Original Research

Study on River Health Assessment Weight Calculation

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Abstract

Weight calculation plays an important role in river health assessment. There are two main classes of methods for determining index weights: subjective weight-assignment methods and objective weight-assignment methods. Both types of methods have their own advantages and disadvantages. Subjective weight-assignment methods reflect the intention of decision makers with certain subjectivity. Objective weight-assignment methods mainly rely on complete mathematical theories and methods and tend to ignore the subjective information of the decision makers; thus, they do not consider the differences among index. Both methods have deficiencies. To make the calculation of index weights more rational, this study introduces a combined weight-assignment idea based on game theory. This method combines a subjective weight-assignment method (analytic hierarchy process) with an objective weight-assignment method (entropy method) to calculate the weight, which avoids the subjectivity of subjective weight-assignment methods and the absolute objectivity of the objective weight-assignment methods. The Luanhe River in the Haihe River Basin was selected as the study area, and the weight of the health evaluation index system of the Luanhe River was calculated using the combined weight-assignment method to assess the degree of influence of each index on river health. The research shows that using this method to calculate the weight has important practical applications for river health assessment.

Keywords: river health assessment, subjective weight-assignment method, objective weight-assignment method, combined weight-assignment method

Introduction

River ecosystem functions include regulating the weather, improving ecological environments, maintaining biodiversity, and providing services to society [1, 2]. A healthy river should be the dialectical unity of natural attributes [3, 4], such as the environment, as well as social attributes, such as ecosystem services [5, 6]. A healthy river should be both a river with a healthy ecosystem and a river where people and water exist in harmony. River health status is an assessment tool for river management

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[7, 8], with river managers managing river status through river health assessment. Its purpose is to establish an evaluation system to assess the changes of river health during the long-term evolution of rivers under the dual effects of natural forces and human activities – particularly in order to develop river ecology through management [9, 10]. (By the way, weight assignment in the health evaluation index system is an important part of river health assessment [11].)

Two main classes of methods are used to determine index weights: subjective weight-assignment methods and objective weight-assignment methods [12]. A subjective weight-assignment method is based on an individual's subjective opinion of each evaluation index; examples of this method include the Delphi method, binomial coefficient method, analytic hierarchy process (AHP), and decision alternative ratio evaluation system (DARE). An objective weight-assignment method assigns corresponding index weights according to the original data for calculation, and includes methods such as principal component analysis, the mean square method, and the entropy method [13].

Both methods have their own advantages and disadvantages. Subjective weight-assignment methods reflect the intention of decision makers with certain subjectivity and are influenced by the evaluation subject [14]. Different individuals will assess the same evaluation object independently and may not always agree. The objective weight-assignment method mainly relies on mathematical theories and methods. Based on objective data, this method tends to emphasize the statistical laws of data and ignore the subjective information of the decision makers, including the 'real' situation the data represents. Both methods have defects, and a good way to avoid some of these faults is to assess the importance of each index and to combine the objectivity of the objective weight-assignment without the influence of human factors [15, 16].

In order to balance the decision makers' preference for attributes, and to reduce the randomness of the weight-assignment to ensure that the subjectivity and objectivity of the weight-assignment of attributes can unite, many experts have proposed a method that combines the two methods: namely, a combined weight-assignment method that embodies the idea of system analysis [17,18]. This paper proposes a combined weight-assignment method based on game theory [19], a method for studying competitive things. Game theory analyzes rational behavior and decision equilibrium when multiple decision-making actors interact with each other. In game theory, it can be assumed that each scheme is the result of rational decision making, and that the decision made by the decision makers is done to maximize their own profits or minimize their own losses. This kind of competition outcome is not controlled by one party's decisions, but instead by all decision makers [20]. When all parties in the game coordinate to find the maximum common interest in the decision-making process, there will be a compromise. Nash equilibrium is to find consistency and compromise among different weights, thereby minimizing the deviation between the combined weight and the weight of individual factors; thus minimizing the sum of deviations in order to maximize the common interest.

In this paper, the AHP and the entropy method are selected as representative methods of the subjective weight-assignment method and the objective weight-assignment method, because these two methods are more typical.

The AHP [21] is a decision-making method that conducts qualitative and quantitative analysis based on the decomposition of elements related to decision-making goals, criteria, and programs. This method [22] is characterized by the in-depth analysis of the nature and influencing factors of a complex decision problem, and the internal relationships between index using less quantitative information to quantify the thinking process of decision making. This transforms multi-objective and multi-criterion complex problems with no structural characteristics into a simple decision-making method. The AHP generally includes several steps, such as constructing a hierarchical model, establishing a judgment matrix, calculating a weight vector, and completing a consistency test.

In information theory, entropy is a measure of the degree of disorder in the system. Entropy can measure the effective information provided by the data. The larger the amount of information, the smaller the degree of disorder and uncertainty in the system; therefore, the less entropy. Conversely, the smaller the amount of information, the greater the uncertainty and, consequently, greater entropy. The entropy method [23] uses index entropy to determine the weight of the index.

In order to logically combine these two types of weight-assignment methods so that the determined weights simultaneously reflect both subjective and objective information, this paper calculates the weight of the Luanhe River health assessment index as an example and analyzes two types of weight-assignment methods. The subjective weight determination method (AHP) and the objective weight determination method (entropy method) are used to determine the weight of the Luanhe River health evaluation index system individually, then the combined weight-assignment method is used to calculate the final weight value of the Luanhe River health assessment index system.

Material and Methods

Study Area

The Luanhe River is located in the eastern part of Hebei Province in China and is the second largest river in the province. The Luanhe has a drainage area of 54400 km², which is approximately 24.4% of the total area of Hebei Province (Fig. 1). The river originates in Fengning, Hebei Province, and passes through Wuyuan
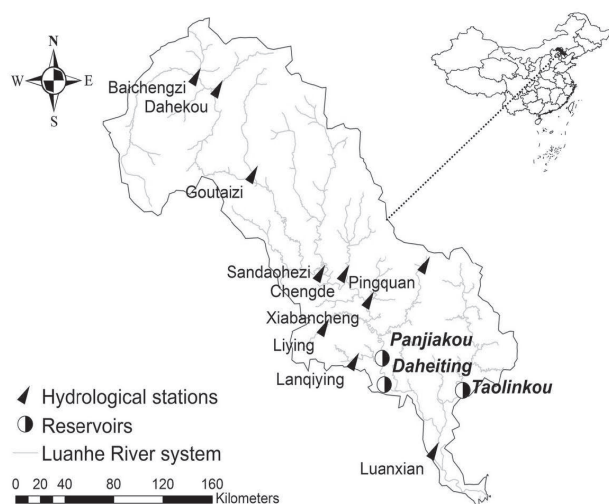
Fig. 1. Location of the Luanhe River.

into Duolun, Inner Mongolia. The outer gully returns to Hebei Province and merges into the main tributaries, such as the XiaoLuanhe River, the Xingzhou River, the Yixun River, the Wulie River, and the Qinglong River. According to hydrological series data from 1980 to 2017, the average annual runoff of the Luanhe is 6.32 billion m^3. The average annual runoff of the Luanhe River Mountain area is 4.52 billion m^3, and the average annual water resources of the plains and the coast of eastern Fujian are 1.8 billion m^3. According to the Water Resources Bulletin, the per capita water resources of the Luanhe River Basin is 855 m^3, which is equivalent to 39.8% and 42.5% of the national average, respectively. In recent years, deforestation, grass destruction, steep slope land reclamation, and overgrazing have not only seriously damaged the growth of grasses and shrubs, but also caused a shortage of wood and raw materials, grassland degradation, and reduced capacity of soil and water conservation [24, 25]. According to a survey, there is light soil erosion in the Luanhe River Basin and the vegetation is scarce, except for the forest vegetation in the upstream dam area. According to the Haihe River Basin water quality annual report from 2008 to 2017, 60-70% of the length of the Luanhe has river water quality of grade I-III, and 50-60% of the water functional area meets the national standard. Therefore, the Luanhe River was selected as the study area for river health assessment.

Principles for Constructing River Health Assessment Index System

The river health assessment index system is designed to serve as a river health assessment and to maintain river health [26]. To achieve this goal, the river health assessment index system must be able to reflect the river's health status objectively, completely, and accurately [27]. The system must also provide an analysis of river health trends and reasons for river health decline in order to inform government decisions and scientific research [28]. Therefore, the screening of river health assessment index should follow the following principles:

- Scientific. Considering the functionality and attributes of rivers, the concepts of the index must have clear scientific intentions that can objectively reflect the basic characteristics of healthy rivers [29].
- Systematic. The index system should be systematic and comprehensive. It should be able to characterize river health status from different perspectives, such as from different rivers, river ecosystems, and social economies within river basins [30].
- Hierarchical. The functions of rivers include natural and social service functions. River health covers three aspects: the health of river channels, the health of river ecosystems, and the socio-economic value of river basins. Therefore, the health evaluation index system is complex and hierarchical to a certain extent, relating to nature, society and the economy. The hierarchical health classification method can intuitively assess the health status of rivers from different perspectives [31].
- Independent. The evaluation index system must not only cover the whole river, but also requires a certain degree of independence between index meanings to ensure the integrity and simplicity of the index system.
- Quantitative and operable index. The selected index cannot be separated from the actual conditions of the information that is related to the index. The established index system should not only be simple and clear, but also be easy to obtain, quantify, calculate and analyze, as well as have strong comparability.

Combined Weight-Assignment Method

Weight Consistency Test

The essence of a combined weight-assignment method is to combine the results of multiple weight-assignment methods through certain formulas in order to obtain a more objective and reasonable weight value. Weight-assignment index that are calculated by different algorithms may vary greatly and even conflict with one another. Therefore, before using the combined weight-assignment method, it is necessary to perform a consistency test on the weighted results obtained by different methods.

Assume there are k weight-assignment methods used to determine the weights. A previous study [32] has shown that when k = 2, the degree of consistency between the subjective and objective weight-assignment methods is suitable to be characterized by the Spearman rank correlation coefficient, or by the distance function, $d(W^{(1)}, W^{(2)}) = [\frac{1}{2}\sum_{j=1}^{n}\left(w_j^{(1)} - w_j^{(2)}\right)^2]^{\frac{1}{2}}$.

When $0 \leq d(W^{(1)}, W^{(2)}) \leq 1$ and $d(W^{(1)}, W^{(2)})$ is calculated and the resultant value is small, the closer the two weight-assignment results.

When $k \geq 3$, Kendall's concordance coefficient test should be used to test the consistency of multiple weight-assignment results. Kendall's concordance coefficient is a rank correlation analysis method. Before checking the consistency, the weight vector determined by each weight-assignment method is converted into a sorting vector. The steps are as follows:

– Record the weight of i group as $W^{(i)} = (W_1^{(i)}, (W_2^{(i)},... W_M^{(i)})$, and convert to a sorted value using $p_{ij}(1 \leq p_{ij} \leq m)$, $i = 1,2,..., k$; $j = 1,2,..., m$, where k is the number of weight reorganizations and m is the number of index.
– Hypothesis H_0: weights of k weight-assignment methods do not have consistency; hypothesis H_1: weights of k weight-assignment methods have consistency.
– Calculate Kendall's concordance coefficient test:

$$K = \sum_{j=1}^{m} \frac{[\sum_{i=1}^{k} p_{ij} - \frac{k(m+1)}{2}]^2}{\frac{k^2 m(m^2-1)}{12}} \quad (1)$$

– Based on the level of significance (α), check Kendall's concordance coefficient test table to obtain the critical value (K_α). When $K \leq K_\alpha$, accept H_0. Otherwise, deny H_0 and accept H_1.

Analytic Hierarchy Process

According to the AHP, the comparison judgment matrix is constructed by expert scoring. Then the hierarchical single order weight value is calculated, and the consistency test is performed.

Entropy Method

Typically, the set of evaluation objects is recorded as $\{A_i\}$ ($i = 1,2,..., m$) and the set of indexes used for the evaluation is recorded as $\{X_j\}$ ($j = 1,2,..., n$). x_{ij} is used as the original value of the index of the project. The calculation steps of the entropy method are as follows:

a. x_{ij} will be forwarded and p_{ij}, the proportion of the j index of i project is calculated as follows:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (i = 1,2,..., m; j = 1,2,..., n) \quad (2)$$

b. Calculate the information entropy value (e_i) of the index based on the definition of entropy:

$$e_i = -k \sum_{j=1}^{n} p_{ij} \ln p_{ij} \quad (3)$$

…where k is a constant that is related to the size of the assessment sample, which is n. For a system with completely disordered information, the degree of order is zero and the entropy value is the largest, e = 1; when n samples are in a completely disordered state, $p_{ij} = 1$ According to the above equation, we obtain k = $(\ln n)^{-1}$.

c. Calculate the difference coefficient g_j of the j index:

$$g_j = 1 - e_j \quad (j = 1,2,..., n) \quad (4)$$

d. Calculate the weight of the j index:

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j} \quad (j = 1,2,..., n) \quad (5)$$

In equation (5), the larger the g_j, the more important the j index is to the assessment, and the greater its weight coefficient (w_j).

Combined Weight-Assignment Method Based on Game Theory

The subjective weight-assignment method and the objective weight-assignment method have different weight-assignment principles and calculation methods. Therefore, the weight assignment of attributes from the same problem may be quite different, and the results comprehensively calculated by simple arithmetic or weighted averages may have a large deviation from the actual situation. Based on game theory, the steps of the combined weight-assignment method are as follows:

a. For a basic set of weights, $U| = \{u_1, u_2,..., u_n\}$, the n vectors are arbitrarily linearly combined into a possible set of weights:

$$U = \sum_{k=1}^{n} \alpha_k u_k^T \quad (\alpha_k > 0) \quad (6)$$

…where u_k is a possible weight vector for a set of possible weight vectors and α_k is the coefficient of the weight.

b. Game theory can be used to find u* in the possible vector sets, where u* is the optimal weight. The basic idea is to find consistency or compromise among different weights, minimizing the respective deviations between the possible weights u* and the individual weights. Finding the most satisfactory weight vector can be converted to optimize the linear combination coefficient (α_k). The goal of optimization is to minimize the dispersion between u and each u_k, which is defined as:

$$\min \left\| \sum_{j=1}^{n} \alpha_j \times u_j^T - u_i^T \right\|_2 \quad (i = 1,2,..., n) \quad (7)$$

According to the differential property of the matrix, we can see that the first derivative condition of the above optimization is:

$$\sum_{j=1}^{n} \alpha_j \times u_i \times u_j^T = u_i \times u_i^T \quad (i = 1,2,..., n) \quad (8)$$

The above equation corresponds to the following linear equations:

$$\begin{bmatrix} u_1 \cdot u_1^T & u_1 \cdot u_2^T & \cdots & u_1 \cdot u_n^T \\ u_2 \cdot u_1^T & u_2 \cdot u_2^T & \cdots & u_2 \cdot u_n^T \\ \vdots & \vdots & \ddots & \vdots \\ u_n \cdot u_1^T & u_n \cdot u_2^T & \cdots & u_n \cdot u_n^T \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_n \end{bmatrix} = \begin{bmatrix} u_1 \cdot u_1^T \\ u_2 \cdot u_2^T \\ \vdots \\ u_n \cdot u_n^T \end{bmatrix}$$

(9)

c. After obtaining α_1, α_2,..., α_n, according to the above formula, the result is normalized, and the formula is as follows:

$$\alpha_k^* = \frac{\alpha_k}{\sum_{k=1}^n \alpha_k}$$

(10)

Finally, the combined weight is:

$$U^* = \sum_{k=1}^n \alpha_k^* \cdot U_k^T$$

(11)

The combined weight-assignment idea, which is based on game theory, is the integration of the weight-assignment methods at different levels of the river health assessment index system. The integration process is not a simple physical process, but a process of mutual comparison and coordination. Both the subjective weight-assignment and objective weight-assignment methods have their own advantages. The importance of the weighted values obtained by various methods is not exactly equivalent, which means that the weights calculated by the various methods have different weights in the combination process. Therefore, using game theory to make rational combinations is more reasonable.

Results and Discussion

Constructing the Luanhe River Health Assessment Index System

According to the above principles for constructing river health assessment index systems, the Luanhe River health assessment index system is shown in Table 1. The meanings of the index are as follows:

(1) Horizontal stability index (C_1)

$$C_1 = \frac{Q^{0.5}}{J^{0.2}B}$$

(12)

...where Q is equal flow, B is actual river width, and J is ratio drop. The greater the lateral stability index, the more stable the bank.

(2) Vertical connectivity index (C_2)

$$C_2 = \frac{V_1}{V_2}$$

(13)

...where V_1 is reservoir capacity and V_2 is average annual runoff of rivers.

(3) Appropriate flow guarantee (C_3)

The Appropriate flow guarantee means the degree of assurance of suitable ecological flow [33].

(4) Percentage of water functional area meeting the standard (C_4)

$$C_4 = \frac{n}{N} \times 100\%$$

(14)

...where n is the number of water functional zones that meet the water quality standards and N is the total number of water functional zones in the evaluated river.

Table 1. Luanhe River Health Assessment Index System.

Target Level		Criterion Level	Index Level
River ecosystem health (A)	River ecosystem subsystem health index I_{rh} (A_1)	Shape (B_1)	Horizontal stability index (C_1)
			Vertical connectivity index (C_2)
		Water quantity (B_2)	Appropriate flow guarantee (C_3)
		Water quality (B_3)	Percentage of water functional area meeting the standard (C_4)
	River water activity subsystem health index I_{se} (A_2)	Ecological characteristic (B_4)	Biodiversity index (C_5)
			Vegetation structural integrity index (C_6)
			Water and soil loss (C_7)
			Wetland preservation (C_8)
		Water resources development and utilization level (B_5)	Water resources development and utilization (C_9)
		Water supply safety (B_6)	Comprehensive water supply guarantee rate (C_{10})
		Flood safety (B_7)	Percentage of flood control projects meeting the standard (C_{11})
		Hydrophilic landscape comfort (B_8)	Landscape diversity index (C_{12})

Table 2. Judge matrix with analytic hierarchy and weight.

A_1	B_1	B_2	B_3			Weight
B_1	1	1/3	1/3			0.1800
B_2	3	1	1			0.4100
B_3	3	1	1			0.4100
A_2	B_4	B_5	B_6	B_7	B_8	
B_4	1	1	3	3	5	0.3475
B_5	1	1	3	3	5	0.3475
B_6	1/3	1/3	1	1	2	0.1201
B_7	1/3	1/3	1	1	2	0.1201
B_8	1/5	1/5	1/2	1/2	1	0.0647
B_1	C_1	C_2				
C_1	1	1/2				0.3333
C_2	1/2	1				0.6667
B_2	C_3					
C_3	1					1
B_3	C_4					
C_4	1					1
B_4	C_5	C_6	C_7	C_8		
C_5	1	2	1/2	1		0.2222
C_6	1/2	1	1/4	1/2		0.1111
C_7	2	4	1	2		0.4444
C_8	1	2	1/2	1		0.2222
B_5	C_9					
C_9	1					1
B_6	C_{10}					
C_{10}	1					1
B_7	C_{11}					
C_{11}	1					1
B_8	C_{12}					
C_{12}	1					1

(5) Biodiversity index (C_5)

$$C_5 = -\sum_{i=1}^{N} \omega_i \ln \omega_i \qquad (15)$$

…where N is number of biological species collected in the sample and is the proportion of the i-th species in the sample to the total number of individual organisms.

(6) Vegetation structural integrity index (C_6)

Vegetation structural integrity index can reflect the health of the riparian structure, which can be described in different levels according to the degree of proximity of the riparian zone to the nature and the degree of vegetation coverage and the number of alien species.

(7) Water and soil loss (C_7)

Soil erosion rate means the proportion of watershed erosion area in watershed land area.

(8) Wetland preservation rate (C_8)

Wetland preservation rate means the proportion of watershed wetland area in the original wetland area.

(9) Water resources development and utilization (C_9)

The utilization rate of water resources development refers to the percentage of water resources development in the total amount of water resources in the basin. The internationally recognized reasonable river development utilization rate is 30%, and the maximum upper limit is 40%. If the upper limit is exceeded, the ecological crisis will endanger the health of the river.

$$C_9 = \frac{w}{W} \times 100\% \qquad (16)$$

…where w is the amount of water resources that have been developed and utilized and W is total river water resources.

(10) Comprehensive water supply guarantee rate (C_{10})

$$C_{10} = \frac{\sum_{i=1}^{n}(W_i \times P_i)}{\sum_{i=1}^{n} W_i} \qquad (17)$$

…where W_i is the average daily water supply for the i-th water supply project and P_i is the design water supply guarantee rate for the i-th water supply project.

(11) Percentage of flood control projects meeting the standard (C_{11})

Percentage of flood control projects meeting the standard means the number of projects that meet the design flood control standards in total flood control works.

(12) Landscape diversity index (C_{12})

$$C_{12} = \frac{m}{M} \times 100\% \qquad (18)$$

…where m is the number of species included in the landscape and M is the maximum number of species contained in the landscape.

Combined Weight-Assignment Method

Consistency Test

Since this study uses two weight-assignment methods, the AHP and the entropy method, to calculate the weights (k = 2), the consistency test is performed with the Spearman's rank correlation coefficient. After testing, the Spearman rank correlation coefficients of the weights of each index from the two methods are in the range of [0, 0.15], indicating that the weights of the two weight-assignment methods are consistent in this study.

Table 3. An example of the weight calculation of the Luanhe River health assessment index system (entropy method).

Assessment Index	Upstream	Midstream	Downstream	Whole flow	h_j	g_j	w_j
Horizontal stability index C_1	0.0795	0.1754	0.1557	0.1064	0.9676	0.0324	0.2969
P_{ij}	0.1538	0.3392	0.3012	0.2058			
$P_{ij}LnP_{ij}$	−0.2879	−0.3667	−0.3614	−0.3254			
Vertical connectivity index C_2	0.7957	3.4964	2.0900	2.2961	0.9233	0.0767	0.7031
P_{ij}	0.0917	0.4029	0.2408	0.2646			
$P_{ij}LnP_{ij}$	−0.2191	−0.3663	−0.3429	−0.3518			
Biodiversity index C_5	4.1000	2.2000	3.9000	3.3900	0.9817	0.0183	0.4497
p_{ij}	0.3017	0.1619	0.2870	0.2494			
$P_{ij}LnP_{ij}$	−0.3615	−0.2948	−0.3582	−0.3464			
Vegetation structural integrity index C_6	0.7500	0.5000	0.7500	0.6500	0.9910	0.0090	0.2206
p_{ij}	0.2830	0.1887	0.2830	0.2453			
$P_{ij}LnP_{ij}$	−0.3572	−0.3147	−0.3572	−0.3447			
Water and soil loss C_7	0.5588	0.6822	0.8329	0.6841	0.9929	0.0071	0.1753
p_{ij}	0.2026	0.2474	0.3020	0.2480			
$P_{ij}LnP_{ij}$	−0.3235	−0.3455	−0.3616	−0.3458			
Wetland preservation C_8	0.2800	0.2200	0.2600	0.2000	0.9937	0.0063	0.1544
p_{ij}	0.2917	0.2292	0.2708	0.2083			
$P_{ij}LnP_{ij}$	−0.3594	−0.3376	−0.3538	−0.3268			

Calculating Weights with the Analytical Hierarchy Method

Results of the comparison between the judgment matrix and weight calculations are shown in Table 2.

Calculating Weights with the Entropy Method

Taking the six indexes of the hydrological characteristics of the Luanhe River Basin (e.g., horizontal stability index C_1, vertical connectivity index

Table 4. The weight value of the Luanhe River health assessment index system (entropy method).

Target Level		Criterion Level	Assessment Index
River ecosystem health (A)	River ecosystem subsystem health index I_{rh} (A_1)	Shape (0.384)	Horizontal stability index (0.2967)
			Vertical connectivity index (0.7033)
		Water quantity (0.508)	Appropriate flow guarantee (1)
		Water quality (0.108)	Percentage of water functional area meeting the standard (1)
	River water activity subsystem health index I_{se} (A_2)	Ecological characteristic (0.372)	Biodiversity index (0.4497)
			Vegetation structural integrity index (0.2206)
			Water and soil loss (0.1753)
			Wetland preservation (0.1544)
		Water resources development and utilization level (0.327)	Water resources development and utilization (1)
		Water supply safety (0.112)	Water supply guarantee (1)
		Flood safety (0.098)	Percentage of flood control projects meeting the standard (1)
		Hydrophilic landscape comfort (0.091)	Landscape diversity index (1)

Table 5. Luanhe River health assessment index system combined weight-assignment results (criterion level).

Unit System	System		
	AHP	Entropy method	Combined weight-assignment method
B_1	0.18	0.384	0.311
B_2	0.41	0.508	0.473
B_3	0.41	0.108	0.216
B_4	0.3475	0.372	0.366
B_5	0.3475	0.327	0.332
B_6	0.1201	0.112	0.114
B_7	0.1201	0.098	0.103
B_8	0.0647	0.091	0.085

C_2, biodiversity index C_5, vegetation structural integrity index C_6, water and soil loss C_7, wetland preservation C_8) as an example of calculation, and according to equations (2)-(5), the weights of the six indexes are shown in Tables 3 and 4.

Similarly, the weights of the entire Luanhe River health assessment index system using the entropy method are shown in Table 4.

Calculating Weights with the Combined Weight-Assignment Method

According to the calculation method of game theory combined with the weight-assignment method given in the above section, equations (6)-(10) are used to derive α_k, and equation (11) is used to calculate the combined weight results from the weights calculated using the AHP and entropy methods. The combined weights of the criterion level of the Luanhe health assessment index system is calculated as shown in Table 5. The weights of the index level are shown in Table 6.

Conclusions

Tables 5 and 6 show that the weight of the index obtained by the combined weight-assignment method is between the weights obtained by the AHP and the entropy method alone. This means that the combined weight-assignment method has achieved the optimized combination, determined the respective proportions of the two methods in a comprehensive evaluation, coordinated and balanced the roles and influences of the two methods, maximally overcome the one-sidedness of a single weight, and reflected the subjectivity and objectivity so that the comprehensive evaluation is more reasonable and scientific.

Based on the calculation of river health assessment weights, the combined weight-assignment method effectively combines the AHP and entropy methods by introducing the combination weight-assignment idea that is based on game theory. This combined approach reflects the decision maker's subjective opinion on each assessment index, considers objective mathematical theories, and achieves a good combination of subjective decision making and objective calculation. The combined weight-assignment method has therefore further improved the rationality of weight determination.

Table 6. Luanhe River health assessment index system combined weight-assignment results (target level).

Unit System	System		
	AHP	Entropy method	Combined weight-assignment method
C_1	0.3333	0.2967	0.315
C_2	0.6667	0.7033	0.685
C_3	1	1	1
C_4	1	1	1
C_5	0.2222	0.4497	0.334
C_6	0.1112	0.2206	0.165
C_7	0.4444	0.1753	0.312
C_8	0.2222	0.1544	0.189
C_9	1	1	1
C_{10}	1	1	1
C_{11}	1	1	1
C_{12}	1	1	1

Conflict of Interest

The authors declare no conflict of interest.

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