Research on Evaluation System and Threshold Value of Water Resources Carrying Capacity Based on Principal Component Analysis

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Abstract. The traditional water resources carrying capacity evaluation system obtained by the fuzzy comprehensive evaluation method has strong subjectivity in factor selection and threshold calculation, and the factor analysis is relatively one-sided. Therefore, water resources carrying capacity evaluation system based on principal component analysis is established and its threshold is studied. First, the main influencing factors of water resources carrying capacity, including water resources endowment, society, ecology, and other resources are analyzed. Then, the water resources carrying capacity evaluation system is established by selecting the relevant indicators in the evaluation system, comprehensively considering the selection principles, and selecting the index with the highest score as the main component. Finally, different methods are used to calculate the threshold value of the evaluation index. So far, the establishment of the evaluation system of water resources carrying capacity based on principal component analysis and the calculation of the threshold value is completed. The results of the case analysis show that the established water resources carrying capacity evaluation system are more scientific and effective than the traditional system.

Keywords: Principal component analysis; Water resources carrying capacity; Evaluation System.

1. Introduction

China is a water-scarce country, and its per capita water resources are 1/4 of the world average. Under the influence of climate change and human activities in recent years, the problems of water pollution
and water scarcity have become more and more serious, which directly restricts our social-economic development and affects the stability of the natural ecological environment [1]. How to resolve the contradiction between population, development, and water supply and demand is a common concern of the whole society. The Ministry of Water Resources of our country has issued a series of documents requiring scientific evaluation of the carrying capacity of water resources in the region, which is more conducive to the protection and sustainable development of water resources. [2]. Water resources carrying capacity is an evaluation means of sustainable utilization of water resources, which can be used to quantify and evaluate water resources security. Through the scientific and reasonable distribution and effective utilization of water resources under certain social and economic development, water resources can be maximized and utilized. In the traditional water resources carrying capacity evaluation system, the fuzzy comprehensive evaluation method is mainly used, but this method is more subjective in factor selection and threshold calculation [3]. Therefore, an evaluation system of water resources carrying capacity based on principal component analysis is established and its threshold value is studied.

2. Research on evaluation system and the threshold value of water resources carrying capacity based on principal component analysis

2.1. Analyzing the main influencing factors of water resources carrying capacity
In this paper, the principal component analysis method is mainly used in the process of establishing the evaluation system of water resources carrying capacity, which requires consideration of the main influencing factors of water resources carrying capacity. According to related literature, the following main influencing factors can be summarized: regional water resources endowment and the extent of development and utilization, socio-economic status, ecological environment level, and other resource conditions [4]. Among the main factors above, the endowment of water resources is a factor that directly affects the carrying capacity of water resources. As the rainfall, geological structure and the degree of socio-economic development in various regions will vary, it will affect the total amount of local water resources and the extent of development and utilization, further affecting the carrying capacity and availability of water resources; The most direct bearing object of water resources is the current population in the area, and people’s lifestyles directly affect the availability of local water resources. There are different levels of productivity in different social and economic conditions, which makes unilateral water produce different quantities and quality of commodities, which brings different economic benefits and affects the carrying capacity of water resources; In the environment where people live, water resources and other resources together constitute the foundation of people’s lives. Therefore, these resources on which humans depend for survival influence and restrict each other [5]. Among the above main components, the most complicated factor is the level of ecological environment. People have different understanding and protection of the ecological environment, which directly affects the quantification and analysis of carrying capacity.

2.2. Selecting evaluation system indicators
The selection of indicators in the water resources carrying capacity evaluation system has an important influence on the final carrying capacity research results and is directly related to the evaluation results
[6]. Therefore, in the selection process of the evaluation system indicators, it is necessary to consider the comprehensiveness, systematicness, hierarchy, regional independence, operability, dynamics, and comparability of the selected indicators. The various indicators should have relatively large differences and be representative. It’s necessary to try to make the indicators, not in the same dimension. Since the carrying capacity of water resources is closely connected and compounded by various subsystems, such as water resources, ecology, economy, etc., multiple subsystems interact and influence each other, so it is necessary to consider the hierarchical relationship between them. And the measurement units between the indicators should be consistent [7] to facilitate subsequent classification and comparison. Therefore, the evaluation indicators need to be standardized:

\[ X'_{ij} = \frac{X_{ij} - \bar{X}_j}{S_j} (i = 1, 2, ..., n; j = 1, 2, ..., p) \]  

Where, \( X_{ij} \) represents the initial value of the \( j \)-th evaluation index of the \( i \)-th sample, \( X'_{ij} \) represents the value after the initial value is standardized, \( \bar{X}_j \) represents the sample mean of the \( j \)-th evaluation index, and \( S_j \) represents the sample standard deviation. After getting the standardized evaluation index, the relevant coefficient matrix needs to be calculated:

\[
R = \begin{bmatrix}
  r_{11} & r_{12} & \ldots & r_{1p} \\
  r_{21} & r_{22} & \ldots & r_{2p} \\
  \vdots & \vdots & \ddots & \vdots \\
  r_{p1} & r_{p2} & \ldots & r_{pp}
\end{bmatrix}
\]  

\( r_{ij} \) in the above matrix can be expressed as:

\[
r_{ij} = \frac{\sum_{k=1}^{p}(x_{ki} - \bar{x}_i)(x_{kj} - \bar{x}_j)}{\sum_{k=1}^{p}(x_{ki} - \bar{x}_i)^2(x_{kj} - \bar{x}_j)^2}
\]

In the calculation of eigenvalues and eigenvectors, the Jacobian method is usually used for solving, and the obtained eigenvalues are arranged in order of magnitude [8], then solving the eigenvector corresponding to the eigenvalue, and calculating the contribution rate \( P_i \) and cumulative contribution rate \( P \) of the principal component:

\[
P_i = \frac{\lambda_i}{\sum_{i=1}^{p}\lambda_i} (i = 1, 2, ..., p)
\]

\[
P = \sum_{i=1}^{p} P_i (i = 1, 2, ..., p)
\]

When the cumulative contribution rate of the eigenvalue reaches 85% or more, the principal component corresponding to the eigenvalue is used as the principal component for calculating the
contribution rate, and finally, the comprehensive score value of the principal component is calculated, and the principal component with the highest score is selected as the evaluation system index.

2.3. Establishing water resources carrying capacity evaluation system

For the evaluation of the water resources carrying capacity in the region, the most important principle is sustainable development. This concept is used as the criterion for the establishment of the evaluation system, and the overall consideration of water resources, society, ecology, and economy is carried out to make water resources better contribute to the sustainable development of the regional economy [9]. Water resources carrying capacity can be divided into the water resources system, social system, and economic system in detail. In the water resources system, it mainly includes per capita water consumption, water consumption per mu, water consumption per capita, water consumption per 10,000 yuan GDP, water consumption 10,000 yuan industrial added value. The social system mainly includes population, per capita irrigated area, and effective irrigated area. In the economic system, it mainly includes per capita GDP, industrial added value, and gross domestic product. Detailed divisions are made from the above systems and evaluation indicators are selected. The evaluation indicators at all levels are shown in the following table:

| First-level evaluation index | Secondary evaluation index | Three-level evaluation index |
|-----------------------------|-----------------------------|------------------------------|
| Water volume A1             | Supporting force A11         | Depth of runoff, available regional water resources, available regional groundwater extraction, total regional water resources, annual precipitation |
|                             | Pressure A12                | Total regional water consumption, groundwater extraction in plain areas, regional water consumption per capita, and average farmland irrigation water consumption |
| Regulating power A13        |                             | Urban and rural per capita comprehensive water quota, rural per capita comprehensive water quota, water consumption per 10,000 yuan of GDP, water consumption per 10,000 yuan of industrial added value |
| Water quality A2            | Supporting force A21        | Water quality compliance rate of water function zone, regional COD, the allowable amount of ammonia nitrogen into the river, water body's pollution holding capacity, the comprehensive compliance rate of river and lake water quality |
|                             | Pressure A22                | COD. The amount of ammonia nitrogen entering the river, the number of pollutants entering the river, and the proportion of river lengths whose water quality is worse than Category IV |
| Regulating power A23        |                             | Sewage discharge compliance rate, domestic sewage compliance rate, wastewater discharge per 10,000 yuan GDP |
| Habitat of aquatic animals and plants A3 | Supporting force A31 | Ecological water volume, natural water area rate, river base flow, annual runoff, river network density, vegetation coverage rate |
|                             | Pressure A32                | Wetland and lake shrinkage rate, indicator species' demand for habitat environment, shoreline development utilization rate |
| Regulating power A33        |                             | Degree of development and utilization of regional water resources |
| Connectivity A4             | Supporting force A41        | Ecological flow guarantee degree, river reservoir diameter ratio |
|                             | Pressure A42                | Number of river obstructions, frequency of river cut-off |
At this point, the construction of the evaluation system is complete.

2.4. Determining the threshold of the evaluation index
The so-called threshold of the evaluation index is the limit of a field, and the limit is quantified to form the threshold. The threshold of the evaluation index mainly includes two aspects. On the one hand, according to the actual development law and production experience of local agriculture, economy, and population, the index can reach a certain limit within the planned period, or according to certain related policies, planning the limits that various indicators can reach within a certain number of years [10]. In the threshold calculation method in this article, the following methods are mainly used according to the content of the indicators: First, research and find the policies, regulations, and plans of relevant provinces and cities in my country regarding water resources carrying capacity; second, collect relevant industry regulations, etc.; third, refer to the indicators of cities that are developing rapidly in our country or abroad; fourth, collect statistical data in various regions and years, and use SPSS software to perform regression analysis on the annual index data, and after obtaining the regression significance model, predict the future value; Fifth, for some missing indicator data, a questionnaire can be designed to summarize and determine the data based on the experience of experts. So far, the research on the evaluation system of water resources carrying capacity and its threshold based on principal component analysis has been completed.

3. Case Analysis

3.1. Research area overview
In order to verify the scientific validity of the water resources carrying capacity evaluation system established in this paper, it is necessary to select a research area for case analysis. This article selects a city as the research area for the case analysis. The city’s permanent population in recent years is shown in the following table:

| Year | Urban permanent population/10,000 | Rural permanent population/10,000 | Total/10,000 |
|------|----------------------------------|----------------------------------|-------------|
| 2012 | 423                              | 355                              | 778         |
| 2013 | 439                              | 349                              | 788         |
| 2014 | 458                              | 338                              | 796         |
| 2015 | 466                              | 332                              | 798         |
| 2016 | 468                              | 326                              | 794         |
| 2017 | 492                              | 314                              | 806         |
| 2018 | 509                              | 302                              | 811         |

Tab. 2 The permanent population in the research area in recent years

Under the general trend of urbanization across the country, the urbanization rate of the research area has risen by 8.3% within six years. According to the population situation in the previous years, the water resources carrying capacity of the study area can be scored. First, according to the evaluation system indicators in 1.3, and the threshold calculation method in 1.4, the thresholds of each indicator in the research area are obtained, as shown in the following table:
Under the above experimental conditions, the water resources carrying capacity evaluation system established in this paper and the original evaluation system are used to evaluate the water resources carrying capacity level of the research area, and the evaluation results are analyzed.

3.2. Experimental results

The evaluation results obtained by the two evaluation systems are shown in the following figure:

![Spatial comparison of water resources carrying capacity evaluation results of the two evaluation systems](image)

**Fig. 1** Spatial comparison of water resources carrying capacity evaluation results of the two evaluation systems

| Index number | Threshold determination method | Threshold result |
|--------------|--------------------------------|-----------------|
| A11          | ①                              | 71.2            |
| A12          | ④                              | 62.30           |
| A13          | ③                              | 40.34           |
| A21          | ④                              | 82.66           |
| A22          | ④                              | 72.54           |
| A23          | ④                              | 49.30           |
| A31          | ④                              | 1.367           |
| A32          | ③                              | 2.11            |
| A33          | ④                              | 3.21            |
| A41          | ①②                            | 72.56           |
| A42          | ④                              | 0.34            |
| A43          | ④                              | 12.37           |

**Tab. 3** Index thresholds of the evaluation system of water resources carrying capacity in the research area
It can be seen intuitively from the above figure that the evaluation results of the two evaluation systems are relatively similar. In the traditional evaluation system, the evaluation result of the township in the upper left corner of the study area is medium to strong, which is recorded as township A. The evaluation result of the township on the right is medium to the low level, which is recorded as township B. Analyzing the existing differences, township A has a better water resource endowment, its rainfall and runoff depth are both at a medium level, 0.78 and 0.89, respectively, and population density and fiscal revenue are at strong levels, 0.70 and 0.75, respectively. The above indicators are all indicators with a relatively large degree of membership, making the socio-economic impact relatively low. The water resources conditions of township B are at a medium level, with rainfall and forest coverage of 0.53 and 0.91 respectively, which belong to the medium-level indicators with a large degree of membership. The socio-economic carrying situation is relatively good, and the population density and fiscal revenue are at the medium level, 0.62 and 0.71 respectively, and the water resources carrying capacity is at a medium level. In the evaluation system of this article, the contribution rate of the first principal component can reach 63%, which has the greatest correlation with the comprehensive score, is more regionally representative, and considers more comprehensive factors. Therefore, it shows that the water resources carrying capacity evaluation system based on principal component analysis designed in this paper have certain scientific validity.

4. Conclusion
Based on the research of the water resources carrying capacity evaluation system, this paper analyzes the shortcomings of the current carrying capacity evaluation system. Starting from the connotation of water resources carrying capacity, its own characteristics, and related theories, a new approach about water resources carrying capacity evaluation system is proposed based on the principal component analysis method. Through a series of processes such as analyzing the main influencing factors of water resources carrying capacity, selecting evaluation system indicators, establishing a water resource carrying capacity evaluation system, and calculating the threshold value of each index, a more comprehensive evaluation index of water resources carrying capacity evaluation system has been established. Through the case analysis of the research area, the evaluation system established in this paper, and the original system are used to evaluate the water resources carrying capacity of the research area. The experimental results show that the evaluation system established in this paper is reliable.

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