Study on water resource carrying capacity of Xi'an based on AHP-fuzzy synthetic evaluation model

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Abstract. Based on the statistical data of water resource in Xi’an from 2005 to 2017, a fuzzy comprehensive evaluation model based on Analytic Hierarchy Process (AHP) was used to analyse the status and influencing factors of water resource carrying capacity in Xi’an for the past 13 years. The results show that the water resource carrying capacity of Xi’an in 2005–2017 has been declining, and the water supply capacity has also shown a downward trend with a decrease of -0.0023/a. Nevertheless, the economic development and urban spatial assessment index have shown a rapid upward trend. In 2017, the annual total water supply of the city increased, leading to the continuous improvement of the environmental status of water resource in Xi’an. However, compared with the urban population growth rate of 9%, GDP growth rate of 19%, and urban consumption rate of 21%, the water resource carrying capacity will continue to decline in the short term and cannot be effectively improved. The main reason for the continuous decline of water resource carrying capacity in Xi’an is the shortage of water resource, and the daily water consumption per capita is increasing. Under the current water resource situation, it is difficult to effectively support the rapid development of urban economy and urbanization. Developing and enhancing citizens’ awareness for water conservation and improvement is necessary to support sustainable urbanization in Xi’an City.

1. Introduction

Water is the source of life and an indispensable part of social and economic development [1]. In recent years, with the rapid development of social economy, ecological and environmental problems have become increasingly serious, and water shortage has become an important factor restricting the sustainable development of China’s economy and society [2]. In the arid and semi-arid regions of northwestern China, the water in the rivers and lakes are scarce. Whether the water problem can be properly solved has become one of the important factors affecting the coordinated development of urban health [2–3]. At present, the evaluation of water resource systems is often characterized by water resource carrying capacity.

The carrying capacity of water resource refers to the reasonable scale of regional water resource that can support the sustainable development of social economy and social development under the conditions of economic and social and scientific and technological development, with the healthy development of ecological environment and the coordination of sustainable social and economic development [3]. According to different research methods and viewpoints, scholars use cluster analysis, analytic hierarchy process and fuzzy matrix analysis to study the regional water resource
carrying capacity safety state, or construct a regional water resource carrying capacity dynamic model to analyze the main drivers for water resource carrying capacity changes[3-4], or consider the differences between the indicator and the weight calculation method to obtain the improved fuzzy evaluation results[4-5], or from the perspective of water supply and urban security to study the carrying capacity of water resource, and putting into urban development planning[5-6]. In the context of rapid economic development, research on water resource carrying capacity has become increasingly important. The composition of the water resource system is very complex and has many uncertain factors including randomness, ambiguity, grayness and uninform factors [6-7]. The fuzzy comprehensive evaluation method is a fuzzy mathematics-based method that can be used to evaluate systems with multiple uncertainties. It is widely used in the evaluation of water resource carrying capacity, providing an effective way for regional water resource carrying capacity research [7-8].

Xi’an is located in arid and semi-arid areas. Precipitation is the main source of water resource in the region. Due to human activities, surface water and groundwater have different degrees of pollution [8-9]. The uneven spatial and temporal distribution of precipitation exacerbates the contradiction between supply and demand between society and water resource. The rapid economic growth has accelerated the pace of urban development, and has increased the burden of water resource and environmental resources, resulting in a continuous decline in water resource carrying capacity [9-10]. Therefore, it is urgent to study the changes and influencing factors of carrying capacity of water resource in Xi’an for the targeted improvement of water resource [8-10].

Based on this basis, this paper aims to use the statistical data from 2005 to 2017 to establish a fuzzy evaluation model for water resource carrying capacity in Xi’an based on the balance of supply and demand of water resource. The Analysis hierarchical method (AHP) of subjective and objective combination is used to determine the level. Index weights are used to analyze the changes and influencing factors of water resource carrying capacity in Xi’an in the past 13 years. Overall to provide theoretical support for Xi’an future water ecological management and sustainable urban development.

2. Study area
Xi’an City is located in the central part of Shanxi Province, between 107°40′-109°49′ E and 33°39′- 34°44′ N. The climate belongs to the warm temperate semi-humid continental monsoon. The average annual precipitation is 515.7mm, which increases gradually from south to north due to the topography. The annual average temperature is about 13.3 ℃, and the highest temperature is 32 ℃ in July, the lowest temperature is January is -4℃, as well as the difference between the highest and lowest temperatures is up to 28 ℃.

The total water resource in Xi’an is about 2.34 billion m³, and the per capita water resource are about 234 m³, which is less than one tenth of the national per capita water resource; the total surface water resource is about 1.80 billion m³, and the available capacity is about 38%; the total amount of groundwater resource is about 1.39 billion m³, and the available amount is about 63%.

3. Methodology

Table 1. Evaluation index system and weight based on AHP.

| First-level | First-level | Index |
|-------------|-------------|-------|
| Water resource Carrying Capacity Evaluation | Water Supply Capacity(X1) | x_{11}, x_{12}, x_{13}, x_{14} |
| Water Demand Analysis | Population Growth(X2) | x_{21}, x_{22} |
| | Economic Development(X3) | x_{31}, x_{32}, x_{33} |
| | City area(X4) | x_{41}, x_{42}, x_{43}, x_{44}, x_{45}, x_{46} |
3.1. Evaluation index

Based on the existing research results and regional characteristics, this paper constructs the index system of water resource carrying capacity evaluation in Xi’an from the aspects of “supply” and “need” [11-12]. Then, based on the theory of AHP, the indicator system is divided into three levels, as shown in Table 1.

As shown, $x_{11}~x_{14}$ is Precipitation, Water supply, Surface water resource and Groundwater resource respectively; $x_{21}~x_{22}$ is Population and Per capita daily water consumption; $x_{31}~x_{33}$ is Gross domestic product (GDP), The first and second industries accounted for the proportion of GDP and Water consumption per 10,000 yuan of GDP, respectively; $x_{41}~x_{46}$ is Industrial wastewater discharge, Industrial wastewater discharge compliance rate, Built-up area, Green coverage rate of built-up area, Green coverage rate of built-up area and Sewage treatment rate, respectively.

3.2. Fuzzy comprehensive evaluation model based on AHP

Fuzzy comprehensive evaluation method is a comprehensive evaluation method based on fuzzy mathematics [11-12]. According to the membership degree theory of fuzzy mathematics, this method transforms qualitative evaluation into quantitative evaluation, which is based on the evaluation of individual factors affecting water resource carrying capacity. AHP assigns weights to the indicator system to determine the final fuzzy comprehensive evaluation results. The specific process is as follows:

1. The first-level indicators are disassembled into two-level indicators $(X_i)$ and three-level indicators $(x_{ij})$, and the index layer elements are standardized, and the objective index weights are calculated by the entropy weight method.

2. Experts are invited to score the relative importance of each level as shown in Table 2, and subjective weights are calculated; the consistency test is carried out to establish a relative importance comparison matrix as shown in Table 3.

3. Calculate the combined weight of each index, and determine the fuzzy evaluation matrix according to the fuzzy evaluation membership matrix calculation formula.

| Table 2. Expert scoring relative importance value table. |
|--------------------------------------------------------|
| Relative importance | Significance               |
| 1                    | Equally important         |
| 3                    | Slightly important        |
| 5                    | Obviously important       |
| 7                    | Strongly important        |
| 9                    | Absolutely important      |
| 2,4,6,8              | Intermediate value of the above scale |

3.3. Standardization of evaluation indicators

Since the original data of different indicators are different in dimension and cannot be directly compared, the original data is standardized and analyzed based on the standardized data [12]. The specific methods of standardization are described as follows:

1. The bigger the better the type (positive type): the larger the index value is, the more favorable it is to improve the carrying capacity of water resource, and the formula for calculating the positive type index is adopted.

$$X_{ij}’ = \frac{x_{ij} - \min x_j}{\max x_j - \min x_j}$$  \hspace{1cm} (1)

2. The smaller the better the type (negative type): the smaller the index value is, the more favorable it is to improve the carrying capacity of water resource, and the negative formula is used to calculate the formula.
\[ X_{ij}^{'} = \frac{\text{max} X_j - X_{ij}}{\text{max} X_j - \text{min} X_j} \]  

(2)

Where: \( X_{ij}^{'} \) is the index value after standardization processing; \( X_{ij} \) is the index value before the standardization process; \( \text{max} X_j \) and \( \text{min} X_j \) are the maximum and minimum values of the jth index, respectively.

**Table 3.** Average random consistency indicator.

| Order | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    |
|-------|------|------|------|------|------|------|------|------|------|
| Ri    | 0.01 | 0.01 | 0.6  | 0.8  | 1.15 | 1.26 | 1.33 | 1.45 | 1.46 |

4. Analysis and discussion of results

The fuzzy comprehensive evaluation model was used to comprehensively evaluate the water resource carrying capacity of Xi'an from 2005 to 2017, and the fuzzy comprehensive score was determined by the principle of minimum membership. The results are shown in Table 4. The maximum score of comprehensive water resource carrying capacity in Xi'an is 0.231 in 2016, and the minimum score is 0.165 in 2014. The fuzzy comprehensive score in 2017 is 0.180, which is lower than the multi-year average of 0.206 and about 12%, of which the lowest water supply capacity is 0.180, the economic and urban indicators were relatively high at 0.317 and 0.352 respectively.

**Table 4.** Statistical table of fuzzy evaluation results.

| Years | Water Supply Capacity | Water Demand Analysis | Fuzzy Comprehensive Score |
|-------|-----------------------|-----------------------|---------------------------|
|       |                       | Population            | Economic                  | City                      |               |
| 2005  | 0.211                 | 0.228                 | 0.28                      | 0.302                     | 0.211         |
| 2006  | 0.214                 | 0.23                  | 0.27                      | 0.279                     | 0.214         |
| 2007  | 0.225                 | 0.23                  | 0.27                      | 0.298                     | 0.225         |
| 2008  | 0.221                 | 0.231                 | 0.27                      | 0.295                     | 0.221         |
| 2009  | 0.201                 | 0.228                 | 0.3                       | 0.345                     | 0.201         |
| 2010  | 0.234                 | 0.227                 | 0.25                      | 0.254                     | 0.227         |
| 2011  | 0.229                 | 0.232                 | 0.26                      | 0.28                      | 0.229         |
| 2012  | 0.193                 | 0.223                 | 0.3                       | 0.336                     | 0.193         |
| 2013  | 0.191                 | 0.229                 | 0.3                       | 0.322                     | 0.191         |
| 2014  | 0.165                 | 0.217                 | 0.33                      | 0.356                     | 0.165         |
| 2015  | 0.189                 | 0.232                 | 0.31                      | 0.351                     | 0.189         |
| 2016  | 0.24                  | 0.231                 | 0.25                      | 0.245                     | 0.231         |
| 2017  | 0.18                  | 0.226                 | 0.32                      | 0.352                     | 0.18          |

According to statistics, the rainfall in 2017 was 649 mm, which was 42% more than 200 mm in 2016; the population of 9.61 million, an increase of 9% compared with 2016, about 0.78 million; the GDP of 747.18 billion yuan, an increase of 19% over 2016, about 121.40 billion; the urban area increased to 683 km², an increase of 21% from 2016 about 117 km². Xi'an City is located in arid and semi-arid areas, and water resource have long lacked effective supply. At present, the urban water supply mainly comes from the Heihe Reservoir and the Weihe River [10]. The source of single water is lacking, and the economy, population and cities are growing rapidly. In comparison, the water supply capacity is becoming weaker and the water resource carrying capacity is declining [9].

As Figure 1 shows from the summary of the fuzzy assessment results of water resource carrying capacity for many years from 2005 to 2017, the water supply capacity is decreasing at a rate of -0.0023/a, and the economic development is rising at a rate of 0.0031/a. The urban expansion is at a rate of 0.0025/a. From the overall development trend, the downward trend of water supply capacity will continue further in the future, mainly because Xi'an's economic development and urban space...
expansion speed is too fast, the water supply capacity is not significantly improved in the short term, and the contradiction between supply and demand is increasingly prominent and intensified [8]. The great pressure on water resource is the main reason for the continuous decline of water resource carrying capacity in Xi'an [10].

5. Influencing factors
In February 2018, Xi'an became the ninth national central city. Under the strong promotion at the national level, Xi'an proposed that the total GDP should reach 1 trillion yuan by 2020. The rapid development of the economy will greatly threaten the existing water resource. The fuzzy evaluation of water resource carrying capacity focuses on the two aspects of “supply” and “need”. From the specific evaluation results, the main impact of water supply is the annual total water supply, while the demand is mainly per capita daily domestic water. The amount and the total amount of water used in the region's GDP. In terms of water supply, the total water supply in 2005–2017 has been increasing at a rate of 35.81 million m³/a as shown in Figure 2. On the demand side, the water consumption per 10,000 yuan of GDP has been decreasing at a rate of -8.25 m³/a, and per capita daily water consumption is increasing at a rate of 3.97 L/a.

The government should take active measures to strengthen industrial water management, strictly limit water consumption indicators, so that the water consumption of GDP will continue to decline; mobilize the whole society, change the traditional water use concept, promote the use of water, and reduce the daily water consumption per capita; properly exploit water resource, expand the total amount of water resource; improve water use efficiency, reduce waste, and save water from the side [9-10].

6. Conclusions
Through the AHP analysis, a comprehensive evaluation index system for water resource carrying capacity was established, and a fuzzy comprehensive evaluation model was established to evaluate and predict the water resource carrying capacity of Xi'an from 2005 to 2017. The main conclusions are as follows:

(1) The results of fuzzy evaluation show that the water resource carrying capacity of Xi'an has been declining in the past 13 years. Although the increased of water supply capacity is the most obvious, economic development and urban space are experiencing rapid [8]. In addition, compared with the urbanized economy and rapid population growth, it is still not enough, and the water resource carrying capacity will continue to decline [9].
(2) The pressure on water resource carrying capacity in Xi'an is mainly due to the continuous increase in per capita daily water consumption. The government should take reasonable measures to increase publicity and increase public awareness of water conservation to improve water use efficiency.

(3) The surface water and groundwater resource in Xi'an are abundant and have great development potential [10]. The water resource in the region should be used reasonably to improve the carrying capacity of water resource and promote rapid and coordinated economic and social development.

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