Development Level Evaluation of Water Ecological Civilization in Yangtze River Economic Belt

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1.Introduction

Water is the source of life, the crux of production, and the foundation of ecology. Therefore, it is of great significance to protect water resources and maintain a good water ecological environment. China’s total freshwater resources are 2.8 trillion cubic meters, accounting for 6% of global water resources, ranking fourth in the world, but per capita is only 2,300 cubic meters, only a quarter of the world average; at the same time, China faces severe challenges from water shortage, pollution of water bodies, and imbalanced distribution of water in time and space. To realize the strategic goal of WEC development, China has taken meaningful measures for the environmental safety of water resources, speeding up the implementation of water resources management system, reasonably allocating water resources, saving water, and planting trees to prevent soil erosion and other measures.

Overall, relatively few foreign literatures clearly put forward the word. Most foreign scholars engaging in WEC tackle the sustainable utilization of water resources, basin management for ecological protection, water environment safety and management, etc. Therefore, it is worthwhile to learn from foreign research of water resources management, water environment protection, and water eco-environment restoration and management. The foreign research of water eco-environment evaluation can be tracked back to the Clean Water Act 1972. Due to the various factors involved in water ecology, many different evaluation systems have been established from diverse angles, namely, fish index of biotic integrity [1], biotic integrity index [2], rapid bioassessment protocols (RBPs) [3], and index of stream condition (ISC) [4]. In addition, some scholars carried out systematic research in river health theory [5], river health evaluation...
2. Methodology

2.1. EIS Construction. Following the framework of the index system in Evaluation Guide of Water Ecological Civilization Construction (SL/Z 738-2016) and drawing on relevant literature [11–13], this paper extends the pressure-state-response (PSR) model of United Nations Environment Programme (UNEP) into an EIS for the YREB WECD level. The data of the selected indices are scientific, comprehensive, and available. Specifically, the pressure subsystem contains five indices, the state subsystem contains five indices, and the response subsystem contains seven indices (Table 1).

2.2. Modelling. This paper sets up a set pair analysis (SPA) model to objectively evaluate the YREB WECD level.

2.2.1. Construction of Evaluation Matrix. Suppose the evaluation system is a set $E = \{e_1, e_2, \ldots, e_n\}$ of $n$ objects, where $e_n$ is the $n$th object. Each object needs to be evaluated against $m$ indices $F = \{f_1, f_2, \ldots, f_m\}$, where $f_m$ is the $m$th index. The scores of each index are recorded as $d_{ij}$, $i = 1, 2, \ldots, n; j = 1, 2, \ldots, m$. Following the idea of SPA, a multiobjective evaluation matrix $Q$ can be obtained:

$$Q = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ d_{m1} & d_{m2} & \cdots & d_{mn} \end{bmatrix}.$$  

The indices in matrix $Q$ are compared to select the optimal indices of each evaluation scheme, forming the best evaluation set $U = [d_{u1}, d_{u2}, \ldots, d_{un}]^T$, and the worst evaluation set $V = [d_{w1}, d_{w2}, \ldots, d_{wm}]^T$, where $d_{uj}$ is the score of the $c_{pk}$th index in the best evaluation set, i.e., the optimal score among the $[v_{p}, u_{p}]$ indices in matrix $Q$, and $d_{vj}$ is the score of the $c_{pk}$th index in the worst evaluation set, i.e., the worst score among the $[v_{p}, u_{p}]$ indices in matrix $Q$.

By comparing the score $w_p$ of each index in the evaluation matrix and the score $d_{uj}$ of the corresponding index in the optimal evaluation set, the weighted similarity matrix $A$ can be obtained for each object and set $[U, V]$:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}.$$

By comparing the score $w_p$ of each index in the evaluation matrix and the score $d_{vj}$ of the corresponding index in the worst evaluation set, the weighted difference matrix $B$ can be obtained for each object and set $[U, V]$:

$$B = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mn} \end{bmatrix}.$$

In matrices $A$ and $B$, $\frac{a_{pk} = (u_{p} v_{p} / (u_{p} + v_{p}))}{c_{pk} = (d_{pk} / (u_{p} + v_{p}))}$; $b_{ij}$ is the similarity and difference between index $f_m$ and set $[U, V]$, respectively.

If $d_{ij}$ has a positive effect on the evaluation result,

$$a_{ij} = \frac{d_{ij}}{d_{uj} + d_{ij}},$$

$$b_{ij} = \frac{d_{u} d_{v}}{d_{ij} (d_{uj} + d_{ij})}.$$  

If $d_{ij}$ has a negative effect on the evaluation result,

$$a_{ij} = \frac{d_{u} d_{v}}{d_{ij} (d_{uj} + d_{ij})},$$

$$b_{ij} = \frac{d_{ij}}{d_{uj} + d_{ij}}.$$  

2.2.2. Construction of the Evaluation Model. According to the weights of indices $W = (w_1, w_2, \ldots, w_m)$ in the EIS for the YREB WECD level, the similarity matrix $A$, the weighted similarity matrix $A_w$ can be obtained for each object and set $[U, V]$:
2.2.3. Calculation of Relative Closeness. The relative closeness \( r_j \) between the \( j \)th object and the optimal evaluation set \( U = (d_{11}, d_{12}, \ldots, d_{mn})^T \) can be calculated by

\[
  r_j = \frac{a_j}{a_j + b_j}.
\]

On this basis, the relative closeness matrix \( R \) can be derived for all objects:

\[
  R = (r_1, r_2, \ldots, r_m).
\]

The relative closeness \( r_j \) represents the association between an object and the optimal evaluation set

\[
A_w = W \times A = (w_1, w_2, \ldots, w_m) \times \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} = (a_1, a_2, \ldots, a_n),
\]

where \( a_j \) is the similarity between the \( j \)th object and set \([U, V]\).

Similarly, the weighted difference matrix \( B_w \) can be obtained for each object and set \([U, V]\):

\[
B_w = W \times B = (w_1, w_2, \ldots, w_m) \times \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mn} \end{bmatrix} = (b_1, b_2, \ldots, b_n),
\]

where \( b_j \) is the difference between the \( j \)th object and set \([U, V]\).

2.3. Index Weighting. Using information entropy, the entropy method calculates the objective weight of each evaluation index, according to the degree of variation of that index. This objective weighting method can prevent the bias induced by subjective factors. Hence, the entropy method is adopted here to assign weights to the indices for the YREB WECD level.

Before multilayer composite evaluation, it is necessary to carry out calculation layer by layer. That is, the initial model should be applied on factors of multiple layers. The evaluation result of the current layer should be introduced to the composite evaluation of the next superior layer. This measure should be repeated until reaching the highest layer.
The research data mainly come from China Statistical Yearbooks (2011–2020), Yearbooks of China Water Resources (2011–2020), and China Environment Yearbooks (2011–2020), as well as the statistical yearbooks, water resources bulletins, statistical bulletins of national economy and social development, and environmental bulletins issued by YREB regions in 2011–2020. The original data were sorted comprehensively before use.

3. Results’ Analysis

3.1. Spatiotemporal Level of WECD. Through SPA on the original index data, the scores of the three subsystems of our EIS were obtained (Table 2).

Next, an SPA was carried out again on the scores of each subsystem, using the subsystem weights in Table 1. Through comprehensive computation, the composite scores of the YREB WECD level were obtained for 2010–2019 (Table 3).

From Tables 2 and 3 and Figure 1, it can be observed that the scores of pressure, state, and response subsystems in the YREB WECD level evaluation changed stably, exhibiting a linear growth. From 2010 to 2019, the score of pressure subsystem increased from 0.3014 to 0.5187, with an annual mean growth rate of 6%. The result show that YREB achieved a good result on water eco-environmental protection in 2020–2019, and the pressure on WECD in the region continued to decrease. From 2010 to 2019, the score of state subsystem increased rapidly, except for the decline in 2015. It can be inferred that, from 2010 to 2019, YREB invested more funds and technologies, improved water utilization efficiency, and stepped up the protection of water resources and water environment, aiming to enhance the water eco-environmental quality and strengthen the environmental carrying capacity of water resources. These measures led to a continuous improvement of the WECD level in YREB.

Further observation of Figure 1 reveals that the overall WECD level of YREB continued to rise in 2010–2019, following the same trajectory as the scores of the three subsystems. Therefore, YREB boasts a strong competitiveness in water eco-environment and a high WECD level. Despite facing long-term heavy pressure of WECD, different regions of YREB have taken forceful protective measures for water environment and water

### Table 2: Scores of the three subsystems, 2010–2019.

| Year | Pressure subsystem | State subsystem | Response subsystem |
|------|--------------------|----------------|--------------------|
| 2010 | 0.3104             | 0.3067         | 0.4016             |
| 2011 | 0.2952             | 0.3100         | 0.4467             |
| 2012 | 0.3148             | 0.3228         | 0.4931             |
| 2013 | 0.3517             | 0.3623         | 0.5214             |
| 2014 | 0.3951             | 0.3976         | 0.5422             |
| 2015 | 0.4014             | 0.4285         | 0.5413             |
| 2016 | 0.4580             | 0.4899         | 0.5604             |
| 2017 | 0.4549             | 0.5024         | 0.5836             |
| 2018 | 0.4962             | 0.5459         | 0.6012             |
| 2019 | 0.5187             | 0.5998         | 0.6453             |

The entropy method was applied to solve the weights of the EIS for the YREB WECD level in 2010–2019 (Table 1). The solved weights are listed in Table 1.

### Table 1: Entropy weights for the YREB WECD level.

| Year | Weight |
|------|--------|
| 2010 | 0.3014 |
| 2011 | 0.2952 |
| 2012 | 0.3148 |
| 2013 | 0.3517 |
| 2014 | 0.3951 |
| 2015 | 0.4014 |
| 2016 | 0.4580 |
| 2017 | 0.4549 |
| 2018 | 0.4962 |
| 2019 | 0.5187 |
resources, which ensure the continued improvement of the overall WECD level and water eco-environmental carrying capacity in YREB from 2010 to 2019.

4. Conclusions

This paper firstly measures the YREB WECD levels in 2010–2019 and then analyzes the spatiotemporal trend of the WECD levels through SPA. The main conclusions are as follows:

1. From 2010 to 2019, the scores of pressures, state, and response subsystems in YREB WECD level evaluation changed stably, exhibiting a linear growth. The overall WECD level of YREB continued to rise in 2010–2019, a sign for strong competitiveness in water eco-environment and high WECD level.

2. The good development trend of YREB WECD in 2010–2019 is inseparable from the fact that YREB stepped up its efforts in capital investment, water utilization, and water environment protection and recovery. To future improve WECD level and achieve the harmony between human and water, YREB should make further efforts to improve water management system, reinforce water supervision, and protect and repair water ecosystem.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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