Dynamic Assessment of Water Resources Carrying Capacity in Heze Using Fuzzy Sets Methods

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Abstract. It’s necessary to assessment the regional water resources carrying capacity for water resources long-term plan and projects. In this paper, the water supply and water utilization of Heze City in the past 10 years are analyzed firstly, and then figured out the current situation and existing problems of water resources in this study area. Thirdly, on the basis of constructing the comprehensive evaluation index system of water resources carrying capacity of Heze City, we introduced a fuzzy comprehensive evaluation model of water resources carrying capacity of Heze City. The purpose is tantamount to dynamically evaluate and analyze the water resources carrying capacity of the current level year and the planning level year of Heze City. The result showed that the water resources carrying capacity level of Heze City are changing to a positive direction, but the trend is weak and the prospect is not optimistic. At the same time, the validity and feasibility of the model and method are verified.

1. Introduction

Heze is a city in south western Shandong province, China. It is located between 114°48'-116°24'E and 34°32'-35°52'N. It borders Jining to the east and the provinces of Anhui and Henan to the south and west respectively, See Figure 1. The average annual precipitation of Heze City is 661.6mm and annual average surface runoff is 50.8mm. Local surface water resource is 621 million m³, and the underground water resource is 1.67 billion m³. After deducting the repeated calculation amount of 230 million m³, the actual total water resources amount is 2061 million m³. For many years, the average annual surface water development and utilization in Heze City is about 330 million m³ per year, with a utilization coefficient of 0.53; the exploitable amount of groundwater is 1.27 billion m³, with an exploitable coefficient of 0.75, and the total exploitable amount of water resources in Heze City is 1.61 billion m³. Heze belongs to the extremely water-deficient areas in China.

The actual water supply of water supply facilities in Heze City is 2284.79 million m³ in current year, of which surface water is 1039.05 million m³ (inter basin water transfer is 902.3484 million m³), accounting for 45.48% of the total water supply; underground water is 1230.0436 million m³, accounting for 53.84% of the total water supply; other (renewable water, rainwater utilization) is 15.7 million m³, accounting for 0.68% of the total water supply. Thus, groundwater and Yellow River water play a very important role in the water supply structure, as showed in Figure 2. According to the data of water conservancy statistics in Heze City, the proportion of surface water supply in total water supply in Heze City has declined slightly over the years, from 56.06% in 1991 to 45.48% in the current year, while the proportion of underground water supply has increased year by year, from 43.94% in 1991 to 53.84% in the current year. The average annual water supply of inter basin water diversion accounts for 78.4% of the average annual water supply of surface water. With the implementation of
the Yellow River water diversion plan and restricted water use, the water diversion of inter basin water
diversion tends to decrease year by year. The situation facing water resources in Heze City is very
serious. Firstly, the trend of declining water resources is decreasing; second, the amount of surface
water resources is greatly reduced; third, the amount of groundwater resources is significantly reduced;
fourth, the water quality is seriously deteriorated. The total amount of local water resources in Heze
City is 2.061 billion m$^3$, and the total available amount is 1.605 billion m$^3$. The per capita acreage is
small, which is a serious water shortage area. The current situation in Heze City is the coexistence of
water shortages and water wastage. At present, we need to study and project how to coordinate the
development of society and water resources sustainable usage in the region. As a basis for above long-
term scientific planning, it is essential to assessment the carrying capacity of Heze and fugues out
local water resources status and trends and the interaction between water system and society.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{heze_city_location.png}
\caption{Location, administrative divisions and water system of Heze City.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{heze_city_water_supplies.png}
\caption{Water supplies in Heze city.}
\end{figure}
2. Index for Water Resources Carrying Capacity Assessment

Assessment index of water resources carrying capacity proposed in this paper consists of three levels: target level, criterion level and index level. The criteria include Society coordination level, economic coordination level and environmental coordination level. As showed in Table 1.

| Table 1. Resources carrying capacity assessment index system. |
|-----------------|-----------------|-----------------|
| **Criterion**   | **Index**       | **units**       | **Expression and implication** |
| Society         | Population density | person /km  | Population / land area |
|                 | Annual population growth rate | %    | Birth rate - mortality |
|                 | Per capita water resources | m³/person | Total water resources / population |
|                 | Daily water consumption per capita | L/(d*) | Total domestic water consumption per day / population |
|                 | Per capita cultivated land | ha/person | Total area of regional cultivated land / population |
|                 | Water resources per area | m³/ha | Total regional water resources / area of regional cultivated land |
| Economic        | Water consumption for 10000 RMB GDP | m³/10⁴yu an | Industrial water consumption / industrial GDP value |
|                 | Effective utilization coefficient of irrigation water | | Water utilization coefficient of canal system * field water utilization coefficient |
|                 | Water consumption per 10000 RMB of GDP | RMB/m³ | Regional GDP / total regional water consumption |
|                 | Grain yield per cubic meter of water | Kg/m³ | Total regional grain output / total amount of regional irrigation water |
|                 | Standard rate of industrial wastewater discharge | % | Total industrial wastewater discharge up to standard / total industrial wastewater discharge |
| Eco-environment | Forest coverage | % | Regional forest area / total area of regional land |
|                 | Cultivated land rate | % | Area of regional cultivated land / total area of regional land |
|                 | Soil erosion rate | % | Soil erosion area / total area of regional land |
|                 | Water use rate of ecological environment | % | Water consumption of ecological environment / total water consumption |
|                 | Soil erosion control rate | % | Soil erosion control area / total area of soil erosion |

3. Fuzzy Comprehensive Assessment Models

Depending on fuzzy comprehensive evaluation theory (Chen, 2013), a fuzzy assessment model for resources carrying capacity assessment is given below.

$$\mu_h = \frac{1}{\sum_{i=1}^{n} \left[ w_i \left( 1 - \mu_{\hat{h}}(x_i) \right) \right]^p} \left( \frac{1}{\sum_{i=1}^{n} \left[ w_i \left( 1 - \mu_{\hat{h}}(x_i) \right) \right]^p} \right)^p$$  (1)

Where $\mu_h$ is the fuzzy membership degree of the assessment object $U$ belong to level $h$ ($h = v_1, v_2, v_3, v_4, v_5$), $p = 2$ is distance parameter. $\mu_{\hat{h}}(u)$ and $\mu_{\hat{h}}(u)$ are the relative membership degree(RMD) function.

The final assessment grade levels of U are determined by the grade characteristic value function given follows
With the index values of $u_i$, the carrying capacity level $U$ can be obtained by the formula (1) and (2). Then, the assessment grade levels can be obtained according classification standard given in table 3.

4. Water Resources Carrying Capacity Dynamic Assessment of Heze

According to the actual situation of the water resources development and utilization of Heze City and its own regional characteristics, we preliminary draw up a set of indicators for the evaluation of water resources carrying capacity, adopt the index screening method mentioned above, determine the weight of different indicators, and remove the indicators that have no obvious impact on the evaluation of sustainable development (i.e. less weight) and water resources utilization and are difficult to collect data (because inaccurate data will only bring negative effects on the evaluation results). After careful consideration, the paper finally selected and determined seven main indicators, namely population density (R1), daily water consumption per capita (R2), water resources per mu(R3), water consumption per 10000 RMB of GDP (R4), effective utilization coefficient of irrigation water (R5), forest coverage (R6) and ecological environment water use rate (R7), as the evaluation index system of water resources carrying capacity of Heze City, and collected and sorted them out. See Table 2 for index value data. Among them, 2025 and 2030 are the planning level years, and the relevant data refer to the planning data of Heze City. At the same time, on the basis of consulting relevant literature and consulting experts' opinions, the corresponding evaluation standards of each index are determined and summarized in Table 3.

| Table 2. Evaluation index value of water resources carrying capacity in Heze. |
|---------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Indicator layer                | Unit          | 2014          | 2015          | 2016          | 2017          | 2018          | 2025          | 2030          |
| The population density (R1)    | per/km        | 768.8         | 778           | 779.7         | 779.7         | 788.7         | 804           | 828           |
| Per capita daily water consumption (R2) | L/(d*per) | 63.9          | 70            | 69.3          | 71.1          | 68.9          | 76            | 81            |
| Per capita water resources per mu (R3) | m³/10⁴mu | 189.11131.99124.65134.07128.11 | 272 | 272 |
| 10,000RMB GDP water consumption (R4) | m³/10⁴ RMB | 186.65 | 197.3 | 130.86 | 114.28 | 102.8 | 102 | 84 |
| Effective use of irrigation water (R5) | % | 0.47960.40070.59880.60470.6104 | 0.791 | 0.855 |
| Forest coverage (R6) | % | 33.60 | 36.90 | 33.60 | 33.60 | 33.60 | 38 | 40 |
| Ecological environment water use rate (R7) | % | 0.30 | 1.60 | 1.10 | 2.30 | 1.70 | 0.56 | 0.48 |

| Table 3. Classification standard of water resources carrying capacity evaluation index. |
|---------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Index item                      | I excellent   | II secondary  | III poor      |
| Population density (R1)         | 300           | 500           | 700           |
| Daily water consumption per capita (R2) | 50 | 100 | 150 |
| Water resources per mu (R3)     | 300           | 200           | 100           |
| Water consumption per 10000 RMB of GDP (R4) | 100 | 200 | 300 |
| Effective utilization coefficient of irrigation water (R5) | 0.7 | 0.5 | 0.4 |
| Forest coverage (R6)            | 50%           | 30%           | 10%           |
| Water use rate of ecological environment (R7) | 0.30% | 0.50% | 1.50% |

4.1. Calculation Results

Entropy weight method and binary comparison method are used to determine the objective and subjective weights of indicators respectively. See Table 4 for the weights of indicators.

| Table 4. Index comprehensive weights. |
|---------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Index                           | Population density(R1) | Daily water consumption per capita (R2) | Water resources per mu (R3) | Water consumption per 10⁴ RMB of GDP (R4) | Effective utilization coefficient of irrigation water (R5) | Forest coverage (R6) | Water use rate of ecological environment (R7) |
| Weight                          | 0.012         | 0.022         | 0.017         | 0.026         | 0.029         | 0.023         | 0.021         |
According to the fuzzy comprehensive assessment model given above, the evaluation values of five consecutive years and long-term planning years are obtained, as shown in Table 5.

| Year   | 2014 | 2015 | 2016 | 2017 | 2018 | 2025 | 2030 |
|--------|------|------|------|------|------|------|------|
| Evaluation result | 2.267 | 2.277 | 2.017 | 2.056 | 2.039 | 1.877 | 1.778 |

4.2. Discussion
It can be observed in the evaluation results that in the past five evaluation years, 2015 was the best, followed by 2014, 2017 and 2016, and the worst was 2018. From the perspective of overall dynamic changes, the evaluation results of Heze City show that the water resources bearing capacity level is basically around Level 2, that is, the medium bearing capacity level, which is a problem that needs to be paid attention to in the planning of water resources development and utilization in this region. At the same time, it can be seen that the water resources carrying capacity level show a trend of dynamic improvement year by year. By planning level year 2025 and 2030, the water resources carrying capacity can reach a better level 1 to 2.

5. Conclusions
Based on the indexes system of the water resources in carrying capacity assessment and the fuzzy comprehensive assessment methods, the level of water resources carrying capacity in Heze City is dynamic evaluated. The results show that the water resources carrying capacity level of Heze City are basically at level 2. That is to say, the level of carrying capacity is gradually improved but the effect is not obvious, which needs attention at present. However, the annual evaluation result of planning level is that the bearing capacity is better, which shows that the future planning aims at the sustainable development and utilization of water resources and the benign cycle of water ecology. To adhere to the unified planning of water quantity, water quality and water ecology, to consider the relationship between surface and underground, conservation and protection, utilization and restoration, to make scientific use of water resources, to promote the sustainable development and utilization of water resources and the transformation of economic development mode, can ensure the coordination of social and economic development and water environment carrying capacity.

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