with a population of 370,000, of which the population participating in agriculture is 306,000, accounting for 82.7% of the total population. The cultivated land area in the region accounts for 67.65% of the entire city, while the total water resources only account for 41.82%. Per capita water availability is only 1464 m^3, far below internationally recognized water needs and verging on what can be officially be defined as a water shortage. There are nine river flow networks in Qing'an County, seven of which have their headwaters within the territory. The total area of the basin is 5905 km^2, the average annual runoff is 2.33 billion km^3 and total groundwater resources are 2.532 billion km^3, including 542 million km^3 of distributable water resources. The utilization coefficient of irrigation water in Qing'an County is 0.47, far behind more advanced levels achieved globally of 0.7–0.8. Growing water shortages across the various industries have been experienced, exacerbated by the low water utilization efficiency and the high costs of water supply. The unsustainable use of groundwater is a serious problem with an evident decline in the groundwater level with concurrent groundwater pollution. The decline in the health of aquatic ecosystems has seen a reduction in ecosystem services, resulting in the water quality of water resources not satisfying basic water-use standards, which aggravates water shortages across different industries. On the other hand, the rapid increase in population and the development of the social economy has resulted in continual year-on-year increases in the utilization of water resources and increasing disparity between available water supply and demand for water in some areas of the region.

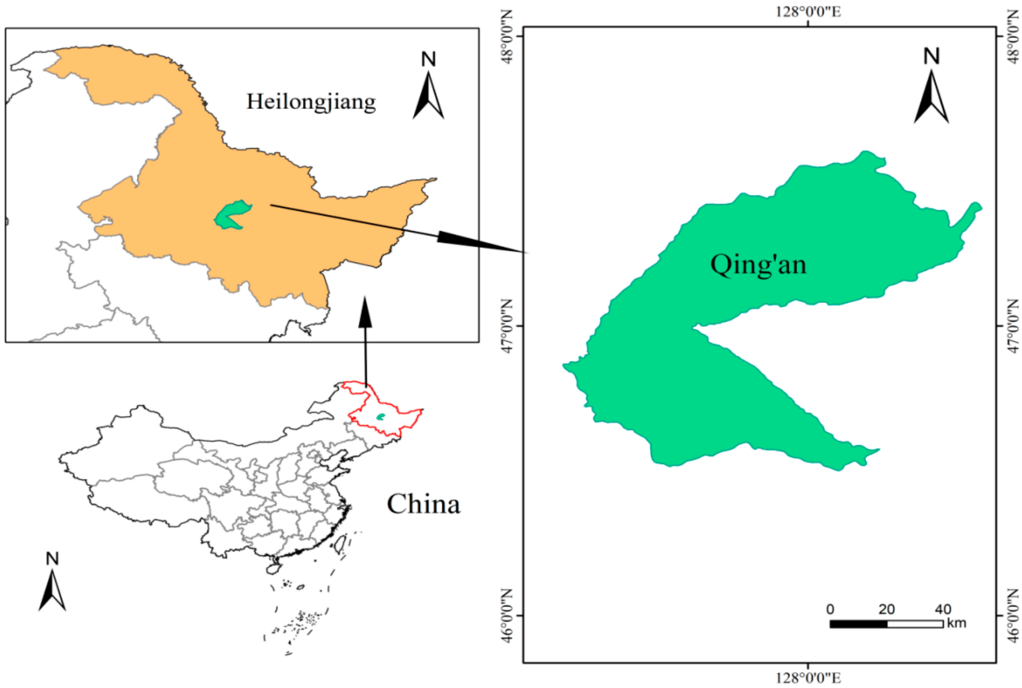

Figure 1. Study area.

In view of the aforementioned challenges in water resources management, the traditional method of allocating water resources can no longer be regarded as adequate to meet the needs for the long-term development of the region. Therefore, there is a need to revisit methods for the initial allocation of initial water rights to different industries as the basis of all water rights and trading of water rights. Qing'an County (Figure 1) was selected based on the importance of this region as a base of grain production in Heilongjiang Province, and because achieving productive agricultural development requires a stable supply of water resources. The attainment of the weighting of indices is a prerequisite for the allocation of initial water rights since these weightings have a decisive influence on the coordinated development of the regional population, society, economy, and environment. The allocation of initial water rights and confirmation of the priorities of allocation of water to different industries in this region remains in a preliminary stage. Thus, the county is one of the first counties in China to allocate and confirm water rights. Therefore, the experience of allocating water rights in Qing'an County is of great practical significance for other areas and can provide a theoretical basis for the establishment of a water resources management system.

2.2. Methods

2.2.1. The Establishment of the Index System

The Delphi technique was developed during the 1950s and has become a widely-used tool for measuring and aiding forecasting of the potential benefits of decision making in a variety of disciplines [38]. The present study adopted the Delphi method to construct an index system for the allocation of initial water rights to different industries, and the representativeness, relevance, independence, ease of quantification, simplicity, and practicability of the evaluation index should be taken into account. First, the levels of the index were constructed by comprehensively considering all relevant factors, which indices are relevant and avoiding repetition. Second, the index system was classified based on economic, social, and environmental characteristics of the study area, and the levels of various indicators were identified. Finally, the index level was expanded to achieve a complete and practical index system with a strong structure and high representativeness. The initial water rights allocation hierarchy consisting of objectives, criteria, evaluation, and index levels based on the Delphi survey results and theoretical analysis was constructed as shown in Figure 2. The hierarchy was classified according to four categories of second-grade indices, 14 third-grade indices, and 30 fourth-grade indices.

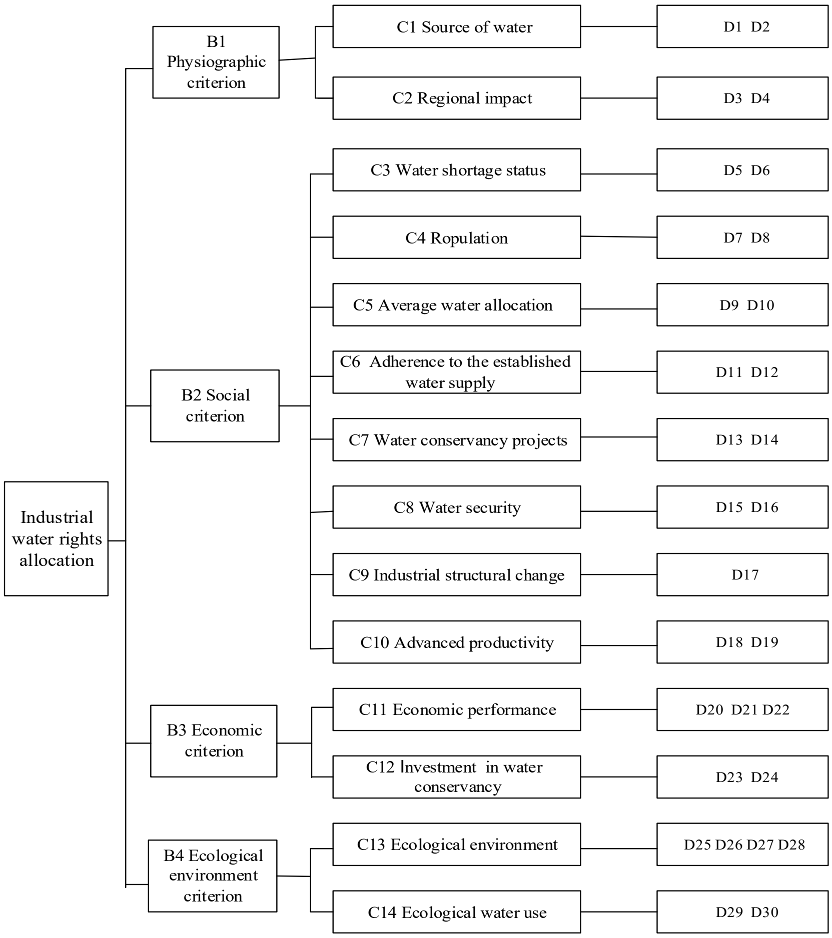

Figure 2. The hierarchy of initial water rights for different industries.

D1: Ratio of available water resources; D2: Water quality; D3: Distance index; D4: Superiority of geographical location; D5: Water quantity shortage; D6: Poor water quality; D7: Population growth rate; D8: Population density; D9: Per capita water allocation; D10: Irrigation quota; D11: Current water supply; D12: Agricultural facilities; D13: Water utilization efficiency; D14: Channel lining rate; D15: Agricultural water safety; D16: Degree of medical and health facilities; D17: Rate of industrial structure change; D18: Scientific and technological progress; D19: Water saving irrigation technology; D20: Ratio of income generated by water conservancy to total GDP; D21: Ratio of income generated by grain to total GDP; D22: Income of per-water production unit; D23: Investment dynamics; D24: Water price on cost; D25: Land salinization control; D26: River cut-off; D27: Artificial groundwater recharge; D28: Influence of permafrost; D29: Ratio of ecological water use to total water use; D30: Guaranteed rate of ecological water use.

2.2.2. Improved Fuzzy AHP Method

1. The original AHP

Once the hierarchy of the index system was established (Figure 2), the relative importance of the indices was determined within each level with respect to the related criteria in the adjacent higher level according to expert knowledge, which facilitated the paired comparison for each level of the index. The assessment matrix $E = (e_{ij})_{n \times n}$ was then constructed using the results of every evaluator's pair-wise comparison. e_{ij} is the relative importance of two indices to the above level, divided into 1–9 categories (Table 1).

$$E = \begin{Bmatrix} e_{11} & e_{12} & \cdots & e_{1n} \\ e_{21} & e_{22} & \cdots & e_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ e_{n1} & e_{n2} & \cdots & e_{nn} \end{Bmatrix} \tag{1}$$

Table 1. The scale and definition of the assessment matrix.

Distinguish Scale	**1**	**3**	**5**	**7**	**9**	**2, 4, 6, 8**
Definition	Equal importance	Weak importance	Obvious importance	Intensely importance	Extreme importance	Intermediate value

The square root method was used to calculate the maximum eigenvalue of the assessment matrix, with the formula as follows:

$$\lambda_{\max} = n\sum_{i=1} \frac{(EW)_i}{nW_i} \tag{2}$$

In Equation (2), W_i is the weight vector and $\lambda_{\max}$ is the maximum characteristic root value.

The eigenvector of the evaluation index was standardized and the final weight (w_i) vector was obtained [39]:

$$P_{si} = G_i^{(1/k)} \tag{3}$$

$$w_i = \left\{ \frac{p_{s1}}{\sum\limits_{i=1}^{m} P_{si}}, \frac{p_{s2}}{\sum\limits_{i=1}^{m} P_{si}}, \cdots \frac{p_{sm}}{\sum\limits_{i=1}^{m} P_{si}} \right\} \tag{4}$$

In Equations (3) and (4), P_{si} is the root value, $G_i = e_{i1} \times e_{i2} ... \times e_{in}$, $i = 1, 2, 3, ..., n$, K is the order of the assessment matrix and w_i is the final weight vector.

As the evaluation system is a complex and the choices made by experts are inevitably often one-sided and subjective, there might be an inconsistency between assessment matrices by different experts. Thus, the original method assesses the consistency of the assessment matrix by calculating the consistency ratio before the weight vector is calculated:

$$CR = \frac{CI}{RI} \tag{5}$$

In Equation (5), CI is the consistency index and RI is the average random consistency index.

When $CR < 0.1$, the assessment matrix can be considered to satisfy the consistency condition; otherwise, the matrix should be reconstructed and re-assessed to meet the consistency.

2. The improved fuzzy AHP.

During the process of constructing the assessment matrix using the original analytic hierarchy process, the assignment on the scale of "1–9" is relatively rough and a reversed order contrary to the actual situation may appear. Moreover, there is a conflict between the matrix consistency and logical consistency, resulting in an inability to accurately quantify the membership relationship between each index. It is considered that more accurate results can be obtained by using exponential scaling in conjunction with a great deal of practical experience. The exponential scaling is based on Weber's law in psychology and has many excellent properties which allowed the problems of "1–9" scaling to be overcome [24]. Therefore, the conversion between the two scales needs to be conducted before evaluating the priority (Table 2).

Table 2. Evaluation index scale conversion.

Priority	Priority Level (Membership Degree)					
	Absolute Priority	**Moderate Priority**	**Appropriate Priority**	**Properly Set Back**	**Set Back**	**Almost No Rights**
1~9 scale	9	7	5	4	2	1
exponential scale	q^9	q^7	q^5	q^3	q^1	q^0
0.1~1.0 scale	1.0	0.828	0.741	0.5	0.259	0.1

Note: q is 1.316 [40].

In the present study, the above method along with a fuzzy consistency matrix were used to assess the consistency of the fuzzy assessment matrix. Each row of the assessment matrix $E = (e_{ij})_{n\times n}$, marked as $m_i = \sum_{k=1}^{n} e_{ik}$ $(i = 1, 2, 3 \ldots n)$, $m_{ij} = \frac{m_i - m_j}{2(n-1)} + 0.5$ was summed, allowing the fuzzy consistency matrix $M = (m_{ij})_{n\times n}$ corresponding to the assessment matrix E to be obtained. For matrix E and matrix M, there are two test indicators:

$$\alpha = max\{\left|e_{ij} - m_{ij}\right| \} \tag{6}$$

$$\beta = \frac{\sqrt{\sum_{i=1}^{n}\left(e_{ij} - m_{ij}\right)\sum_{j=1}^{n}\left(e_{ij} - m_{ij}\right)}}{n} \tag{7}$$

a. When $\alpha < 0.2$ and $\beta < 0.1$, it can be considered that the fuzzy complementary matrix accords with reality. By normalizing the fuzzy consistency matrix, the weight vector W can be obtained.

b. When $\alpha \geq 0.2$ or $\beta \geq 0.1$, it is considered that the fuzzy complementary matrix does not accord with reality; therefore, it is necessary for experts to re-judge and recalculate according to the steps until the conditions are met.

2.2.3. Fuzzy Comprehensive Evaluation Method

The fuzzy comprehensive evaluation theory was adopted to address the uncertainty problems resulting from the quantification of the non-quantitative indices during the process of allocating initial water rights. The complex system is optimized and the membership function is fuzzified to eliminate the skipping phenomenon when the evaluation grade changes in a small range at the endpoint of an interval. The membership degree matrix R is calculated so that $r_i^{(t)}$ $(t = 1, 2, 3, 4, 5)$ is the membership degree of the tth grade. $x_{max}^{(t)}$ is the upper limit of the tth evaluation grade and $x_{min}^{(t)}$ is the lower limit of the tth evaluation grades. $\overline{x^{(t)}} = \frac{x_{max}^{(t)} + x_{min}^{(t)}}{2}$ is the average of the tth evaluation grade.

1. For indices in which bigger values indicate better outcomes:

When $r_i < x_{max}^{(1)}$:

$$r_i^{(1)} = 1, r_i^{(2)} = r_i^{(3)} = r_i^{(4)} = r_i^{(5)} = r_i^{(6)} = 0 \tag{8}$$

When $x_{min}^{(t)} < r_i \leq \overline{x^{(t)}}$:

$$\begin{cases} r_i^{(t-1)} = 0.5(1 - \frac{r_i - x_{min}^{(t)}}{\overline{x^{(t)}} - x_{min}^{(t)}}) \\ r_i^{(t)} = 0.5(1 + \frac{r_i - x_{min}^{(t)}}{\overline{x^{(t)}} - x_{min}^{(t)}}) \end{cases} \tag{9}$$

The membership degree of other grades is 0;

When $r_i = \overline{x^{(t)}}$ (i = 2, 3, 4, 5),

$$r_i^{(t)} = 1 \tag{10}$$

The membership degree of other grades is 0;

When $\overline{x^{(t)}} < r_i \leq x_{max}^{(t)}$,

$$\begin{cases} r_i^{(t)} = 0.5(1 + \frac{x_{max}^{(t)} - r_i}{x_{max}^{(t)} - \overline{x^{(t)}}}) \\ r_i^{(t+1)} = 0.5(1 - \frac{x_{max}^{(t)} - r_i}{x_{max}^{(t)} - \overline{x^{(t)}}}) \end{cases} \tag{11}$$

The membership degree of other grades is 0;

When $r_i > x_{min}^{(6)}$:

$$r_i^{(1)} = r_i^{(2)} = r_i^{(3)} = r_i^{(4)} = r_i^{(5)} = 0, r_i^{(6)} = 1 \tag{12}$$

2. For indices in which smaller values are better outcomes:

When $r_i > x_{min}^{(1)}$:

$$r_i^{(1)} = 1, r_i^{(2)} = r_i^{(3)} = r_i^{(4)} = r_i^{(5)} = r_i^{(6)} = 0 \tag{13}$$

When $x_{min}^{(t)} < r_i \leq \overline{x^{(t)}}$,

$$\begin{cases} r_i^{(t)} = 0.5(1 + \frac{r_i - x_{min}^{(t)}}{\overline{x^{(t)}} - x_{min}^{(t)}}) \\ r_i^{(t+1)} = 0.5(1 - \frac{r_i - x_{min}^{(t)}}{\overline{x^{(t)}} - x_{min}^{(t)}}) \end{cases} \tag{14}$$

The membership degree of other grades is 0;

When $r_i = \overline{x^{(t)}}$ (i = 2, 3, 4, 5),

$$r_i^{(t)} = 1 \tag{15}$$

The membership degree of other grades is 0;

When $\overline{x^{(t)}} < r_i \leq x_{max}^{(t)}$,

$$\begin{cases} r_i^{(t-1)} = 0.5(1 - \frac{x_{max}^{(t)} - r_i}{x_{max}^{(t)} - \overline{x^{(t)}}}) \\ r_i^{(t)} = 0.5(1 + \frac{x_{max}^{(t)} - r_i}{x_{max}^{(t)} - \overline{x^{(t)}}}) \end{cases} \tag{16}$$

The membership degree of other grades is 0;

When $r_i < x_{max}^{(6)}$:

$$r_i^{(1)} = r_i^{(2)} = r_i^{(3)} = r_i^{(4)} = r_i^{(5)} = 0, r_i^{(6)} = 1 \tag{17}$$

The membership matrix (R) is built according to the membership function of each index. Equations (8)–(17).

$$R = \begin{Bmatrix} r_{11}(x_1, 1) & r_{12}(x_1, 2) & \ldots & r_{1n}(x_1, n) \\ r_{21}(x_2, 1) & r_{22}(x_2, 2) & \ldots & r_{2n}(x_2, n) \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1}(x_n, 1) & r_{n2}(x_n, 2) & \ldots & r_{nn}(x_n, n) \end{Bmatrix} \tag{18}$$

Then the fuzzy synthesis matrix B would be calculated based on the weight w of each index by improved fuzzy AHP method.

$$B = w \times R \tag{19}$$

2.2.4. The Total Weight Coefficient of Initial Water Rights for Different Industries

1. The relative weight and priority of each index were determined in the objective, criteria, evaluation, and index levels before the total weight coefficient of each index was be calculated.

$$F_m = \sum B_i \times C_j \times D_k \tag{20}$$

In Equation (20), F_m is the total weight coefficient of the mth index, B_i (i = 1, 2, 3, 4) is the weight coefficient of the type i criterion, C_j (j = 1, 2, 3, ..., 14) is the weight coefficient of type j evaluation and D_k (k = 1, 2, 3, ..., 30) is the weight coefficient of the kth index.

2. The data of each grade was quantified by assigning a value between 0–1, following which the water rights weight coefficient of each industry was obtained according to the membership grade of each water industry, combined with the total weight coefficient of each index.

$$G_l = \frac{\sum_{m=1}^{30} F_m \times g_l}{\sum_{l=1}^{4} \sum_{m=1}^{30} F_m \times g_l} \tag{21}$$

In Equation (21), G_l (l = 1, 2, 3, 4) is the total weight coefficient of the lth industrial water rights and g_l is the membership grade of the l^{th} industrial water rights.

2.3. Data Collection

Data representing the society, economy, water resources utilization and water conservancy projects in the study area were sourced from the Heilongjiang Institute of Water Resources and Hydropower Research, the Qing'an County Water Conservancy Bureau, the Qing'an County Bureau of Statistics, irrigation district management units and other departments. The total available water rights would be affected by natural and artificial factors. For example, precipitation can result in fluctuations in available water resources, which may influence available water rights. In addition, the total of available water rights is limited by available water resources in the county, and artificial water resources management such as "three red lines" regulation may result in the reduction of total available water rights during planning periods (Appendix A Table A1).

In the present study, a total of 58 water conservancy experts participated in the evaluation of the allocation of initial water rights using a questionnaire survey. The 58 experts originated from Heilongjiang University, Heilongjiang Provincial Water Resources Department, the Heilongjiang Institute of Water Resources and Hydropower Research, the China Institute of Water Resources and Hydropower Research, irrigation district management units, rural water use associations, and other departments.

3. Results and Discussion

3.1. The Weightings of Initial Water Rights for Different Industries

3.1.1. The Establishment of the Fuzzy Assessment Matrix

Appendix B Tables A2–A4 show the results of the evaluation of the consistency of the assessment matrix as well as the calculation results for different levels. The assessment matrix for different evaluation levels met the criteria of $CR < 0.1$, $\alpha < 0.2$, and $\beta < 0.1$; therefore, this approach was appropriate for calculating the weight of each index for allocating initial water rights to different industries using the improved fuzzy AHP method.

3.1.2. The Weighting of the Evaluation Indices for Allocating Water Rights to Different Industries

Appendix C Table A5 and Figure 3 shows the weights of the evaluation indices at a criterion level. At the evaluation criteria level, the results indicated that the weight of the social criterion of 0.2925 was the highest in the system of allocation of water rights to different industries. This is because social criteria were the most important criteria within the allocation of initial water rights. Thus, the continuous development of society is crucial for enhancing water use efficiency in irrigation districts. Water-saving technology within society criterion is important for water-saving efficiency and agricultural water management, contributing to the high weighting of this index. The economic criterion was assigned the second-highest weighting of 0.2650 because investment in water conservancy projects is essential for the allocation of initial water rights to different industries. The environment and physiographic indices had the lowest weightings of 0.2407 and 0.2018, respectively. However, they should nevertheless be considered within the allocation of water rights. The degradation of global water resources has received increasing attention in recent years. Therefore, the weight of the environmental index is greater than that of the physiographic index.

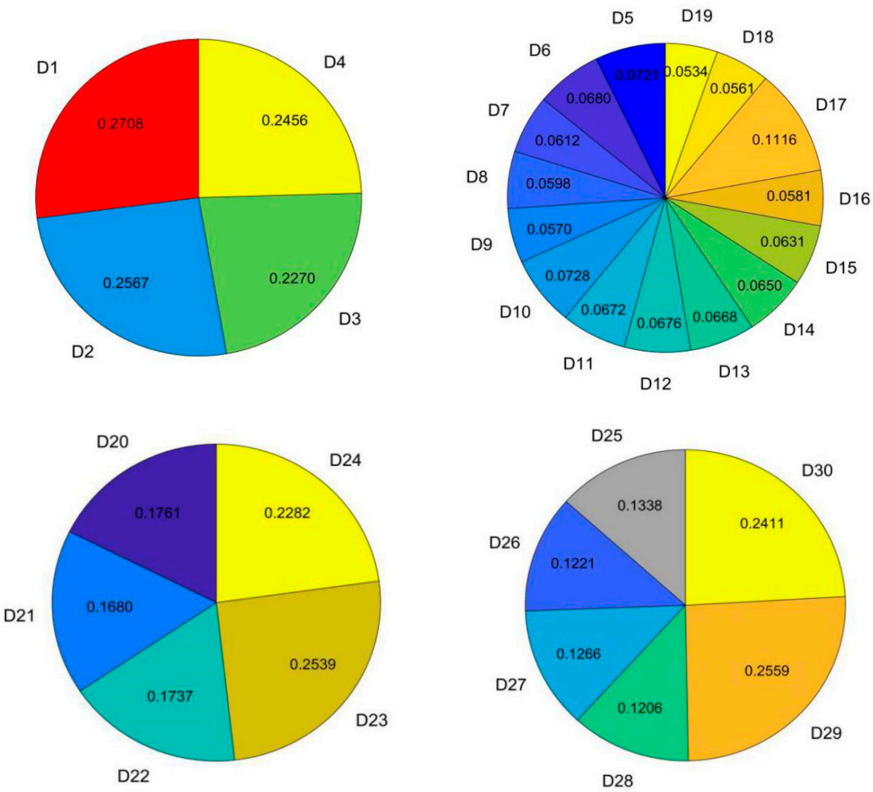

Figure 3. The total weight of evaluation indices.

Appendix C Table A5 and Figure 3 shows the weights of the evaluation indices in affecting the priority level. For the physiographic criterion, the source of water had a total weight of 0.1064, which was higher than that of the regional impact of 0.0954. This is because a shortage of water resources is one of the most important challenges facing water supply. Thus, sufficient water supply should be ensured through water source protection and practical water-saving technology. There were eight evaluation indices within the social index, ranked in descending order of their total weights as: (1) the water shortage status: 0.0410; (2) adherence to the established water supply: 0.0394; (3) water conservancy projects: 0.0386; (4) average water allocation: 0.0380; (5) water security; 0.0355; (6) the population; 0.0354; (7) industrial structural change: 0.0326; (8) advanced productivity: 0.0320. This order was established because water use efficiency is one of the most important challenges facing the allocation of initial water rights, and water shortage can be reduced by various approaches including strengthening high-tech water-saving facilities, improving the construction standard of irrigation engineering and reducing water waste. Within the economic criterion, the total weight of the economic performance index was highest at 0.1372, whereas that of investment in water conservancy was lower at 0.1278. Within the environment criterion, the ecological environment index had the highest total weight of 0.1211 as there should be integrated management of different water resources to prevent the decline in the groundwater level. Compared with the ecological environment index, ecological water use had a relatively lower total weight of 0.1196.

Appendix C Table A5 and Figure 3 shows the total weights of the 30 evaluation indices used for determining the initial allocation of water rights. Within the source of water criterion, the total weight of the ratio of available water resources index was higher than the total weight of water quality index at 0.0546 and 0.0518, respectively, as the former was a significant index within the allocation of the total number of water rights. Similarly, within a water shortage status, the weighting of the water quantity shortage index was higher than that of the poor water quality index, with weights of 0.0211 and 0.0199, respectively. This is because a reduction in water quantity has a greater effect on the availability of water resources. However, under the population criterion, the population growth rate and population density had similar weights, with values of 0.0179 and 0.0175, respectively. Within the average water allocation criterion, the irrigation quota index had the highest weight of 0.0213, whereas per capita water allocation had a lower weight of 0.0167. This is because since the study area is a major agricultural production area, water demand for agricultural is much higher than residential water demand; thus, the average per unit area water use can be decreased by the application of up-to-date irrigation water-saving technology. However, within the adherence to the established water supply, the weights of the agricultural facilities and current water supply indices were similar, with values of 0.0198 and 0.0196, respectively. Within the water conservancy project criterion, the total weight of water utilization efficiency was marginally higher than that of the channel lining rate, with values of 0.0195 and 0.0190, respectively. This is because water utilization efficiency and channel lining rate are both important for improving the efficiency of water use. Within the advanced productivity criterion, the weight of the scientific and technological progress index was 0.0164, slightly higher than that of the water-saving irrigation technology index with a value of 0.0156. This is because scientific and technological progress is the primary productive force; therefore, advanced technology is needed to save water and improve water efficiency. Within the economic performance criterion, the ratio of income generated by water conservancy to total GDP index had the highest total weight of 0.0467. The indices of income of per-water production unit and the ratio of income generated by grain to total GDP had the lowest total weights of 0.0460 and 0.0445, respectively. Therefore, guaranteeing the grain yield per unit is important for increasing farmer income. Within the ecological environment criterion, the evaluation indices ranked in descending order according to their weightings were: (1) land salinization control: 0.0322; (2) artificial groundwater recharge: 0.0305; (3) river cut-off index: 0.0294; (4) influence of permafrost: 0.0290. This ranking was established because the increasing land salinization rate in the irrigation districts directly leads to a reduction in grain production and economic benefits. In the ecological water use criterion, the weighting of the ratio of ecological water use to total water use index of 0.0616 was higher than that of the guaranteed rate of ecological water use index of 0.0580.

3.2. The Allocation of Initial Water Rights to Different Industries

Table 4 shows the total weights of the four major industries. The total weight of agriculture was the highest at 0.9508 since the study area is an important grain production county in Heilongjiang Province. Thus, the continuous development of water-saving techniques is crucial for enhancing water use efficiency in irrigation districts. Residential water had a higher total weight compared to non-agricultural production at 0.0240 and 0.0173, respectively, as residential water is essential for sustaining human life. The total weight of the environment of 0.0078 was lower than that of non-agricultural production.

3.3. Discussion

Within the present study, data for water consumption of various industries in the study area over the past five years were collected. This allowed the calculation of the five-year average weight of water rights for each industry. These weights were compared with the weights calculated by the model (Table 3 and Figure 4). The weight of actual agricultural use was higher than that calculated by the improved fuzzy AHP, with values of 0.9780 and 0.9508, respectively. Therefore, the actual agricultural water consumption is larger than the calculated value. This discrepancy can mainly be attributed to the low efficiency of past agricultural water use. Thus, water use efficiency of agricultural irrigation should be improved by introducing more advanced irrigation water-saving technology and improving the rate of canal lining. The total weight of the residential water right calculated by the improved fuzzy AHP was higher than that of the actual residential water right, with values of 0.0240 and 0.0191, respectively. As residential water is essential for human survival, this right should be guaranteed. The total weight of the non-agricultural production water right calculated by the improved fuzzy AHP was larger than the weight of actual residential water right, with values of 0.0173 and 0.0024, respectively. This result illustrates that more water resources should be set aside for non-agricultural production in the future to promote the development of industry and tertiary industry, which is conducive to industrial transformation. The water right for the environment is important for sustainable development, resulting in the total weight of the environment water right calculated by the improved fuzzy AHP being 0.0078. The actual weight of the environment water right was the second highest at 0.0004. Therefore, more water resources should be distributed to meet environmental water needs in the future. The allocation of initial water rights to different industries is an important component of water rights trading and sustainable water management to improve water efficiency and to achieve sustainable use of water resources through appropriate water diversion and distribution.

Table 3. The weight of initial water rights in different industries.

Computing Method	Residential	Agricultural	Non-Agricultural Production	Ecological Environment
The five-year average weight of water actual rights	0.0191	0.9780	0.0024	0.0004
The improved fuzzy AHP	0.0240	0.9508	0.0173	0.0078

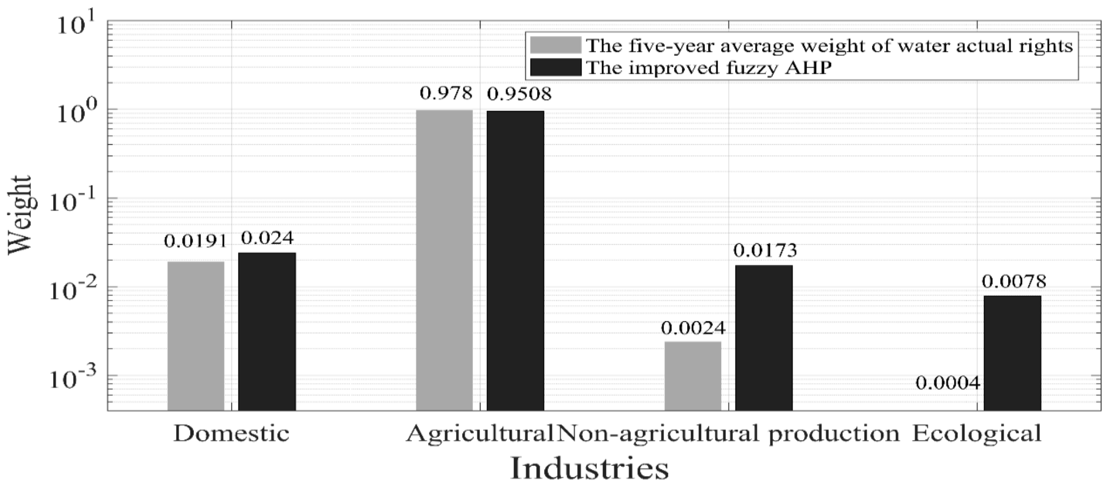

Figure 4. The weight of initial water rights of improved fuzzy AHP in comparison with that of the actual five-year average.

Table 4. The total priority coefficient of water use in different industries.

Evaluation Indices	Total Weight	Relative Membership Degree				Total Priority Coefficient			
		Residential	Agricultural	Non-Agricultural Production	Ecological	Residential	Agricultural	Non-Agricultural Production	Ecological
Ratio of available water resources	0.0546	0.00	0.99	0.00	0.00	0.0000	0.0541	0.0000	0.0000
Water quality	0.0518	0.24	0.65	0.00	0.00	0.0125	0.0337	0.0000	0.0000
Distance index	0.0458	0.00	1.00	0.00	0.00	0.0000	0.0457	0.0000	0.0000
Superiority of geographical location	0.0496	0.00	1.00	0.00	0.00	0.0000	0.0496	0.0000	0.0000
Water quantity shortage	0.0211	0.00	1.00	0.00	0.00	0.0000	0.0211	0.0000	0.0000
Poor water quality	0.0199	0.02	0.88	0.00	0.00	0.0005	0.0176	0.0000	0.0000
Population growth rate	0.0179	0.11	0.79	0.00	0.00	0.0020	0.0141	0.0000	0.0000
Population density	0.0175	0.09	0.88	0.00	0.00	0.0016	0.0153	0.0000	0.0000
Per capita water allocation	0.0167	0.10	0.67	0.00	0.00	0.0017	0.0112	0.0000	0.0000
Irrigation quota	0.0213	0.00	1.00	0.00	0.00	0.0000	0.0212	0.0000	0.0000
Current water supply	0.0196	0.00	0.98	0.03	0.02	0.0000	0.0193	0.0006	0.0004
Agricultural facilities	0.0198	0.00	1.00	0.00	0.00	0.0000	0.0198	0.0000	0.0000
Water utilization efficiency	0.0195	0.00	0.99	0.00	0.00	0.0000	0.0194	0.0000	0.0000
Channel lining rate	0.0190	0.00	1.00	0.00	0.00	0.0000	0.0190	0.0000	0.0000
Agricultural water safety	0.0185	0.00	1.00	0.00	0.00	0.0000	0.0185	0.0000	0.0000
Degree of medical and health facilities	0.0170	0.00	0.98	0.00	0.00	0.0000	0.0166	0.0000	0.0000
Rate of industrial structure change	0.0326	0.01	0.95	0.03	0.00	0.0003	0.0309	0.0010	0.0000
Scientific and technological progress	0.0164	0.00	0.89	0.02	0.00	0.0000	0.0146	0.0003	0.0000
Water saving irrigation technology	0.0156	0.00	1.00	0.00	0.00	0.0000	0.0156	0.0000	0.0000
Ratio of income generated by water conservancy to total GDP	0.0467	0.00	0.92	0.04	0.00	0.0000	0.0429	0.0019	0.0000
Ratio of income generated by grain to total GDP	0.0445	0.00	1.00	0.00	0.00	0.0000	0.0445	0.0000	0.0000
Income of per-water production unit	0.0460	0.00	0.90	0.07	0.00	0.0000	0.0414	0.0032	0.0000
Investment dynamics	0.0673	0.00	1.00	0.00	0.00	0.0000	0.0673	0.0000	0.0000
Water price on cost	0.0605	0.04	0.98	0.13	0.00	0.0023	0.0593	0.0080	0.0000
Land salinization control	0.0322	0.00	1.00	0.00	0.02	0.0000	0.0322	0.0000	0.0006
River cut-off	0.0294	0.00	0.84	0.00	0.00	0.0000	0.0247	0.0000	0.0000
Artificial groundwater recharge	0.0305	0.00	0.78	0.00	0.00	0.0000	0.0238	0.0000	0.0000
Influence of permafrost	0.0290	0.00	0.96	0.00	0.03	0.0000	0.0279	0.0000	0.0009
Ratio of ecological water use to total water use	0.0616	0.00	0.00	0.00	0.05	0.0000	0.0000	0.0000	0.0031
Guaranteed rate of ecological water use	0.0580	0.00	0.00	0.00	0.03	0.0000	0.0000	0.0000	0.0017
Industry comprehensive weight						0.0240	0.9508	0.0173	0.0078

4. Conclusions

The current study proposed an improved fuzzy analytic hierarchy process combined with fuzzy decision theory to calculate the weights of the evaluation indices in view of the multiple level, multiple index, and multiple objective characteristics of the allocation of initial water rights to different industries in Qing'an County. At the criteria level, the evaluation indices ranked in descending order according to their weights were: (1) the social criterion: 0.2925; (2) the economic criterion: 0.2650; (3) the environment criterion: 0.2407; (4) the physiographic criterion: 0.2018. According to the weighting order of the evaluation indices, it was concluded that the order of total weights of water rights allocation for different industries in descending order is as follows: (1) agricultural water: 0.9508, which accounts for the largest percentage. Thus, the focus of future research is to improve water-use efficiency of agricultural irrigation; (2) residential water: 0.0240. Since residential water is essential for human survival, this right should be guaranteed; (3) non-agricultural production water: 0.0173, this result illustrates that more water resources should be set aside for non-agricultural production in the future to promote the development of industry and tertiary industry, which is conducive to industrial transformation; (4) environment water: 0.0078. More water resources should be distributed to meet environmental water needs in the future.

The results of the method of allocated water rights for various industries presented in the current study provide a theoretical basis for the sustainable management of water resources and water rights trading in the study area. Whereas, the study only attached importance to one area of Northeast China to the allocation of water rights to different industries, rather than researching on multiple areas of the country, which is not comprehensive enough. Therefore, the conclusions of this study are only applicable to the study area or the area with similar basic conditions of initial water rights allocation. Because of this, it needs more specific theoretical and practical demonstration when the method is used in other areas. Furthermore, although the current study presents a novel allocation of the water rights calculation method, the weight calculation method was still classic in the allocation of water rights. Future work would find a more suitable method.

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Appendix A

Data representing the society, economy, water resources utilization, and water conservancy projects in the study area were listed. The classification standard of membership degree of evaluation index.

Table A1. The classification standard of membership degree of evaluation index.

Evaluation Criteria	Affecting Priority Factors	Evaluation Indices	Excellent	Good	Average	Fair	Poor	Particularly Poor
B1 Physiographic criterion	Source of water	Ratio of available water resources	>0.9	0.9~0.8	0.8~0.7	0.7~0.6	0.6~0.5	<0.5
		Water quality	>0.8	0.8~0.7	0.7~0.6	0.6~0.5	0.5~0.3	<0.3
	Regional impact	Distance index	<600	600~1000	1000~1500	1500~2000	2000~2500	>2500
		Superiority of geographical location	>0.75	0.75~0.6	0.6~0.5	0.5~0.35	0.35~0.2	<0.2
B2 Social criterion	Water shortage status	Water quantity shortage	<0.05	0.05~0.1	0.1~0.15	0.15~0.2	0.2~0.25	>0.25
		Poor water quality	<0.1	0.1~0.2	0.2~0.3	0.3~0.45	0.45~0.65	>0.25
	Population	Population growth rate	<0.01	0.01~0.08	0.08~0.12	0.12~0.16	0.16~0.20	>0.2
		Population density	<1.0	1~1.1	1.1~1.3	1.3~1.8	1.8~3.0	>3.0
	Average water allocation	Per capita water allocation	>150	150~120	120~100	100~85	85~60	<60
		Irrigation quota	>858	858~725	725~608	608~480	480~325	<325
	Adherence to the established water supply	Current water supply	>0.9	0.9~0.72	0.72~0.65	0.65~0.52	0.52~0.38	<0.38
		Agricultural facilities	>0.85	0.85~0.7	0.7~0.5	0.5~0.35	0.35~0.21	<0.21
	Water conservancy projects	Water utilization efficiency	>0.62	0.62~0.58	0.58~0.52	0.52~0.45	0.45~0.37	<0.37
		Channel lining rate	>0.82	0.82~0.7	0.7~0.62	0.62~0.55	0.55~0.44	<0.44
	Water security	Agricultural water safety	>2	2~1.7	1.7~1.2	1.2~0.8	0.8~0.5	<0.5
		Degree of medical and health facilities	>0.88	0.88~0.75	0.75~0.63	0.63~0.55	0.55~0.34	<0.34
	Industrial structural change	Rate of industrial structure change	<0.12	0.12~0.25	0.25~0.32	0.32~0.4	0.4~0.56	>0.56
	Advanced productivity	Scientific and technological progress	>25	15~25	10~15	5~10	2~5	<2
		Water saving irrigation technology	>0.55	0.55~0.42	0.42~0.35	0.35~0.2	0.2~0.1	<0.1

Table A1. *Cont.*

Evaluation Criteria	Affecting Priority Factors	Evaluation Indices	Excellent	Good	Average	Fair	Poor	Particularly Poor
B3 Economic criterion	Economic performance	Ratio of income generated by water conservancy to total GDP	>0.78	0.78~0.62	0.62~0.0.5	0.5~0.38	0.38~0.25	<0.25
		Ratio of income generated by grain to total GDP	>0.42	0.42~0.35	0.35~0.28	0.28~0.22	0.22~0.16	<0.16
		Income of per-water production unit	>25	15~25	10~15	5~10	2~5	<2
	Investment in water conservancy	Investment dynamics	>0.9	0.8~0.9	0.7~0.8	0.6~0.7	0.5~0.6	<0.5
		Water price on cost	<0.12	0.12~0.18	0.18~0.24	0.24~0.32	0.32~0.38	>0.38
B4 Ecological environment criterion	Ecological environment	Land salinization control	>0.7	0.6~0.7	0.5~0.6	0.4~0.5	0.3~0.4	<0.3
		River cut-off	<1.0	1~1.2	1.2~1.5	1.5~2.0	2.0~3.5	>3.5
		Artificial groundwater recharge	<0.1	0.1~0.2	0.2~0.3	0.3~0.4	0.4~0.5	>0.5
		Influence of permafrost	<0.1	0.1~0.16	0.16~0.25	0.25~0.38	0.38~0.5	>0.5
	Ecological water use	Ratio of ecological water use to total water use	>0.15	0.15~0.12	0.12~0.08	0.08~0.05	0.05~0.02	<0.02
		Guaranteed rate of ecological water use	>0.75	0.75~0.63	0.63~0.51	0.51~0.42	0.42~0.3	<0.3

Appendix B

Show the results of the evaluation of the consistency of the assessment matrix as well as the calculation results for different levels. λ_{max} is the maximal eigenvalue of A, *CI* is the consistency index, *CR* is the consistency ratio.

Table A2. The fuzzy judgment matrix of criterion layers.

The Criterion Layers	B1	B2	B3	B4	W
B1	1.000	0.577	0.760	1.004	0.670
B2	1.732	1.000	1.009	1.112	0.200
B3	1.316	0.991	1.000	1.004	0.080
B4	0.996	0.899	0.996	1.000	0.040
Consistency check	$\lambda_{max} = 4.022$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$ A < 0.2, and $\beta < 0.1$			

Table A3. The fuzzy judgment Matrix of factors affecting priority.

The Fuzzy Judgment Matrix of Factors C1–C2 Affecting Priority.

Priority Factors	C1	C2
C1	1	1.116
C2	0.896	1
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$

The Fuzzy Judgment Matrix of Factors C3–C10 Affecting Priority.

Priority factors	C3	C4	C5	C6	C7	C8	C9	C10
C3	1.000	1.086	1.095	0.996	1.004	1.247	1.272	1.361
C4	0.921	1.000	0.998	0.760	0.898	0.994	1.073	1.185
C5	0.913	1.002	1.000	0.907	0.993	1.199	1.218	1.153
C6	1.004	1.316	1.102	1.000	0.998	1.007	1.138	1.131
C7	0.996	1.113	1.007	1.002	1.000	1.134	1.120	1.110
C8	0.802	1.006	0.834	0.993	0.882	1.000	1.143	1.193
C9	0.786	0.932	0.821	0.879	0.893	0.875	1.000	1.005
C10	0.735	0.844	0.867	0.884	0.901	0.838	0.995	1.000
Consistency check	$\lambda_{max} = 8.015$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$						

The Fuzzy Judgment Matrix of Factors C11–C12 Affecting Priority.

Priority Factors	C11	C12
C11	1	1.074
C12	0.931	1
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$

The Fuzzy Judgment Matrix of Factors C13–C14 Affecting Priority.

Priority Factors	C13	C14
C13	1	1.012
C14	0.988	1
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$

Table A4. The fuzzy judgment matrix of evaluation index.

The Fuzzy Judgment Matrix of Evaluation Index D1–D2.		
Evaluation Indices	**D1**	**D2**
D1	1.000	1.055
D2	0.948	1.000
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$
The Fuzzy Judgment Matrix of Evaluation Index D3–D4.		
Evaluation Indices	**D3**	**D4**
D3	1.000	0.924
D4	1.082	1.000
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$
The Fuzzy Judgment Matrix of Evaluation Index D5–D6.		
Evaluation Indices	**D5**	**D6**
D5	1.000	1.060
D6	0.943	1.000
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$
The Fuzzy Judgment Matrix of Evaluation Index D7–D8.		
Evaluation Indices	**D7**	**D8**
D7	1.000	1.024
D8	0.977	1.000
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$
The Fuzzy Judgment Matrix of Evaluation Index D9–D10.		
Evaluation Indices	**D9**	**D10**
D9	1.000	0.783
D10	1.277	1.000
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$
The Fuzzy Judgment Matrix of Evaluation Index D11–D12.		
Evaluation Indices	**D11**	**D12**
D11	1.000	0.993
D12	1.007	1.000
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$
The Fuzzy Judgment Matrix of Evaluation Index D13–D14.		
Evaluation Indices	**D13**	**D14**
D13	1.000	1.028
D14	0.973	1.000
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$
The Fuzzy Judgment Matrix of Evaluation Index D15–D16.		
Evaluation Indices	**D15**	**D16**
D15	1.000	1.087
D16	0.920	1.000
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$
The Fuzzy Judgment Matrix of Evaluation Index D18–D19.		
Evaluation Indices	**D18**	**D19**
D18	1.000	1.052
D19	0.951	1.000
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$

Table A4. *Cont.*

The Fuzzy Judgment Matrix of Evaluation Index D20–D22.		
Evaluation Indices	**D20**	**D21**
D20	1.000	1.079
D21	0.927	1.000
D22	1.015	1.005
The Fuzzy Judgment Matrix of Evaluation Index D23–D24.		
Evaluation Indices	**D23**	**D24**
D23	1.000	1.112
D24	0.899	1.000
Consistency check	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$
The Fuzzy Judgment Matrix of Evaluation Index D25–D28.		
Evaluation Indices	**D25**	**D26**
D25	1.000	1.119
D26	0.894	1.000
D27	0.992	1.017
D28	0.878	0.987
Consistency check	$\lambda_{max} = 4.001$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$
The Fuzzy Judgment Matrix of Evaluation Index D29–D30.		
Evaluation Indices	**D29**	**D30**
D29	1.000	1.062
D30	0.942	1.000
Consistency check,	$\lambda_{max} = 2.000$	C.R. < 0.1, $\alpha < 0.2$, and $\beta < 0.1$

Appendix C

Show the weights of all the evaluation indices.

Table A5. The total weight of evaluation indices.

Evaluation Criteria	Weight	Affecting Priority Factors		Local Weight	Total Weight	Evaluation Indices		Local Weight	Total Weight
B1 Physiographic criterion	0.2018	C1	Source of water	0.5274	0.1064	D1	Ratio of available water resources	0.5133	0.0546
						D2	Water quality	0.4867	0.0518
		C2	Regional impact	0.4726	0.0954	D3	Distance index	0.4803	0.0458
						D4	Superiority of geographical location	0.5197	0.0496
B2 Social criterion	0.2925	C3	Water shortage status	0.1402	0.0410	D5	Water quantity shortage	0.5147	0.0211
						D6	Poor water quality	0.4853	0.0199
		C4	Population	0.1210	0.0354	D7	Population growth rate	0.5058	0.0179
						D8	Population density	0.4942	0.0175
		C5	Average water allocation	0.1298	0.0380	D9	Per capita water allocation	0.4392	0.0167
						D10	Irrigation quota	0.5608	0.0213
		C6	Adherence to the established water supply	0.1348	0.0394	D11	Current water supply	0.4983	0.0196
						D12	Agricultural facilities	0.5017	0.0198
		C7	Water conservancyprojects	0.1319	0.0386	D13	Water utilization efficiency	0.5068	0.0195
						D14	Channel lining rate	0.4932	0.0190
		C8	Water security	0.1212	0.0355	D15	Agricultural water safety	0.5208	0.0185
						D16	Degree of medical and health facilities	0.4792	0.0170
		C9	Industrial structural change	0.1116	0.0326	D17	Rate of industrial structure change	0.0326	0.0326
		C10	Advanced productivity	0.1095	0.0320	D18	Scientific and technological progress	0.5126	0.0164
						D19	Water saving irrigation technology	0.4874	0.0156

Table A5. *Cont.*

Evaluation Criteria	Weight	Affecting Priority Factors		Local Weight	Total Weight	Evaluation Indices		Local Weight	Total Weight
B3 Economic criterion	0.2650	C11	Economic performance	0.5179	0.1372	D20	Ratio of income generated by water conservancy to total GDP	0.3401	0.0467
						D21	Ratio of income generated by grain to total GDP	0.3244	0.0445
						D22	Income of per-water production unit	0.3355	0.0460
		C12	Investment in waterconservancy	0.4821	0.1278	D23	Investment dynamics	0.5266	0.0673
						D24	Water price on cost	0.4734	0.0605
B4 Ecological environment criterion	0.2407	C13	Ecological environment	0.5030	0.1211	D25	Land salinization control	0.2659	0.0322
						D26	River cut-off	0.2427	0.0294
						D27	Artificial groundwater recharge	0.2517	0.0305
						D28	Influence of permafrost	0.2397	0.0290
		C14	Ecological water use	0.4970	0.1196	D29	Ratio of ecological water use to total water use	0.5149	0.0616
						D30	Guaranteed rate of ecological water use	0.4851	0.0580

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