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Application of Entropy Weight Method and Philo Model Coupling in Evaluation of Water Resources Carrying Capacity——Taking Hefei City as an example

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Abstract. Since the reform and opening up, with the rapid development of economy and society, China's water resources are facing severe challenges. However, there is no recognized best method for the evaluation of water resources carrying capacity. The evaluation process is either subjective and random. Either the researcher relies too much on the inherent information of the sample and ignores the subjective initiative. The results of both evaluations are not objective and fair. The entropy weight method is used to determine the weight of sample index, and the water resources carrying capacity is comprehensively evaluated through the coupling of the Philo model. Taking Hefei City as an example, the evaluation results are scientific, reasonable and authentic, which can provide reference for the comprehensive evaluation of water resources carrying capacity of related cities.

1 Introduction

Water is the source of life and an extremely important resource of the earth. Although the total amount of water resources in China is relatively high, ranking the fourth in the world, the per capita amount is far lower than that of developed countries in the world, which can be said to be a country with relatively poor water resources [1]. As an indispensable resource for economic and social development, the comprehensive evaluation of water resource carrying capacity is of great value and significance. The research on water resource carrying capacity in China started in the 1980s. In order to solve the tension between social economy and water resource, shi yafeng et al. first proposed the concept of water resource carrying capacity [2]. In recent years, al-kalbani et al[3]. used the DPSIR framework as a tool to assess the carrying capacity of water resources in Oman, Sudan, and comprehensively evaluated the sustainable utilization of local water resources. Swirepik et al[4]. used the umbrella environmental assets (UEA) assessment method to predict the total ecological environmental water demand in eastern Australia.YvesTramblay et al[5]. discussed the future availability of water resources in north Africa from the perspective of climate change, and believed that the future availability of water resources was not optimistic, so it was necessary to make water management policies to adapt to future climate change as much as possible. Duan xinguang et al[6]. used the fuzzy comprehensive evaluation model to evaluate the current situation of water resource carrying capacity in xinjiang. Cao lijuan et al[7]. conducted comprehensive assessment and research on water resource carrying capacity of some counties and cities in gansu based on principal component analysis. Dai tao et al[8]. established an evaluation model of water resource carrying capacity based on set pair analysis method. In conclusion, some scholars at home and abroad have accumulated valuable experience in the study of water resource carrying capacity, which provides reference for further studies. However, in previous studies, the research methods are relatively single, either subjective and volatile, or too dependent on the inherent information of samples and ignore subjectivity. The index weight is determined by entropy weight method, and the dynamic analysis and comprehensive evaluation of water resource carrying capacity are carried out through philo model coupling with hefei city as an example.

2 Research background and methods

2.1 Research background

Hefei is the capital of anhui province, located between the jianghuai river and chaohu lake. The total area of the city is 7266 square kilometers, and the built-up area is 130 square kilometers. The total population of the city is more than 4.6 million, among which the urban population is more than 1.3 million. It is the tourism center city of the whole province[9]. Hefei has a subtropical humid monsoon climate, with four distinct seasons, mild climate, moderate rainfall, changeable spring temperature, cool autumn, significant plum rain

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and concentrated summer rain. The annual average temperature is 15.7 degrees, the rainfall is nearly 1000 mm and the sunshine is more than 2100 hours. Hills, wei and lakes coexist in hefei, with developed water system and crisscross rivers and channels. Due to the influence of subjective and objective factors, soil erosion exists in different degrees.

2.2 Data sources

The data used in this paper are from hefei statistical yearbook, hefei water resources bulletin, hefei environment bulletin, hefei government work report and related departments' bulletins and reports from 2008 to 2018.

2.3 Research methods

The key of comprehensive evaluation of water resource carrying capacity lies in the establishment of evaluation index, the calculation of index weight, and the establishment of a perfect evaluation index system. In the previous investigation and research, there are many methods to determine the index weight, such as principal component analysis[10], fuzzy comprehensive evaluation[11], subjective weighting [12], etc. At present, there is no recognized best method.

2.3.1 Entropy weight method

The basic idea of entropy weight method is to determine the degree of variation according to the value of information entropy Ej of the evaluation index after establishing a perfect evaluation index system, and then get the weight value of the evaluation index. As a mature index weight evaluation method, entropy weight method has objectivity and adaptability to the evaluation results in this study.

Calculation steps:

(1) Data standardization, standardized processing of data of various indicator:

Suppose k indices $X_{1,}X_2,...,X_k$ are given, there are $X_i = \{x_1, x_2,...,x_n\}$. Suppose the standardized value of each index data is $Y_1, Y_2,...,Y_k$, then

$$Y_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \tag{1}$$

Where: x_{ij} is the initial value of the given index, Y_{ij} is the value after standardized processing, $\max(x_{ij}), \min(x_{ij})$ is the initial maximum and minimum value of the corresponding index.

(2) Entropy value of each evaluation index E_j:

According to the definition of information entropy in information theory, the information entropy of a group of data

$$E_j = -\ln(n)^{-1} \sum_{i=1}^{n} P_{ij} \ln P_{ij} \tag{2}$$

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \tag{3}$$

Where, E_j is the information entropy value of the index, P_{ij} is the proportion of the j evaluation factor in i evaluation index, $0 \le E_j \le 1$, $p_{ij} = 0$, $\ln p_{ij}$ is meaningless, so P_{ij} needs to be modified, and the modified formula is

$$P_{ij} = \frac{1 + Y_{ij}}{\sum_{i=1}^{n} (1 + Y_{ij})} \tag{4}$$

(3) Weight of each evaluation index α_j :

According to formula (2), the entropy value of each evaluation index is calculated as $E_1, E_2,..., E_k$, Calculate the weight of each index by entropy value

$$\alpha_j = \frac{1 - E_j}{\sum_{j=1}^{k} (1 - E_j)} \tag{5}$$

Where $\sum_{j=1}^{k} \alpha_j = 1, 0 \le \alpha_j \le 1$.

(4) Determine the comprehensive weight of evaluation indicators W_i :

The weight of the subsystem obtained by entropy weight method is denoted as α_i , the weight of the index in the subsystem is denoted as β_i, where $i = 1,2,...,n$. Then the comprehensive weight is:

$$W_i = \frac{\alpha_i \times \beta_i}{\sum_{i=1}^{n} \alpha_i \bullet \beta_i} \tag{6}$$

2.3.2 Philo model

Fishbein-Rosenberg model [13] (hereinafter referred to as philo model), which is mostly used for comprehensive tourism resource assessment. The reason why this model is chosen in this study is that it can comprehensively consider the factors in the evaluation system of water resource carrying capacity, carry out weighted summation, and convert people's subjective judgment on the factors into scientific mathematical processing and expression, so as to carry out accurate quantitative evaluation of water resource carrying capacity. The model formula is as follows:

$$E = \sum_{i=1}^{n} Q_i P_i \tag{7}$$

Where: E is the final score of water resource carrying capacity

Q_i is the weight value of the i factor

P_i evaluate the value for the i factor

n is the number of evaluation factors

The entropy weight method has been adopted to obtain the comprehensive weight Q_i of each evaluation factor. For the evaluation value P_i of each evaluation factor, this paper adopts the expert scoring method and asks the hydrology and water resources related experts for their opinions anonymously. conduct statistics, processing and analysis of expert opinions, objectively integrate the majority of expert experience and subjective judgment, summarize and sort out the statistical evaluation values, and feedback them to all experts again for the opinions of expert groups. The evaluation value P_i of the evaluation factor is determined after the experts agree.

3 Results and analysis

3.1 Construction of water resource evaluation index system

Bearing capacity of water resources refers to the supporting capacity of water resources in a certain area to the society, economy and ecology under the comprehensive effects of natural conditions, social and economic development pressure and artificial regulation and management based on the principle of sustainable development [14]. System of water resources and the social economic system, ecological environment are interdependent and influence each other between the complex relationship, cannot be isolated computing system to support a particular aspect of water resources, but on the system of water resources and the social economic system, the ecological environment system to study the combined, in the water - the - ecological environment complex large system of social economy, the seeking of the water resources condition should be the largest scale. Based on the scientific nature, rationality and accuracy of the evaluation indexes, 12 evaluation indexes were selected from the aspects of water resources, social economy and ecological environment and combined with the actual situation of hefei city on the basis of previous studies. The evaluation index system of carrying capacity of water resources in hefei city was constructed, as shown in table 1.

Tab1 Water resource carrying capacity index system

Target layer	Rule layer	Index layer	Unit	Meaning of selection	Category
Water resource carrying capacity index (WRCC)	Water resources	x1: Water resources per capita	m3/per	Represents the abundance and shortage of regional water resources	positive
		x2: Runoff modulus	10^5m3/ km2	Represents the dynamic change of water resources	positive
		x3: Rainfall	mm	Represents the amount of rainfall	positive
		x4: Utilization rate of water resources	%	Represents the development and utilization of water resources	negative
	Social	x5: Natural rate of population growth	%	Reflect the trend of natural population growth	negative
		x6: The population density	per/ km2	The concentration of population	negative
		x7: Urban domestic water consumption	10^9m3	Water resources for urban residents	negative
		x8: Agricultural irrigation water consumption	10^9m3	Water for irrigation	negative
	Economic	x9: GDP per capita	10^5yuan	Economic development	negative
		x10: Water consumption per ten thousand yuan of GDP	m3/10^5yuan	Coordination degree between water resources and economy	negative
		x11: Water consumption per ten thousand yuan of industrial output	m3/10^5yuan	The impact of industrial output on water resources	negative
	Ecological	x12: Sewage treatment rate	%	Sewage treatment	positive
		x13: Water quality compliance rate	%	Water quality up to standard	positive
		x14: Deep forest coverage	%	The greening degree of the area	positive

3.2 Calculation of index weight

Entropy weight method will determine the weight of each index according to the change of each index, effectively avoid the influence of human subjective factors, so that the result is more objective and fair. The original data of each index of hefei city from 2008 to 2018 were substituted into (1) - (6) to obtain the weight of each subsystem of water resource carrying capacity of hefei city and the comprehensive weight of evaluation index, as shown in table 2.

Tab2 Evaluation index weight for water resources carrying capacity in Hefei

The subsystem	Subsystem weight (W1)	Index layer	Index layer (W2)	Index comprehensive weight(W)
Water resource subsystem	0.366	x1	0.318	0.117
		x2	0.161	0.059
		x3	0.267	0.097
		x4	0.254	0.093
Social subsystem	0.246	x5	0.367	0.090
		x6	0.283	0.070
		x7	0.178	0.044
		x8	0.172	0.042
Economic subsystem	0.202	x9	0.34	0.069
		x10	0.34	0.069
		x11	0.32	0.065
Ecological subsystem	0.186	x12	0.334	0.062
		x13	0.371	0.069
		x14	0.295	0.055

3.3 Expert evaluation

Through anonymous way to consult the opinions of the experts, hydrology and water resources statistics, processing, analysis was carried out on the expert opinion, most experts experience and subjective judgment objectively, sums up, after the statistical evaluation values again feedback to all experts, consult the opinion of the expert group, divided into 10 full marks, higher scores on behalf of the greater the impact on water resources carrying capacity; Conversely, the lower the score, the smaller the effect. Finally, the comprehensive evaluation values of each water resource evaluation index P_i in hefei were obtained, as shown in table 3.

Tab3 Evaluation value of water resources evaluation index in Hefei city

p1	p2	p3	p4	p5	p6	p7
9.5	7.8	9.3	9.2	9.1	8.8	7.3
p8	p9	p10	p11	p12	p13	p14
7.4	8.4	8.3	8.0	7.8	8.2	7.5

3.4 Comprehensive evaluation of water resource carrying capacity

The comprehensive evaluation value of water resource carrying capacity calculated by philo model in each year is shown in table 4.

Table4 Water resource carrying capacity score of each year

Year	2008	2009	2010	2011	2012
Result	815.58	743.11	1543.56	851.91	938.34
2013	2014	2015	2016	2017	2018
1042.22	1506.11	1455.08	1779.43	995.24	1180.84

3.5 Results and analysis

The sample data of representative water resource evaluation indexes x1, x3, x5 and x9 were selected as shown in figure 1 and 2, and the change trend was observed. The comprehensive evaluation indexes of water resource carrying capacity in each year were shown in figure 3.

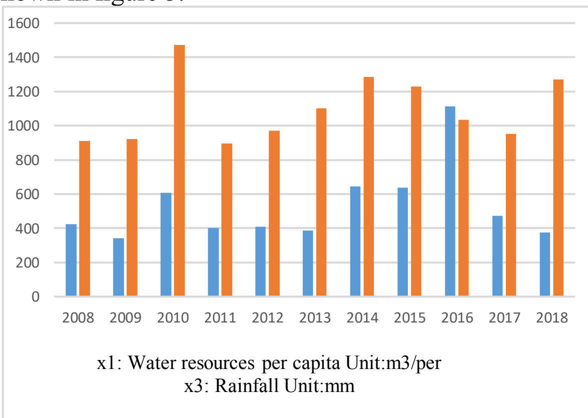

Figure1 Water resources evaluation indicators x1, x3

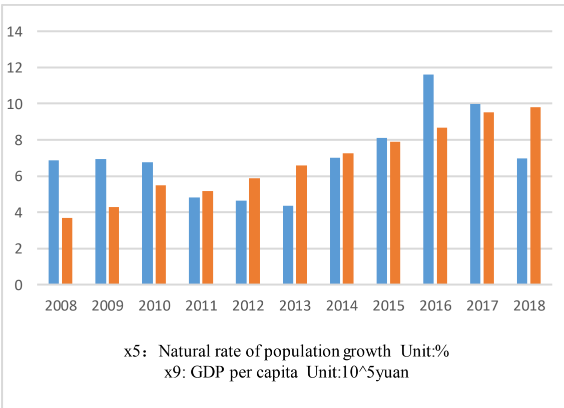

Figure 2 Water resources evaluation indicators x5, x9

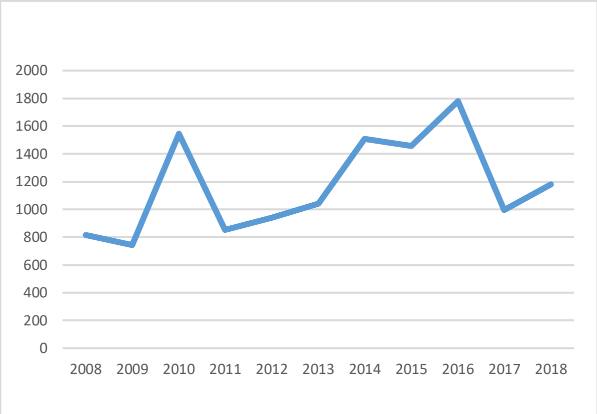

Figure 3 Comprehensive evaluation value of water resources carrying capacity in each year

From figure 1-2, it can be seen that the per capita water resources showed an increasing trend from 2008 to 2016, and a decreasing trend from 2016 to 2018. The changes in 2010 and 2016 were relatively significant. The rainfall was evenly distributed from 2008 to 2018, with the most abundant rainfall in 2010. The natural population growth rate decreased year by year from 2008 to 2013, and increased year by year from 2013 to 2018, with the per capita GDP increasing year by year.

According to table 4, the maximum comprehensive carrying capacity of water resources in 2016 was 1779.43, and the minimum carrying capacity of water resources in 2008 was 815.58. It can be seen from figure 3 that the overall bearing capacity of water resources increased from 2008 to 2018, but decreased significantly in 2011 and 2017, mainly due to the decrease in precipitation and the increase in irrigation water consumption. In general, the carrying capacity of water resources in hefei keeps increasing steadily and orderly, which is greatly affected by rainfall, natural population growth rate, water consumption per ten thousand yuan of GDP and water quality compliance rate. With the rapid development of hefei city and the influx of a large number of outsiders, while making great contributions to hefei city, we should also protect the ecological development and the environment of water sources, improve the water quality and sewage treatment rate, as general secretary xi said: "clear water and green mountains are mountains of gold and silver."

4 Conclusion

After selecting 14 indicators from the aspects of water resources, society, economy and ecology to build a comprehensive water resources evaluation system, philo model was used to comprehensively evaluate the water resources carrying capacity of hefei city from 2008 to 2018, and the following conclusions were drawn:
the carrying capacity of water sources in hefei increased from 815.58 in 2008 to 1180.84 in 2018, and the overall bearing capacity of water resources showed a steady rise. The highest carrying capacity of water resources in 2016 (1779.43) was 2.18 times of the lowest carrying capacity of water resources in 2008 (815.58). Among them, the economic subsystem and the ecological subsystem make great contributions, and the social subsystem is generally stable. The water resource subsystem is affected by the spatial and temporal distribution of water resource in hefei city, which shows a fluctuating trend.

The entropy weight method is used to calculate the weight of each evaluation index, which can avoid the influence of human subjective factors. Combined with philo model, the comprehensive evaluation of water resource carrying capacity of hefei city is carried out. The process is more comprehensive and objective, the result is more scientific and reasonable, and the evaluation result is more consistent with the actual situation of hefei city. However, the evaluation system is relatively single, and no other evaluation system is selected as the reference comparison, and it is affected by the availability of data, which is also the deficiency of this paper and the need for improvement in the future.

In recent years, the carrying level of water resources in hefei has increased obviously on the whole, but it is still at the general level. As the capital of anhui province, hefei 2025 pilot demonstration city, deputy centre city of Yangtze river delta urban agglomeration, national science center, in the high-speed economic development at the same time, also want to notice to strengthen the implementation of water conservation and management measures of reducing irrigation water and industrial water consumption, improve sewage treatment and water quality success rate, further improve the level of water resources carrying capacity, promote the sustainable utilization of water resources.

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