Study of the Value of Water Resource Driven by the Evolution of Water Resource Scarcity in Inner Mongolia

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Abstract

The fuzzy-gray relational model is established to effectively combine the scarcity of water resources with the value of water resources, so as to find out the driving effect of water scarcity on the value of water resources, so as to make the research on the value of water resources more objective and true, and contribute to the protection of water resources environment and efficient utilization of water resources.

Keywords

Water value; Fuzzy-gray relational model; Value drivers; Inner Mongolia.

1. INTRODUCTION

Water resource is one of the important factors influencing China's economic development. With the continuous development of industry and agriculture, China is facing severe water resource shortage. In 2017, the report to the 19th national congress of the communist party of China (CPC) explicitly called for "adhering to green development" and "strengthening ecosystem protection". The research and protection of water resources value has become a hot topic in the field of water resources research. It is the core content of water resources economic management; At a press conference of the ministry of water resources on March 22, 2019, Wei, Shanzhong, vice-minister of water resources, said that in view of "the current low utilization rate of water resources and waste of water for agriculture, industry and urban life", he would make the supervision of water conservation the focus of industry supervision and push forward comprehensively and deeply. We will speed up the implementation of water-saving legislation. By strengthening the main body's responsibility for water conservation, we will fully incorporate water conservation into the legal system, and speed up the implementation of national water-saving regulations.

As early as the 19th century, there were many international theories on the value of water resources, such as western utility theory of value, Marxist labor theory of value, ecological theory of value and philosophical theory of value. These theories all explain "what determines the value of water resources and what aspects are included in the value of water resources", but there are still many differences in the understanding of these problems.

Most of the recent studies abroad focus on the realization of the value of water resources, trying to solve the water resources crisis in the 21st century through pricing and cost recovery of water resources. The 1970s can be regarded as the beginning of water resource value research abroad. At this time, people use willingness to pay method and opportunity cost method to determine the value of water resources. In 1974, residual difference method and linear programming method were used to estimate the water resource value of irrigation water in Peru. In the late 1980s, Mercer analyzed the profitability of the municipal water sector after water pricing.

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To solve the water resources crisis, the focus should still be put on the protection of natural resources, which requires more effective allocation of water resources, improve management efficiency, and fundamentally solve the problem. Therefore, the inclusion of water resources sustainable quantitative research can highlight the necessary role.

Inner Mongolia autonomous region is the largest and most comprehensive ecological functional zone and important ecological barrier in north China, which plays a unique and irreplaceable role in maintaining national ecological security and ensuring regional sustainable development. However, with the advancement of industrialization and urbanization, the increase of aquatic agriculture area, and the uneven and poor distribution of resources, the shortage of water resources has become more serious. Therefore, we believe that Inner Mongolia is the best research object.

With the economic and social development, our country's water resources situation is still very serious, shortage of water resources, water ecological damage, water environment pollution problem is very outstanding, water conservancy principal contradiction from the masses of the people to the water disasters and the contradiction between water demand and water conservancy engineering ability is insufficient, into people's demand for water resources, water ecology, water environment and the supervisory ability of the water conservancy industry the contradiction of insufficient. Therefore, through this project, we will base on the measurement of water resource value, explore the mechanism of the impact of water resource scarcity on the change of water resource value, so as to find the feasible measures for water resource allocation supervision and protect water resource in China.

2. ESTABLISHMENT OF WATER RESOURCE SCARCITY MODEL

Like other resources, water resources have the characteristics of labor value, social value and scarcity, so it has the attribute of value. Due to the uncertainty of inflow and water use, the regional water resources system is prone to the risk of water supply shortage, and the degree of shortage further affects the scarcity, thus causing value changes. The value of water resource is a complex system influenced by multiple factors. Because of the "incompatibility principle" in such a system, the conventional mathematical model is difficult to explain. So fuzzy grey correlation model, the thesis from the stress state of ‘Pressure’ P, ‘State’ S and ‘Response’ R three dimensions of scarce water resources evaluation system, using the analytic hierarchy process (AHP) and entropy value method to determine the parts internal index weight, calculation of Inner Mongolia in 2007-2016 water resources value, provide a reference for the sustainable development of water resources in Inner Mongolia.

2.1. Establishment of Water Resource Value Index System Based on PSR

Index system of the rule layer by pressure, state and response three first-level indicators, according to the actual situation of water resources in Inner Mongolia, and according to the principles of accuracy, representative, purpose and other indexes, each level of index system is divided into a number of secondary indicators, through correlation analysis and expert analysis to reduction of the primary index layer, form the final index layer.

2.2. Calculation of the Weight of Water Resource Value Index Based on AHP and Entropy Method

AHP method is a simple, flexible and practical method for quantitative analysis of qualitative problems. Through expert consultation, the importance of each element of the first-level index was ranked, and the weight of various indicators influencing the evaluation results was calculated after analysis and summary. Entropy method is an objective weighting method used to quantitatively describe the dispersion degree of an index. The smaller the entropy value of the index, the greater the information provided by the index and the greater the role it plays in

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the comprehensive evaluation. As the secondary index is greatly affected, the weight will fluctuate every year. Based on the data of 24 provinces in China, this paper will calculate the weight value of secondary index every year. The index system and first-level index weights established according to the hierarchical index method and entropy value method are shown in table 1:

Table 1. Weight of each indicator hierarchy

Target layer A	First-level indicators B (W)	Secondary indicators C (w_i)
Water value	Pressure $B_1(0.2)$	Year-end resident population c_1
		Amount of water supply c_2
		Per capita water consumption c_3
	State $B_2(0.4)$	Effective irrigated area c_4
		Total water c_5
		Total discharge of wastewater c_6
	Response $B_3(0.4)$	GDP per capita c_7
		Investment in wastewater treatment project completed c_8
		Daily sewage treatment capacity c_9

2.2.1. The contribution of the secondary index was determined

Let the index value of i(i=1,2,3), the second-level index j(j=1,2,···,24), be $\boldsymbol{x_{ji}}$, then the index sample matrix is as follows:

$$M=\begin{pmatrix} x_{11} & \cdots & x_{1i} \\ \vdots & \ddots & \vdots \\ x_{j1} & \cdots & x_{ji} \end{pmatrix}_{j\times i} \tag{1}$$

Then, the contribution of the i(i=1,2,3) secondary index in the j(j=1,2,···,24) province and city:

$$P_{ji}=\frac{x_{ji}}{\sum_{j=1}^{24} x_{ji}} \tag{2}$$

2.2.2. Total contribution of secondary indicators

Total contribution of all provinces and cities to the secondary index i(i=1,2,3):

$$E_i=-K\sum_{i=1}^{3} P_{ji}\mathbf{ln}(P_{ji}) \tag{3}$$

To ensure that $0\leq E_i\leq 1$, let the constant $K=\frac{1}{\ln(j)}$

2.2.3. The contribution of the secondary index was determined

The consistency degree of contribution degree of each province under the secondary index i(i=1,2,3):

$$D_i=1-E_i \tag{4}$$

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Then the weight of each secondary index:

$$c_i = \frac{D_i}{\sum_{i=1}^{3} D_i} \tag{5}$$

2.3. Construction of Fuzzy-Gray Correlation Model

The grey relational theory is used to compare and study the correlation of incomplete information systems. Fuzzy theory is to analyze the affinity of fuzzy objects, so as to classify the research objects objectively. In general, the grey of expert evaluation information is considered, which can effectively reduce the influence of qualitative evaluation on some indicators.

2.3.1. Determine the evaluation level

Rating with V, i.e., $V=(V_1,V_2,V_3)$, according to ten "full marks, this paper is divided into three evaluation of water resources value class, namely, V = (excellent, medium, bad), and the corresponding numerical, (9,6,3).

2.3.2. Determine the evaluation matrix

The sample matrix was obtained by three experts scoring separately. If the score of x(x=1,2,···,t) experts on the secondary indicators y(y=1,2,3) is s_{yx} then the fuzzy evaluation sample matrix formed by all experts on all secondary indicators is:

$$S = \begin{pmatrix} s_{11} & \cdots & s_{1x} \\ \vdots & \ddots & \vdots \\ s_{y1} & \cdots & s_{yx} \end{pmatrix}_{y\times m} \tag{6}$$

2.3.3. Evaluation of fuzzy gray

The evaluation of gray class is represented by K, and the evaluation gray class is divided into three grades, namely K=1,2 and 3, which correspond to excellent, medium and poor respectively, and the corresponding whitening weight function, as shown in table 2.

Table 2. Whitening weight function of gray class

Gray class (K)	Grade	Gray number	Whitening weight function
First gray class (K=1)	Excellent	$\otimes\in[0,3,9]$	$f_1(s_{yx})=\begin{cases} \frac{s_{yx}}{3}, & s_{yx}\in[0,3)\& \\ 1, & s_{yx}\in[3,9] \\ 0, & s_{yx}\notin[3,9] \end{cases}$
Second gray class (K=2)	Medium	$\otimes\in[0,2,6]$	$f_2(s_{yx})=\begin{cases} \frac{s_{yx}}{2}, & s_{yx}\in[0,2) \\ 3-\frac{s_{yx}}{2}, & s_{yx}\in[2,6] \\ 0, & s_{yx}\notin[2,6] \end{cases}$
Third gray class (K=3)	Bad	$\otimes\in[0,1,3]$	$f_3(s_{yx})=\begin{cases} s_{yx}, & s_{yx}\in[0,1) \\ 3-s_{yx}, & s_{yx}\in[1,3] \\ 0, & s_{yx}\notin[1,3] \end{cases}$

2.3.4. Calculate grey statistics and grey evaluation weights

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Let the y-th secondary index under a certain first-level index belong to the k-th(k=1,2,⋯,t) fuzzy statistics gray type number n_{yk}, the fuzzy evaluation sample matrix S at a certain level indicators substituted into whitening weight function $\mathrm{f_k}(\mathrm{s_{yx}})$ to obtain the gray statistics of the evaluation matrix:

$$n_{yk} = \sum_{x=1}^{\mathrm{t}} \mathrm{f_k}(\mathrm{s_{yx}}) \tag{7}$$

For the first-level index, the second-level index y belongs to the total grey statistics of each evaluation gray category:

$$n_y = \sum_{x=1}^{\mathrm{t}} n_{yk} \tag{8}$$

Based on n_{yk} and n_y the gray weight of the y-th second-order evaluation index belonging to the k-th gray class of a first-level index can be calculated:

$$r_{yk} = \frac{n_{yk}}{n_y} \tag{9}$$

Fuzzy weight matrix of an index of a certain level constituted by r_{yk}:

$$\mathrm{R} = \begin{pmatrix} r_{11} & \cdots & r_{1t} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{nt} \end{pmatrix}_{n\times t} \tag{10}$$

2.4. Calculation of Comprehensive Evaluation Matrix and Evaluation Results

According to the weight vector w_i of the second–order index, the fuzzy comprehensive evaluation vector B_i of the first-order index is obtained:

$$\mathrm{B_i = w_i \times R} \tag{11}$$

According to the weight vector W of the target layer, the fuzzy comprehensive evaluation vector B of the criterion layer is obtained:

$$\mathrm{B = W \times B_i} \tag{12}$$

According to the fuzzy set V=(V_1,V_2,V_3) water resources value evaluation results are obtained:

$$\mathrm{Z = B \times V^T} \tag{13}$$

3. EMPIRICAL ANALYSIS

3.1. Determine the Weight of Secondary Indicators

According to the entropy method and the data in table 3, weight was calculated for all the secondary indexes under the primary indexes.

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Table 3. Water resources data of some provinces and cities in 2016

Secondary indicators	Inner Mongolia	Beijing	Shanghai
Year-end resident population (thousand people)	25,200	21,730	24,200
Amount of water supply (billion m^3)	19.029	3.881	10.484
Per capita water consumption (m^3)	756.51	178.64	433.51
Effective irrigated area (thousand ha)	3131.53	128.47	189.81
Total water (billion m^3)	19.03	3.88	10.48
Total discharge of wastewater (thousand M/T)	1,046,959.7	1,664,192.8	2,207,587.9
GDP per capita (RMB)	72,064	118,198	116,562
Investment in wastewater treatment project completed (thousand RMB)	399,590	32,350	801,440
Daily sewage treatment capacity (thousand RMB)	2,455	6,309	8,069

In 2016, for example, according to the type (3) for primary index under the 'Pressure' secondary index contribution amount results matrix $\mathrm{E_i} = (0.0021, 0.0012, 0.0022)$, 'State' under the $\mathrm{E_i} = (0.0009, 0.0012, 0.0028)$ and 'Response' under the $\mathrm{E_i} = (0.0039, 0.0002, 0.0015)$.

According to type (4) for primary index under the 'Pressure' secondary indicators on the contribution degree of consistency matrix $\mathrm{D_i} = (0.9979, 0.9988, 0.9978)$, 'State' under the $\mathrm{D_i} = (0.9991, 0.9988, 0.9972)$, and 'Response' under the $\mathrm{D_i} = (0.9961, 0.9998, 0.9985)$.

Then, according to equation (5), the weight values of second-level indicators in 2016 are obtained, as shown in table 4.

Table 4. Weight of each indicator level (2016)

Target layer A	First-level indicators B (W)	Secondary indicators C (w_i)
Water value	Pressure $B_1(0.2)$	Year-end resident population $c_1(0.3332)$
		Amount of water supply $c_2(0.3336)$
		Per capita water consumption $c_3(0.3332)$
	State $B_2(0.4)$	Effective irrigated area $c_4(0.3336)$
		Total water $c_5(0.3335)$
		Total discharge of wastewater $c_6(0.3329)$
	Response $B_3(0.4)$	GDP per capita $c_7(0.3327)$
		Investment in wastewater treatment project completed $c_8(0.3339)$
		Daily sewage treatment capacity $c_9(0.3335)$

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3.2. Fuzzy Evaluation Sample Matrix

According to the analytic hierarchy process, experts are required to refer to the data in table 5 and score each indicator based on the actual situation.

Table 5. Specific data of water resources in Inner Mongolia from 2014 to 2016

Secondary indicators	2016	2015	2014
Year-end resident population (thousand people)	25,200	25,110	25,050
Amount of water supply (billion m^3)	19.029	18.58	18.201
Per capita water consumption (m^3)	756.51	740.85	727.61
Effective irrigated area (thousand ha)	3131.53	3086.9	3011.88
Total water (billion m^3)	19.03	18.58	18.201
Total discharge of wastewater (thousand M/T)	1,046,959.7	1,108,613.7	1,119,169.3
GDP per capita (RMB)	72,064	71,101	71,046
Investment in wastewater treatment project completed (thousand RMB)	399,590	395,680	209,390
Daily sewage treatment capacity (thousand RMB)	2,455	2,120	1,895

Now, taking 2016 as an example, the fuzzy gray evaluation is conducted on the second-level indicators under the first-level indicator "pressure", and the fuzzy evaluation sample matrix is shown in table 6.

Table 6. Expert scoring table for second-level indicators under the first-level indicator "Pressure"

Items	Expert 1	Expert 2	Expert 3
Year-end resident population (thousand people)	5	6	6
Amount of water supply (billion m^3)	6	8	5
Per capita water consumption (m^3)	7	4	6

3.3. Calculation of Grey Evaluation Weight Coefficient

Take the first-level indicator "pressure" as an example to calculate its evaluation coefficient:

When K = 1, by type (7) to calculate n_{yk}, $n_{11}=f_1(5)+f_1(6)+f_1(6)=3$; Similarly, when K=2, $n_{12}=0.5$; When K=3, $n_{13}=0$

By type (8) to calculate total grey evaluation coefficient of the secondary indexes $n_1 = n_{11} + n_{12} + n_{13}=3.5$, (9) can be determined by the type of grey fuzzy evaluation weight vector for the $r_1=(0.8571,0.1429,0)$

Similarly, the evaluation weight vector of other secondary indicators can be obtained, so as to obtain the gray fuzzy evaluation weight matrix of "pressure" index:

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$$R_{B_1\text{-}C}=\begin{pmatrix} 0.8571 & 0.1429 & 0 \\ 0.8571 & 0.1429 & 0 \\ 0.7500 & 0.2500 & 0 \end{pmatrix}$$

By repeating the above steps, grey fuzzy evaluation matrix of other secondary indexes can be obtained.

3.4. Comprehensive Fuzzy Evaluation

By establishing the comprehensive fuzzy evaluation matrix of the overall objective, the comprehensive evaluation result of 2016 $B=(0.7951,0.2049,0)$ was obtained according to equation (12), and then the fuzzy set $V=(9,6,3)$ was used to make comprehensive calculation combined with equation (13) : $Z=B\times V^T=8.3854$. The following is the hierarchical structure diagram of water resource value evaluation, as shown in figure 1.

According to the principle of maximum membership, the comprehensive evaluation of Inner Mongolia water resources value in 2016 is above "medium". Similarly, the comprehensive evaluation of Inner Mongolia water resources value from 2007 to 2015 can be calculated, as shown in table 7

Table 7. Evaluation results of water resource value from 2007 to 2016

Year	Comprehensive evaluation	Year	Comprehensive evaluation
2016	8.3854	2011	8.0089
2015	8.4259	2010	8.0559
2014	8.3161	2009	7.8202
2013	8.2662	2008	7.6354
2012	8.1602	2007	7.4901

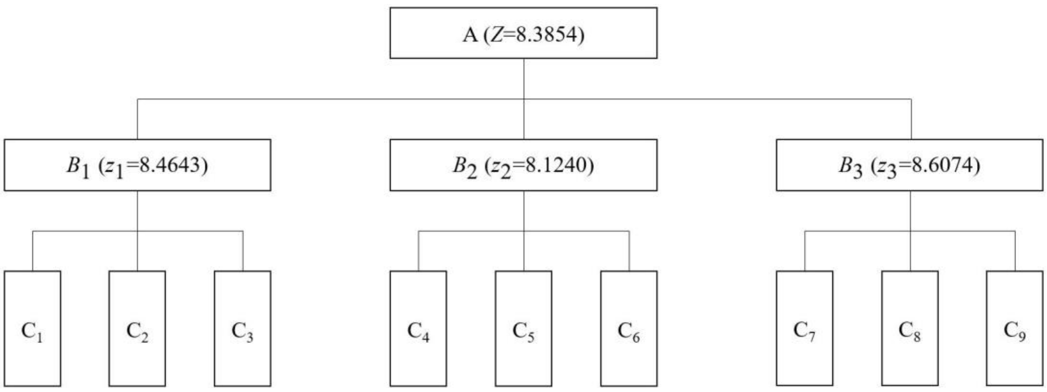

Figure 1. Hierarchical structure of resource value evaluation in 2016

4. RESULT ANALYSIS AND CONCLUSION

4.1. Result Analysis

Since the weight of the three first-level indicators 'Pressure', 'State' and 'Response' is constant, the impact of the three first-level indicators on the evaluation of water resources value is stable. The main reason for the difference of evaluation results lies in the evaluation of secondary indicators.

As can be seen from the calculation results in table 7, there is a small difference between the evaluation results in 2016 and 2015, and the total score is the highest, and the score has been

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rising steadily in the past 10 years, thanks to the efficient use of water resources and residents' enhanced awareness of water conservation. Inner Mongolia has made full use of its geographical advantages to increase the efficiency of agricultural irrigation and expand the area of effective irrigation. At the same time, the water use efficiency of residents has been gradually improved and the discharge of waste water has been effectively controlled.

Advances in science and technology and advanced water resources management regulations have also significantly enhanced the daily treatment capacity of urban sewage, thus driving the economic development of Inner Mongolia. In addition to the good effect of water use efficiency, it is necessary to pay attention to the relationship between resident water supply and urban population. Although the per capita water consumption is increasing year by year, how to further reduce the discharge of waste water to a greater extent and properly balance the water supply on the basis of population increase is one of the issues that Inner Mongolia needs to discuss in terms of residential water use in the future.

4.2. Conclusions and Recommendations

The fuzzy grey relational model of water resource value is used to calculate water resource value, and the driving effect of water resource scarcity on water resource value is analyzed by discussing the evolution of water resource scarcity. Not only the natural amount of water resources, but also the economic and social attributes of resources; The analytic hierarchy process (AHP) and entropy method are used to make the determination of weights more objective and real, and to change the artificial influence of traditional methods, so as to make the evaluation results more scientific. The research on the future development and evolution of water resources from the perspective of resource scarcity can better introduce the impact of scarcity on the value of water resources, and then make the water resources market achieve long-term stable development, which can provide a more comprehensive theoretical reference value for the sustainable development of water resources in the future.

By establishing the fuzzy grey relational model to study the change of water resource value, the best conclusion is obtained that the evolution of water resource scarcity drives the value of water resource. In the analysis of water resource value, it is found that the improvement of water use efficiency of residents and agricultural irrigation efficiency is still an important problem that aggravates water resource scarcity in Inner Mongolia. To improve the value of water resources, the following efforts should be made:

Perfect water resources management system, reasonable allocation of water resources is imperative. As the direct supplier and manager of water resources, the government should cooperate closely and work together to achieve this goal. In view of the pillar status of water in national life and national economy, as well as one of the important driving forces for China to realize all-round well-off society; Moreover, because water management involves and extends to a wide range of departments, multiple departments participate in the management, so that water resources management measures related to water supply policies are not coordinated, or difficult to implement, or cannot be introduced in time; As the water market is characterized by large area and wide distribution, it is suggested that the water resources department of Inner Mongolia should coordinate the administrative actions of relevant ministries and departments, strengthen the governance capacity, and further strengthen the regulation and supervision of the water market. The resource management department of Inner Mongolia should: first, make a comprehensive, timely and in-depth analysis of water resources and price situation, make authoritative judgment, and provide scientific basis for national decision-making; Second, promote the reform of the water market system and promote the realization of a well-off society; Third, check the development and utilization of water and investigate and deal with the loss of water resources revenue in the process of water market transactions.

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