Evaluation of Water Resources Carrying Capacity in Shandong Province Based on Fuzzy Comprehensive Evaluation

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Abstract. Water resources carrying capacity is the maximum available water resources supporting by the social and economic development. Based on investigating and statisticing on the current situation of water resources in Shandong Province, this paper selects 13 factors including per capita water resources, water resources utilization, water supply modulus, rainfall, per capita GDP, population density, per capita water consumption, water consumption per million yuan, The water consumption of industrial output value, the agricultural output value of farmland, the irrigation rate of cultivated land, the water consumption rate of ecological environment and the forest coverage rate were used as the evaluation factors. Then,the fuzzy comprehensive evaluation model was used to analyze the water resources carrying capacity Force status evaluation. The results showed : The comprehensive evaluation results of water resources in Shandong Province were lower than 0.6 in 2001-2009 and higher than 0.6 in 2010-2015, which indicating that the water resources carrying capacity of Shandong Province has been improved.; In addition, most of the years a value of less than 0.6, individual years below 0.4, the interannual changes are relatively large, from that we can see the level of water resources is generally weak, the greater the interannual changes in Shandong Province.

1 Introduction

Water resources carrying capacity refers to the specific areas within the premise of a certain level of living production and the ecological function of water environment subsystem, through scientific and reasonable distribution measure, the maximum capacity to support the needs of the population, social, economic and ecological environment that the water supply can provide[1-5]. Shandong province is one of the northern water shortage regions. Based on Shandong province economic-socio-environment basic research date from 2001 to 2015, the application of fuzzy comprehensive evaluation model to evaluate the water resources carrying capacit, which aimed to provide a basis for the rational development and utilization of water resources in the leap-forward development of Shandong province.

2 Overview of Water Resources in the Study Area

Shandong province is located in the eastern seaboard of China, the northernmost end of east China area, there are three drainage areas of Yellow River, huai river and hai river. Precipitation is the main water resources in Shandong, and is greatly affected by rainfall. The Yellow River is the main external water source in Shandong, and the nansi lake is the largest lake in Shandong province. The average annual precipitation of the whole province is 679.5mm, and the yearly average total water resources is 30582 million m^3; The per capita water resource is 344m^3, less than 1/6 of the national average, and 1/25 of the world average, the third lowest per capita water resources in all provinces (cities and autonomous regions). According to the international water shortage standard, per capita water resource occupancy less than 500m^3 would be considered as extreme water shortage area. While Shandong is only 344 m^3 per capita, which shows that Shandong is in extreme water shortage.

3 The Construction of Fuzzy Comprehensive Evaluation Model

The fuzzy comprehensive evaluation method can provide an effective way for the research of regional water resources carrying capacity, the essence of this method is to affect the carrying capacity of water resources, on the basis of single factor evaluation, through comprehensive evaluation matrix expansion multi-factor comprehensive evaluation of water resources carrying capacity, thus it is concluded that the size of the water resources carrying capacity. In this paper, the fuzzy comprehensive evaluation model was applied to evaluate the overall water carrying capacity of Shandong province.

3.1. The Selection of Evaluation Factors, Classification and Grading

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According to the characteristics of regional water resources, referring to the analysis of supply and demand of water resources in the index system, on this basis, fully considered the differences between the stock of natural water resources assigned and the different way of development, and used the water resources supply and demand analysis index system of the national and Shandong province as the basis, the evaluation index was divided into three levels (table 1). In this paper, the carrying capacity of water resources was divided into 3 levels, and the V_1 level is excellent, which indicates that the water resources in this region still have a large carrying capacity, and the water resources supply is adequate. The V_3 level is poor, which indicates that water resources carrying capacity is to allow the lowest, it is difficult to develop in depth, has restricted the social economy and stable development; the V_2 level status is somewhere in between, which indicates that this region basically can adapt to the economic development of the basin water resources, water resources development and utilization to the larger size, but still has certain potential of development and utilization.

Table.1 Rating Criteria for Each Evaluation Index

Index layer	Rule layer	Index layer	V_1	V_2	V_3
Water resources carrying capacity O	Water resources condition A_1	Per capita water resources u_1 （m^3/per)	>600	300～600	<300
		utilization rate of water resources u_2 （%）	<30	30～80	>80
		Water supply modulus u_3 （ten thousand m^3/km^2）	>39	15～39	<15
		precipitation u_4 （mm）	>800	500～800	<500
	Socio-economic condition A_2	Per capita GDP u_5 （ten thousand yuan）	>4	2～4	<2
		Per capita density u_6 （a/km^2）	<550	550～700	>700
		Water consumption per capita. u_7 （m^3）	<30	30～100	>100
		Water consumption of ten thousand yuan. u_8 （m^3/ten thousand yuan）	<70	70～200	>200
		Water consumption of industrial output of ten thousand yuan. u_9 （m^3/ten thousand yuan）	<180	80～500	>500
		Water consumption of agricultural output of ten thousand yuan. u_{10} （m^3/ten thousand yuan）	<400	400～1000	>1000
	Ecological environmental conditions A_3	Arable irrigation rate u_{11} （%）	>80	40～80	<40
		Water rate of ecological environment. u_{12} （%）	>5	1～5	<1
		Forest coverage rate u_{13} （%）	>35	10～35	<10

To better reflect the level of water resources carrying capacity, to take 1 point of numerical evaluation level: a_1 =0.05, a_2 =0.5, a_3 =0.95, after quantification can quantitatively reflect the level degree of the influence of the carrying capacity factors, the higher the value, the greater the water resources development capacity. According to the value of a_j and the value of membership b_j in B matrix, the comprehensive evaluation score of water resources carrying capacity in the comprehensive evaluation matrix B was calculated according to formula (1).

$$a = \frac{\sum_{j=1}^{3} b_j a_j}{\sum_{j=1}^{3} b_j} \qquad (1)$$

In the formula, a is the comprehensive evaluation value of water resources carrying capacity based on the comprehensive evaluation result matrix B .

3.2 The Calculation of the Evaluation Matrix

According to the actual value of each evaluation factor, the value of the subordinate function γ_i of the judging matrix was evaluated by comparing the classification index. Fuzzy processing was used to construct membership function to smooth transition between all levels. For the evaluation factors γ_1, γ_2 and γ_3 ...... the evaluation grade membership function was calculated as follows:

$$\gamma_1 = \begin{cases} 0.5\left(1+\dfrac{k_1-u_1}{k_2-u_1}\right) & u_1 > k_1 \\ 0.5\left(1-\dfrac{u_1-k_2}{k_2-k_1}\right) & k_2 < u_1 \le k_1 \\ 0 & u_1 \le k_2 \end{cases} \quad (2)$$

$$\gamma_2 = \begin{cases} 0.5\left(1-\dfrac{k_1-u_1}{k_2-u_1}\right) & u_1 > k_1 \\ 0.5\left(1+\dfrac{u_1-k_2}{k_2-k_1}\right) & k_2 < u_1 \le k_1 \\ 0.5\left(1+\dfrac{k_3-u_1}{k_2-u_1}\right) & k_3 < u_1 \le k_2 \\ 0.5\left(1-\dfrac{k_3-u_1}{k_3-k_2}\right) & u_1 \le k_3 \end{cases} \quad (3)$$

$$\gamma_3 = \begin{cases} 0.5\left(1+\dfrac{k_3-u_1}{k_2-u_1}\right) & u_1 \le k_3 \\ 0.5\left(1-\dfrac{u_1-k_3}{k_2-k_3}\right) & k_3 < u_1 \le k_2 \\ 0 & u_1 > k_2 \end{cases} \quad (4)$$

Where: k_1 is the critical value of the evaluation level V_1 and V_2 ; k_3 is the critical value of rating V_2 and V_3 ; k_2 is the midpoint of the evaluation level V_2 . The critical value of each evaluation level corresponding to each indicator was shown in table 1.

3.3 Calculation of Index Weight

First of all, according to the index level of the partition, referring to China's water resource evaluation standard, the "1-9" scale method commonly used in AHP [6-8], was adopted to construct the judgment data matrix. Secondly, according to the judgement matrix, used the mathematical matrix to calculate the importance of the indicator layer (U) relative to the principle layer (A), the importance of the criterion layer relative to the target layer (O), and then end up with a judgment matrix. Note that the water resources condition is the foundation of water resources carrying capacity, so water condition here than the social and economic condition and ecological environment condition more important, got 3:1:1. Finally, the weight of the indicator layer to the principle layer multiplied by the weight of the principle layer to the target layer, so the weight of the indicator layer to the target layer was obtained (W), and the weight calculation results can be gotten.

3.4 Calculation of Comprehensive Evaluation of Water Resources Comprehensive Capacity

According to the weight vector W and the judgment matrix R calculated above, the calculation formula for comprehensive evaluation result of the water carrying capacity is as follows:

$$B = W \times R = \begin{bmatrix} W_1 & W_2 & \bullet & W_{13} \end{bmatrix} \times \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} \\ \bullet & \bullet & \bullet \\ \gamma_{13,1} & \gamma_{13,2} & \gamma_{13,3} \end{bmatrix} = \begin{bmatrix} b_1 & b_2 & b_3 \end{bmatrix} \quad (5)$$

4 Integrate Assessment of Water Resource Carry Capacity in Shandong Province

According to the evaluation index of carrying capacity of table 1, the evaluation index of water resources carrying capacity in Shandong province was quantified. Through formula (2) (3) (4), we can find the values of each index belonging to V_1 , V_2 and V_3 : γi1, γi and γi3. The calculated results of each year were in the form of a matrix, which referred to the total number of fifteen matrices, namely [γi1、γi2 和 γi3], which was R. The results in 2002, 2005 and 2015 were shown in table 2.

Table.2 Each Indicator Corresponds to Each Level of Membership of Shandong Province in 2001、2005、2010、2015

Iindicators	2001			2005			2010			2015		
	γi1	γi2	γi3	γi1	γi2	γi3	γi1	γi2	γi3	γi1	γi2	γi3
u_1	0	0.404	0.597	0	0.999	0.001	0	0.576	0.424	0	0.269	0.731

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u_2	0	0.738	0.262	0.962	0.038	0	0.818	0.182	0	0.530	0.470	0
u_3	0	0.546	0.454	0.603	0.397	0	0	0.468	0.532	0	0.446	0.554
u_4	0	0.836	0.164	0.533	0.467	0	0.654	0.346	0	0	0.752	0.248
u_5	0	0.256	0.744	0.000	0.499	0.502	0.550	0.451	0	0.854	0.146	0
u_6	0.828	0.172	0	0.740	0.260	0	0.599	0.401	0	0.507	0.493	0
u_7	0.988	0.012	0	0.582	0.418	0	0.550	0.450	0	0.551	0.449	0
u_8	0	0.245	0.755	0.660	0.341	0	0.586	0.414	0	0.679	0.321	0
u_9	0	0.275	0.725	0.862	0.138	0	0.680	0.320	0	0.735	0.265	0
u_{10}	0	0.136	0.864	0	0.444	0.556	0.656	0.344	0	0.947	0.053	0
u_{11}	0.655	0.345	0	0.676	0.324	0	0.562	0.438	0	0.692	0.308	0
u_{12}	0	0.397	0.603	0	0.530	0.470	0	0.773	0.228	0.560	0.440	0
u_{13}	0	0.852	0.148	0.560	0.440	0	0.600	0.400	0	0	0.732	0.268

Table.3 Comprehensive Evaluation Results of Water Resources Carrying Capacity

B value	b_1	b_2	b_3	a
2001year	0.0266	0.5249	0.4485	0.3101
2002year	0.0652	0.3142	0.6205	0.2501
2003year	0.4031	0.4048	0.192	0.595
2004year	0.3395	0.4341	0.2263	0.5509
2005year	0.3752	0.5032	0.1216	0.6141
2006year	0.2114	0.461	0.3275	0.4477
2007year	0.3446	0.5116	0.1438	0.5904
2008year	0.3477	0.4784	0.1739	0.5782
2009year	0.3184	0.4704	0.2112	0.5482
2010year	0.3833	0.4744	0.1423	0.6085
2011year	0.4656	0.4132	0.1211	0.6550
2012year	0.453	0.3602	0.1867	0.6198
2013year	0.3848	0.4348	0.1803	0.5920
2014year	0.1485	0.442	0.4094	0.3825
2015year	0.3668	0.3921	0.241	0.5566

By the data in table 2 and formula (1) to (5) for carrying capacity of water resources in Shandong province comprehensive evaluation results were shown in table 3. For example, in 2014, the comprehensive evaluation result set B=[0.1485, 0.442, 0.4094], and the comprehensive ability a=0.3825, which shown that the capacity of water resources in Shandong province was not optimistic in 2014. It was not difficult to see the annual rainfall data of Shandong province in 2014, and the water resources capacity of Shandong province was very weak. But the value of B control was in good condition of $b_2 > b_3$, which indicated that a series of protective measures in recent years had effectively avoided the problem of insufficient carrying capacity of water resources brought by the climate problem, and improved the threat defense capability posed by natural disasters.

The change trend chart of water resources grading evaluation factor B and comprehensive evaluation factor a were shown in figure 1,2. Overall, the water resources carrying capacity gradually ascending steadily at the same time, through the growth of the 2001 to 2009, the a value gradually began to more than 0.6, the main above 0.6 in 2010-2015, which showed that Shandong province water resources carrying capacity has improved in general; The ranking coefficient b_2 remains the highest, indicated that the overall performance of water resources carrying capacity was in good condition, and the coefficient b_1 was gradually increasing at the same time, and the proportion b_3 was decreasing, it indicated that the water resource carrying capacity of Shandong province has a tendency to improve the membership of V_1, which was inseparable from the rational development of these years and scientific management. Secondly, the capacity of water resources was closely related to the amount of groundwater resources. In 2001, 2002, 2006 and 2014, the a value was significantly smaller than other years, again through the Shandong province water resources statistics showed that the groundwater resources in the past few years was lower than other years, and the carrying capacity of water resources in Shandong province were associated with groundwater reserves, namely once encountered drought years (dry year), groundwater can play the main water supply capacity.

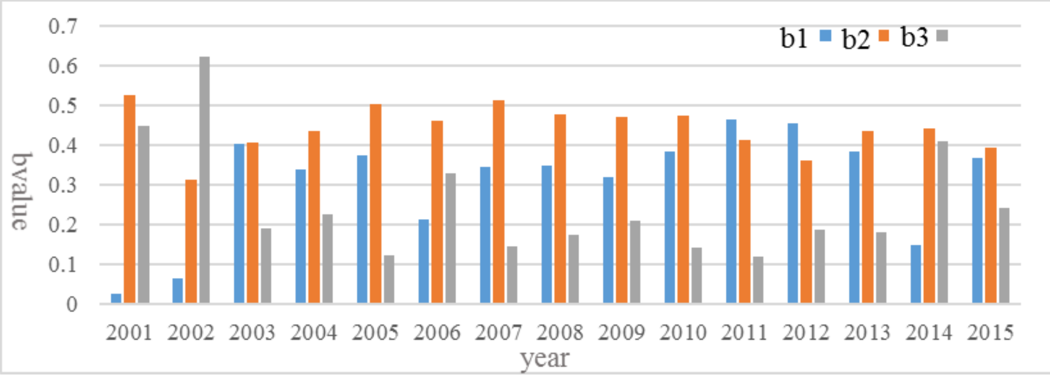

Fig. 1. Classifiction of Water Resources Carrying Capacity Evaluation Value b

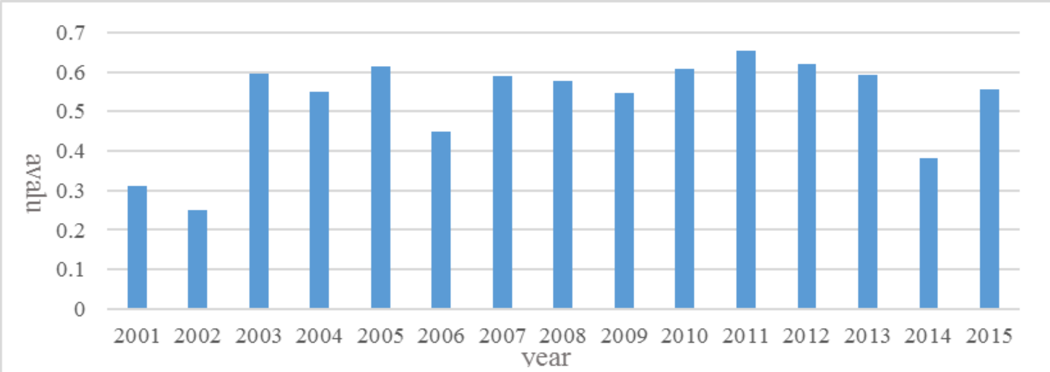

Fig. 2. Comprehensive Assessment of Water Resources Carrying Capacity Value a

5 Conclusion

This paper started from the characteristics of Shandong province economy-society-environmental composite system, comprehensive analyzed the main influencing factors of regional water resources carrying capacity as evaluation factors(to table 1), and the current status of water resources carrying capacity of Shandong province was evaluated by fuzzy comprehensive evaluation model. Results shown that the carrying capacity of water resources in Shandong province level gradually guaranteed, annual change gradually narrowed, but the contradiction between supply and demand of water resources is outstanding, the water shortage area is widely distributed, and in the later development should adhere to the open source throttling, pay equal attention to practical ability of to increase the supply capacity of water resources.

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