Comprehensive Measuring the Development Level of Water Resources Circular Economy in Beijing-Tianjin-Hebei Urban Agglomeration

JING YANG, PING JING*, DIE GAO
College of Geography and Environmental Sciences, Tianjin Normal University, Tianjin 300387, China
*Corresponding author’s E-mail: jingpping@sina.com

Abstract. With the rapid increasing population and rapid economic development, water shortages and water environmental pollution problems have become increasingly prominent. In this paper, based on the concept of circular economy, starting from the four dimensions of water supply, water use, drainage, and regeneration, the comprehensive evaluation index system was established for Beijing-Tianjin-Hebei about water resource circular economy, the entropy weight method is used to determine the index weight, and the weighted comprehensive index method is used to comprehensively evaluate the development level of water resources circular economy. The results show that the development level of water resources circular economy has spatial heterogeneity in 13 cities of Beijing-Tianjin-Hebei from 2012 to 2016, which is in a state of unbalanced development. The utilization of water resources in Beijing and Tianjin is significantly better than that of other cities in Hebei Province. Only Chengde and Qinhuangdao have better water resources recycle in Hebei Province.

1. Introduction
The Beijing-Tianjin-Hebei urban agglomeration is located in the north-central of the North China Plain. With the rapid development of industrialization and urbanization, the problems of regional water pollution, water shortages, and low efficiency of water use have become increasingly prominent [1], which is a bottleneck effect on social and economic development. The development concept of circular economy must be adopted to analyze and evaluate the development level of regional water resources circular economy, to provide a basis for environmental management and decision-making.

Based on the concept of circular economy, this paper constructs an evaluation index system from the four dimensions of water supply, water use, drainage, and regeneration. The entropy method is used to determine the weight of the evaluation index, and the comprehensive index of the development level of water resources circular economy is calculated, which can judge the development trend of water resources circular economy in the Beijing-Tianjin-Hebei urban agglomeration, and provide theoretic support to implement the management policy.

2. Index system and data source
2.1. Index screening
To establish index system should follow the principles of scientific, systematic, operability and comprehensiveness [2]. According to the water supply, discharge and utilization in the Beijing-Tianjin-
Hebei region, the relevant indicators are selected. A system of 22 evaluation indicators in four categories has been constructed. The comprehensive evaluation of water resources circular economy in the Beijing-Tianjin-Hebei urban agglomeration is taken as the goal, and the water supply index, water use index, drainage index, and recycling index are taken as the criterion level. The water supply index includes 5 indexes (Total water supply (C1), Total water resources (C2), Surface water resources (C3), Groundwater resources (C4), New water intake (C5)), and the water use index includes 7 indexes (Water consumption (C6), Industrial water consumption (C7), Agricultural water consumption (C8), Urban public water consumption (C9), Residential water consumption (C10), Urban environmental water consumption (C11), Daily domestic water consumption per capita (C12)), The discharge index includes 3 indexes (Sewage discharge (C13), Industrial wastewater discharge (C14), Drainage pipe length (C15)), the regeneration indexes include 7 indicators (Repeat utilization (C16), Repeat utilization rate (C17), Sewage treatment volume (C18), Sewage treatment rate (C19), Reclaimed water utilization (C20), Reclaimed water production capacity (C21), Save water (C22)).

2.2. Data sources
The data mainly can be acquired from the 2013 to 2017 with China Statistical Yearbook, China Urban Construction Statistical Yearbook, China Environmental Statistical Yearbook, Beijing Water Resources Bulletin, Tianjin Water Resources Bulletin, Hebei Water Resources Bulletin and other relevant statistical yearbooks and bulletins of the Beijing-Tianjin-Hebei urban agglomeration.

3. Research methods
In order to promote the sustainable development among the economic development, social progress and environmental protection of the Beijing-Tianjin-Hebei urban agglomeration, it is necessary to comprehensively evaluate the development level of water resources circular economy in the Beijing-Tianjin-Hebei urban agglomeration. The entropy method are used to process the original data of the evaluation indicators, the weights of the criterion layer and the indicator layer can be obtained, and then the weighted comprehensive index method is used to calculate the comprehensive evaluation value of 13 cities in Beijing-Tianjin-Hebei, which is helpful to propose targeted management and control measures.

3.1. Entropy Weight Method
Generally speaking, according to the difference of the indicators [3], the index weight can be determined by the entropy weight method. The entropy value of an indicator is inversely related to the amount of its effective information and its weight. That is, the larger the entropy value of an indicator, the smaller the variation value of the indicator, the less effective information provided, and the smaller the weight of the indicator. The entropy method is more objective to determine the weight, and is almost unaffected by subjective factors. It effectively compensates for the result inaccuracy caused by human action [4], and which can make the calculation results more true and reliable. Using information entropy to reflect the utility value of the data itself, the weight coefficient of the evaluation index can be calculated, which make the weight value in line with the objective attributes of the data.

Data standardization: There are m valuation objects and n evaluation indicators. Then the original data matrix is \( X = (x_{ij})_{m \times n} \). Standardizing the data of each indicator, and getting the matrix as \( R = (r_{ij})_{m \times n} \):

\[
X = \begin{bmatrix}
    x_{11} & \cdots & x_{1n} \\
    \vdots & \ddots & \vdots \\
    x_{m1} & \cdots & x_{mn}
\end{bmatrix} \quad (1)
\]

\[
R = \begin{bmatrix}
    r_{11} & \cdots & r_{1n} \\
    \vdots & \ddots & \vdots \\
    r_{m1} & \cdots & r_{mn}
\end{bmatrix} \quad (2)
\]

Data standardization is as follows:

For high-quality indicators, there are \( r_{ij} = \frac{x_{ij} - (x_{ij})_{min}}{(x_{ij})_{max} - (x_{ij})_{min}} \);
For low-quality indicators, there are 

\[ r_{ij} = \frac{(x_{ij})_{\max} - x_{ij}}{(x_{ij})_{\max} - (x_{ij})_{\min}}. \]

Determine the entropy value

\[ e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \quad (3) \]

where \( e_j \) represents the entropy value of the \( j \)-th index, \( p_{ij} \) represents the contribution of the \( i \)-th evaluation object under the \( j \)-th index, and defines \( p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \) in case \( p_{ij} = 0 \), then make \( p_{ij} \ln p_{ij} = 0 \).

Determine the index weight

\[ W_j = \frac{g_j}{\sum_{j=1}^{n} g_j} \quad (4) \]

where \( W_j \) represents the weight of the \( j \)-th index, \( g_j \) represents the difference coefficient of the \( j \)-th index, and defines \( g_j = 1 - e_j \).

### 3.2. Weighted comprehensive index method

With the weights of every indicator determined by the entropy method, the weighted comprehensive index method is used to calculate the comprehensive evaluation values of 13 cities in criterion layers and target layers. The calculation formula is shown in table 1:

| Index name | Water supply index | Water use index | Drainage index | Regeneration index |
|------------|--------------------|----------------|---------------|-------------------|
| Method     | \( F_{11} = \sum_{i=1}^{13} \sum_{j=1}^{5} w_{ij} r_{ij} \) | \( F_{12} = \sum_{i=1}^{13} \sum_{j=6}^{12} w_{ij} r_{ij} \) | \( F_{13} = \sum_{i=1}^{13} \sum_{j=13}^{15} w_{ij} r_{ij} \) | \( F_{14} = \sum_{i=1}^{13} \sum_{j=16}^{22} W_{ij} r_{ij} \) |

Where: \( F_{11} \) is the comprehensive score of the water supply index, \( F_{12} \) is the comprehensive score of the water use index, \( F_{13} \) is the comprehensive score of the drainage index, \( F_{14} \) is the comprehensive score of recycling index, \( W_{ij} \) is the weight of the \( i \)-th evaluation object on the \( j \)-th evaluation index, and \( r_{ij} \) represents the standard value of the \( i \)-th evaluation object on the \( j \)-th evaluation index.

Composite index value is calculated as follows:

\[ F_i = \sum_{j=1}^{n} W_j r_{ij} \quad (9) \]

Where: \( F_i \) represents the comprehensive score of the \( i \)-th evaluation object, \( W_j \) represents the weight of the \( j \)-th index, and \( r_{ij} \) represents the standard value of the \( i \)-th evaluation object on the \( j \)-th evaluation index.

### 4. Results and Analysis

#### 4.1. Analysis of weight calculation results

All indicators of water supply indicator belong to high-quality indicators. The weights of each indicator are quite different. The two largest weights are new water intake and total water supply. In 2016, new water intake is 0.438 and total water supply is 0.290. This indicates that the difference in water supply in Beijing-Tianjin-Hebei is mainly affected by new water intake and total water supply. The weights of total water resources, surface water resources and groundwater resources are 0.080, 0.082 and 0.110, respectively, which have little influence. All indicators in the water use index layer belong to low-quality indicators, and the weights of the indicators have little difference, which indicates that the water use
situation in Beijing-Tianjin-Hebei is affected by multiple factors. The weight of each indicator in the drainage indicators has a large difference. The weight of the length of the drainage pipe is the largest one, value is about to 0.5, followed by the amount of industrial wastewater discharge, and finally the amount of sewage discharge. All indicators in the regeneration index layer are high-quality indicators, and the difference in the weight of each indicator is small, indicating that the regeneration and reuse of water resources in Beijing-Tianjin-Hebei is jointly affected by many factors.

The entropy method analyzes the weights of water resources recycling in the Beijing-Tianjin-Hebei region, and it can be used to determine the differences between the weights of various indicators. The weights of water supply indicators, drainage indicators, and recycling indicators are relatively high. The weight of water use indicators is relatively low. Beijing and Tianjin have the best water recycling utilization conditions, Chengde and Tangshan have good water recycling utilization conditions, and other cities in Hebei Province have poor comprehensive water recycling utilization conditions. This shows that Beijing and Tianjin have great advantages in water resources management, utilization, and distribution. Hebei Province needs to gradually improve the level of water resources management and utilization.

4.2. Evaluation result analysis
Using the weighted comprehensive index method, the comprehensive evaluation value of water resource circular economy in the Beijing-Tianjin-Hebei region in 2016 can be calculated (see Table 2), and the comprehensive evaluation value from 2012 to 2015 can be calculated in the same way.

| City         | Comprehensive score of water supply index | Comprehensive score of water use index | Comprehensive score of drainage index | Comprehensive score of recycling index | Composite index value |
|--------------|------------------------------------------|---------------------------------------|--------------------------------------|--------------------------------------|-----------------------|
| Beijing      | 0.974                                    | 0.118                                 | 0.474                                | 0.761                                | 0.855                 |
| Tianjin      | 0.296                                    | 0.239                                 | 0.557                                | 0.331                                | 0.509                 |
| Shijiazhuang | 0.302                                    | 0.373                                 | 0.087                                | 0.227                                | 0.235                 |
| Tangshan     | 0.204                                    | 0.345                                 | 0.062                                | 0.190                                | 0.172                 |
| Qinhuangdao  | 0.151                                    | 0.487                                 | 0.173                                | 0.036                                | 0.161                 |
| Handan       | 0.141                                    | 0.577                                 | 0.166                                | 0.089                                | 0.190                 |
| Xingtai      | 0.179                                    | 0.714                                 | 0.204                                | 0.076                                | 0.233                 |
| Baoding      | 0.219                                    | 0.644                                 | 0.064                                | 0.203                                | 0.222                 |
| Zhangjiakou  | 0.133                                    | 0.742                                 | 0.088                                | 0.119                                | 0.182                 |
| Chengde      | 0.187                                    | 0.745                                 | 0.403                                | 0.141                                | 0.373                 |
| Cangzhou     | 0.002                                    | 0.780                                 | 0.228                                | 0.035                                | 0.181                 |
| Langfang     | 0.006                                    | 0.803                                 | 0.176                                | 0.014                                | 0.148                 |
| Hengshui     | 0.002                                    | 0.911                                 | 0.330                                | 0.016                                | 0.242                 |

The comprehensive evaluation results of the circular economy of water resources in Beijing and Tianjin from 2012 to 2016 were excellent, ranging from 0.752 to 0.886 and 0.509 to 0.574, respectively, ranking first and second, which reflects the dual-core location. Tangshan, Chengde, Qinhuangdao and Handan showed a downward trend in the comprehensive evaluation value of water resources circular economy from 2012 to 2016, the value is 0.316, 0.498, 0.280 and 0.269 in 2012 and 0.172, 0.373, 0.161 and 0.190 in 2016, respectively. The average annual decline rates were 14.11%, 6.97%, 12.92% and 8.33%. In total, Chengde's comprehensive evaluation value of water resources recycling economy is in the range of 0.295 to 0.498, ranking third. As for other cities in Hebei Province, the results of the comprehensive evaluation of water resources circular economy from 2012 to 2016 were poor and the range of changes was not large, which is closely related to the development level of the three major industries, population, technical level, and infrastructure.
The comprehensive evaluation results show that the development level of circular economy of water resources in 13 cities has obvious differences in Beijing-Tianjin-Hebei from 2012 to 2016, distribution characteristics belong to "Beijing and Tianjin are high and Hebei is low", and the development status of water resources is unbalanced. The utilization of water resources in Beijing and Tianjin is significantly better than other cities in Hebei Province. In Hebei Province, Chengde and Qinhuangdao have better water recycle utilization.

5. Conclusion
Water resources are the important material basis for the development of industry, agriculture, and urban areas, also are an important support for the economic development and social progress of a country and region. Stable and high-quality water resources are very important to the development of urban agglomeration. The water resources circular economy system of the Beijing-Tianjin-Hebei urban agglomeration is divided into four dimensions: water supply, water use, drainage, and regeneration. The comprehensive evaluation index system has been established for the circular economy of water resources in the Beijing-Tianjin-Hebei Region, and the entropy method is used to determine the weights effectively and objectively, in order to avoid the influence of human subjectivity.

In the comprehensive evaluation of the development level of the water resources circular economy in Beijing-Tianjin-Hebei, the evaluation index system is constructed based on the concept of circular economy development, and the entropy method is used to determine the weight of the evaluation index. It can be determined that there is a certain difference between the weights of various indicators. Water supply indicators, drainage indicators, and regeneration indicators have relatively higher weights, while water use indicators have lower weights.

The comprehensive weighted index method is used to calculate the comprehensive index of the development level of water resources circular economy, and provide theoretical support for the implementation of related policies. The comprehensive evaluation results of the circular economy of water resources in Beijing and Tianjin from 2012 to 2016 were relatively good, reflecting the location advantage of dual-core; Tangshan, Chengde, Qinhuangdao and Handan’s comprehensive evaluation value of water resources circular economy is declining. The comprehensive evaluation results of water resources recycling economy in other cities in Hebei Province are poor and have little change. This is closely related to the development of the three major industries, population, technical level, and infrastructure.

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