Safety Assessment of Urban Water Metabolism Based on PSR Framework——— Taking Tianjin City as an Example

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Abstract. The complex urban water circulation system is developing in a more severe and complicated direction, and the phenomenon of urban water metabolism imbalance and water metabolism crisis become more and more obvious. The PSR framework model is introduced to construct the urban water metabolism safety evaluation index, and the entropy weight method is used to determine the weight of the corresponding evaluation index and the calculation of the safety index, at the same time, taking Tianjin city as an example. Research results show that, the evolution process of water metabolism in Tianjin showed a trend of development during the evaluation period, that is, obviously improved in the early stage, stable in the medium term, and decreased in the later period, the empirical data show that the evaluation results are reasonable.

1. Introduction

Compared with the orderly and self-organized natural water circulation system, the urban complex water circulation system is moving in a more intense and complicated direction by the comprehensive role and profound impact of the scale of population and the pressure of economic and social development. With the continuous expansion of the impact of social and economic activities, the competition between water consumption in different industries is fierce, environmental capacity and emissions of contradictory sharp, urban water shortage, urban water pollution and urban water ecological degradation is particularly prominent, the resulting urban complex water cycle metabolic imbalance and metabolic security crisis is more significant. Therefore, based on this related to promote the metabolic healthy operation of urban water cycle system and the realization of urban water resources security and efficient use of research will have an urgent practical significance.

With urban water metabolism safety connotation analysis and conceptual system development process continues to deepen, the domestic and foreign related research is gradually turning to explore the evaluation method based on the deep understanding of urban water metabolism safety connotation, and the evaluation index system of urban water metabolism safety was established by using different methods and research paths such as fuzzy sets ([1]; [2]), entropy weight method ([3]), multiple regression structure ([5]), water footprint ([6]; [7]) etc., and the evaluation method of urban water metabolism safety was enriched. However, some scholars believe that, because the concept of water metabolism safety itself is still expanding, so far there is no uniform water metabolism safety evaluation standards and methods ([8]). More importantly, due to the limitations of the relevant evaluation tools and methods, the study of urban water metabolism safety assessment has not been able to play an ideal interpretation and prediction of water metabolism imbalance. In view of this, this paper explores the problem of urban water metabolism safety evaluation from the perspective of complex system, using PSR framework model and entropy weight method to take the metabolic PSR mechanism of urban complex water circulation system as a fundamental angle of view, in order to establish scientific and reasonable urban water metabolism safety evaluation index, and to a certain extent, promote the development of water metabolism safety research field evaluation method.
2. Method

2.1. Construction of Water Metabolism Safety Evaluation Index

The determination of the evaluation index is the basic condition and important prerequisite for the comprehensive evaluation and quantitative analysis of the degree of urban water metabolism safety. The PSR framework model is widely used in the development of human society to produce the pressure on the ecosystem caused a series of ecological security issues of evaluation and early warning research for its "natural - social" binary coupling system between the elements of the causal relationship between the scientific interpretation and logical advantages, and with its simple optimization, structured and logical clarity and other characteristics in the environment, ecology, land use and other research areas to obtain good application and feedback. The urban water metabolism process as a typical "natural-social" binary complex coupling system characterization phenomenon, fully based on the PSR framework analysis tools within the scope of systematic evaluation. In this paper, the PSR framework model is introduced to construct a reasonable and scientific evaluation index of urban water metabolism safety, at the same time to Haihe River Basin in Tianjin as an empirical object for the collection of indicators of data, At the same time to Haihe River Basin in Tianjin as an empirical object for the collection of indicators of data, the data collected in this paper are mainly based on the "China Statistical Yearbook", "Tianjin Statistical Yearbook" and "Tianjin Water Resources Bulletin" in the evaluation period (2006-2015).

Table 1. Urban water metabolism safety PSR evaluation index

| Target layer | System layer | Numbering | Index layer | Dimension | Nature |
|--------------|--------------|-----------|-------------|-----------|--------|
| Urban Water Metabolic Pressure | P1 | Per capita GDP | yuan | negative |
| | P2 | Water resources development intensity | % | |
| | P3 | COD emission intensity | Million tons | negative |
| | P4 | Fertilizer application strength | Million tons | negative |
| | P1 | Pesticide application intensity | Million tons | negative |
| Urban Water Metabolic State | S1 | Per capita water resources | m³/per | positive |
| | S2 | Water quality condition index | — | positive |
| | S3 | Water use efficiency | % | positive |
| | S4 | Ecological environment | % | negative |
| | S5 | Groundwater overrun rate | % | negative |
| Urban Water Metabolic Response | R1 | Environmental management investment rate | % | positive |
| | R2 | Industrial water repetition rate | % | positive |
| | R3 | Domestic sewage treatment rate | % | positive |
| | R4 | Water quality comprehensive compliance rate | % | positive |
| | R5 | Sewage discharge compliance rate | % | positive |

2.2. Determination of Index Weight and Safety Index

In view of the accuracy of the subjective evaluation method, too much depends on the level of experience of the evaluators, the inevitable result bias often exists and the evaluation does not conform to the facts, so it is possible to control distractors and ensure the rigorous and credibility degree of the system evaluation, the use of the system to measure the degree of disorder degree of entropy method for urban water metabolism safety evaluation index weight and safety index to determine the work. The evaluation principle is to analyze the relative merit of the object to be evaluated, and to calculate and compare the close distance between the optimal solution of the analysis unit, evaluation standard is that when the object is close to the optimal value and away from the worst when more ideal. The specific operation flow is as follows:
2.2.1. Construction of evaluation matrix. Constructs the initial evaluation matrix $X$, and contains the judgment object $m$ and the judgment index $n$, the matrix form is as follows:

$$ X = (x_{ij})\_{m \times n}, \quad i = 1, 2, ..., m; \quad j = 1, 2, ..., n $$

2.2.2. Standardized matrix processing. In view of the existence of certain differences in the indicators measurement units, and have a greater impact on the follow-up index entropy weight determination and comparison work. In addition, the different indicators on the urban water metabolism safety state of the role of the nature of the difference, leading to its direction of play (positive and negative effects) are also different, as shown in table 1. Therefore, the initial data of the original price matrix $X$ is standardized by dimensional standardization, and the evaluation indexes of different properties are processed as follows:

For the evaluation of the positive nature of the indicators, the increase in such indicators will be conducive to the improvement of urban water metabolism safety status, the standardization formula is as follows:

$$ x'_{ij} = \frac{x_{ij} - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}} $$

For the evaluation of the negative nature of the indicators, the increase in such indicators will lead to urban water metabolism safety state out of control, the standardization formula is as follows:

$$ x'_{ij} = \frac{x_{\text{max}} - x_{ij}}{x_{\text{max}} - x_{\text{min}}} $$

Among them, $x_{ij}$ indicates the initial value of the object to be evaluated, $x'_{ij}$ is the index value after dimension normalization, $x_{\text{max}}$ and $x_{\text{min}}$ represent the best value of the corresponding evaluation index respectively.

2.2.3. Determination of entropy weight of index. The entropy weight method is used to determine the index weight of each evaluation index, this method is used as an objective weighting method in information theory to represent information entropy, can fully tap and reflect the implicit information and make the system within the evaluation of the resolution of the meaning of a more clear, the specific calculation process is as follows:

$$ y_j = \frac{h_j}{\sum_{i=1}^{m} y_i \ln y_i}, \quad 0 < y_j < 1 $$

$$ h_j = -\frac{1}{\ln m} \sum_{i=1}^{m} y_i \ln y_i $$

$$ W_j = \frac{1 - h_j}{\sum_{i=1}^{m} (1 - h_i)} $$

Among them, the information entropy of each evaluation index is calculated as $h_j$, the entropy weight of each evaluation index is calculated as $W_j$.

2.2.4. Determination of relative merits. After the entropy weight is determined, the evaluation matrix $Y_j$ after normalization is weighted to establish the weighted decision matrix, that is

$$ V = [V_{ij}]_{m \times n} = W_j \times Y_j $$

Among them, the weighted solution matrix positive and negative ideal solution (with the corresponding $V^+_j$ and $V^-_j$ respectively) can be expressed as the following form:
Finally, in order to determine the relative merit of each index, the distance between the evaluation index and the positive and negative ideal solution needs to be determined and can be expressed as the following form. At the same time, the lower the T value is, the smaller the distance between the evaluation index and the ideal solution is, and the better the urban water metabolism safety state. Similarly, the lower the Y value is, the smaller the distance from the negative ideal solution, and is reflected in the city water metabolism safety state out of control.

\[
\begin{align*}
D_i^+ &= \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}, (i = 1, 2, \ldots, m) \\
D_i^- &= \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, (i = 1, 2, \ldots, m)
\end{align*}
\]

2.2.5. Calculation of safety index. The safety degree of urban water metabolism safety is expressed by the degree of closeness \(C_i\) between the evaluation index and the optimal scheme, where the value of the proximity degree \(C_i\) should be within the range of (0, 1), when the bigger to the degree of \(C_i\), that is, the corresponding evaluation of the object and the optimal solution closer to the city water metabolism more healthy state of health.

\[
C_i = \frac{D_i^-}{D_i^+ + D_i^-}, (1 \leq i \leq m)
\]

At the same time, drawing on the relevant literature results ([9]; [10]; [11]) and the status of water metabolism in Tianjin, divided to characterize the degree of urban water metabolism safety and health of the safety index, as shown in Table 2.

| Urban water metabolism safety index interval | Degree of urban water metabolism safety and health |
|---------------------------------------------|--------------------------------------------------|
| >0.0~0.1                                   | Severe safety                                   |
| >0.1~0.3                                   | Poor safety                                     |
| >0.3~0.6                                   | Critical state                                  |
| >0.6~0.9                                   | Good security                                   |
| >0.9~1.0                                   | Excellent security                              |

3. Result and Discussion

3.1. Empirical Evaluation Results

First of all, after the above experimental process, the entropy of each index of urban water metabolism safety PSR is shown in table 3. According to the evaluation results, the water resources development strength (WP2=0.069) and COD emission intensity (WP3=0.046), water quality index (WS2=0.072) and the utilization rate of water resources (WS3=0.130) and environmental governance investment rate (WR1=0.109) and the sewage discharge standard rate (WR5=0.107) were the main influencing factors of urban water metabolism safety pressure, safety status and safety response system respectively within the experimental period.
At the same time, the effect of urban water metabolism safety response on the overall urban water metabolism safety evaluation (WR = 0.476) is the most significant, indicating that the health status of water metabolism in Tianjin depends largely on the social level of urban water metabolism response measures. In addition, it can be seen that the improvement of environmental management investment rate as a typical government water governance behavior measures have a strong positive effect on the overall urban water metabolism safety (WR1 = 0.109, the highest weight of the evaluation index), this point to a certain extent for the evaluation results provided a confirmation.

Table 3. Urban water metabolism safety PSR evaluation index entropy weight

| PSR evaluation index entropy weight               |
|------------------------------------------------|
| P     | P1 | P2 | P3 | P4 | P5 |
| entropy | 0.03 | 0.06 | 0.04 | 0.03 | 0.02 |
| weight | 2 | 9 | 6 | 8 | 6 |
| S     | S1 | S2 | S3 | S4 | S5 |
| entropy | 0.02 | 0.07 | 0.10 | 0.05 | 0.05 |
| weight | 6 | 2 | 6 | 0 | 9 |
| R     | R1 | R2 | R3 | R4 | R5 |
| entropy | 0.10 | 0.08 | 0.09 | 0.08 | 0.10 |
| weight | 9 | 0 | 4 | 6 | 7 |

Through the treatment of weighted decision matrix and the calculation of urban water metabolism safety indicators, the comprehensive evaluation results are shown in Fig 1. According to the comprehensive evaluation results, it is concluded that the safety status of water metabolism in Tianjin shows a trend of "obvious improvement in the early period, medium-term stable but late decline", among them, 2008 and 2012 for two important turning point, and accordingly divided into three cities metabolic safety trends change year interval. On the other hand, the urban water metabolism safety indicators of each year are above the critical state, and the system safety and health degree in 2008 - 2012 and 2014 are "safe", but in recent years the overall security trend has declined significantly, need to take measures to actively respond.

Figure 1. Urban water metabolism safety index evolution trend

3.2. Empirical Evaluation Analysis

The comprehensive evaluation conclusion shows that the water quality of Tianjin in 2006-2008 has been improved continuously, the safety status of water metabolism in 2008 - 2012 has maintained a good and healthy development trend and gradually stabilized, but the degree of security has dropped significantly and showing uncertain fluctuations in the state in 2012 ~ 2015. Overall, the urban water metabolic safety situation in Tianjin is not ideal, and according to the actual feedback from the relevant data (such as the public data of Tianjin Water Resources Bulletin over the years), this general trend can better explain the evolution of water metabolism in Tianjin. 2006 (and before) Tianjin has long been in urban water metabolic disorders caused the shortage of urban water resources, water
supply tense relations and urban water pollution seriously and other serious situation, in order to cope with and alleviate the crisis of water metabolism in Tianjin, the relevant departments have actively carried out the response measures such as the Luan River and the Yellow River water into Tianjin and water source protection, and achieved remarkable results to achieve a significant improvement in the urban water metabolism safety situation in the 2007-2008 year. At the same time, with the relevant policies (such as water transfer projects, water restrictions, sewage treatment, etc.) landing and efficient use of water resources and awareness of conservation, making the mid-term (2008 - 2012) ushered in the Tianjin water metabolic security status of good maintenance and sustained stability. However, late (after 2012) urban water metabolism safety and health status is not ideal, or even a significant ups and downs and fall. Through the investigation of the historical data of water metabolism in Tianjin, it can be found that the main causes of the above-mentioned situation are as follows: 1. since 2013, the annual precipitation in Tianjin has been gradually reduced and continuously entered into the low water years (including 2015, the level of flat water), And with the spatial and temporal distribution of precipitation, the city’s surface water resources and reservoir water storage capacity continued to decline, and with the increase in water demand intensity led to the city water supply and demand relationship disorder; 2. The late waste water discharge increased rapidly, this index for 2015 data for the 6.136 million tons, compared with 2012 increased by 7.88%, in the context of urban water recycling capacity has not been greatly improved, make urban water pollution further deteriorated. The two driving forces together contributed to the non-sustainable development of water metabolism in Tianjin.

4. Conclusion

In this paper, the urban water metabolism safety evaluation as the research object, the use of complex system research perspective, the introduction of PSR framework model to build urban water metabolism safety evaluation index. In order to avoid the deviation of the evaluation result caused by the subjective evaluation method, the entropy weight method is used to determine the weight of the evaluation index and the calculation of the safety index, and the data acquisition and conclusion analysis are made in Tianjin as the empirical case. According to the results of Tianjin water metabolism safety evaluation, it is found that the evolution process of water metabolism safety in the empirical area shows a development trend of "obvious improvement in the early stage, stable in the middle period and ups and downs in the later period". The research is beneficial to the development of the evaluation method of water metabolism safety research field, and it has certain reference value for Tianjin water metabolism safety evaluation and management policy.

5. References

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