

Research on evaluation methods for water regulation ability of dams in the Huai River Basin

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Abstract. Water environment protection is a global and urgent problem that requires correct and precise evaluation. Evaluation methods have been studied for many years; however, there is a lack of research on the methods of assessing the water regulation ability of dams. Currently, evaluating the ability of dams has become a practical and significant research orientation because of the global water crisis, and the lack of effective ways to manage a dam's regulation ability has only compounded this. This paper firstly constructs seven evaluation factors and then develops two evaluation approaches to implement the factors according to the features of the problem. Dams of the Yin Shang ecological control section in the Huai He River basin are selected as an example to demonstrate the method. The results show that the evaluation approaches can produce better and more practical suggestions for dam managers.

1. Introduction

Recent studies on evaluating the water regulation abilities of dams have responded to the wide concerns about the global water resource crisis [6, 8]. In contrast, previous research mainly focused on water scheduling for flood control, drainage, water supply, pollution prevention, control, and so on. [7]. According to Abbas et al. [1], research on related water schedules in the past did not pay enough attention to the evaluation of the specific water regulating ability of dams that can be useful for making water schedules. With the development of social economy and the need for the efficient usage of water resources, the precise evaluation of water regulation ability has become an urgent need [11]. Although there are many evaluation methods [2, 3], research on evaluating dams' regulation abilities are rare. Furthermore, considering that managers are in need of water regulating suggestions, this study has crucial practical significance.

This paper selects dams in the Yin Shang ecological control section as examples to implement the idea. The multi-dam regulation of the Huai He River basin has been developed for many years [9, 10]. Recent research has mainly focused on the dams' regulation of multiple indexes of water quantity, water quality, and water ecology. The evaluation model



and related evaluation methods presented in this paper can produce a more precise evaluation of dams' regulation abilities when considering water ecology and water quality.

This paper adapts the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Fuzzy Comprehensive Evaluation approaches to implement the evaluation process based on the adopted evaluation model. The results can provide technical support for the connection regulations for dams and suggestions for related decision-makers.

2. Evaluation factors

For evaluating the specific ability of dams to regulate water schedules, this paper adopts an assessment model that includes seven influential factors: water quantity that a dam is able to use (V1), water transmitting time of the schedule (V2), status of getting water along the river of a dam (V3), environmental remains of different contaminants (V4), dam management status (V5), construction status of dams (V6), and emergency handling capability of dams (V7). These factors can be classified into three aspects, which are included in the model as shown in Figure 1.

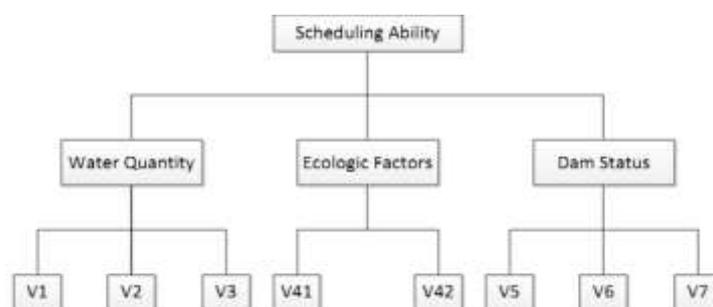


Figure 1. Classification of influential factors for evaluating the dam ability.

From Figure 1, the factors affecting the water regulating ability for evaluation of a dam can be divided into three types. This model depicts how the factors are composed and how they influence the regulating ability of dams.

3. Methods

Using these evaluation factors, this paper presents two approaches to implement the model and compares their results. Determining the regulating ability of dams is, in fact, the process of making an evaluation. There are many methods of evaluation. This paper uses the methods TOPSIS and Fuzzy Comprehensive Evaluation because of their suitability for this evaluation problem.

3.1. TOPSIS

Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) is an evaluation solution that assesses the target according to the distance between attributes producing the best and the worst composite solutions [5].

This paper sets every dam as a target and its evaluation indexes as its attributes. For N dams, the best scheduling composite dam is listed according to all the best attributes, and the worst scheduling dam is obtained by combining all its worst attributes. The specific notation for the process is shown in Table 1.

Table 1. TOPSIS Evaluation Process for Dams.

Dams	V1	V2	V3	V4	V5	V6	V7
Dam 1	v_{11}	v_{12}	v_{13}	v_{14}	v_{15}	v_{16}	v_{17}
Dam 2	v_{21}	v_{22}	v_{23}	v_{24}	v_{25}	v_{26}	v_{27}
...
Dam n	v_{n1}	v_{n2}	v_{n3}	v_{n4}	v_{n5}	v_{n6}	v_{n7}

Table 1 lists all the dams and their relevant weights. In the table, v_{ij} is the value of dam i 's j^{th} index. The results of the TOPSIS method can be calculated by the following steps.

- Step 1: Data normalization

Any positive index can be standardized by the following formula:

$$\bar{v}_{ij} = \frac{v_{ij} - v_i^{mi}}{v_i^{ma} - v_i^{mi}} \quad (1)$$

Any negative index can be standardized by the following formula:

$$\bar{v}_{ij} = \frac{v_i^{ma} - v_{ij}}{v_i^{ma} - v_i^{mi}} \quad (2)$$

Using equations (1) and (2), all values of indexes can be standardized into the range [0-1]. In the equations, v_i^{ma} is the best (maximum) performance value of V_i among all the dams, and v_i^{mi} indicates the worst (minimum) performance value of V_i among all the dams. v_{ij} is the j^{th} value of dam i , and \bar{v}_{ij} is the standardized value of v_{ij} .

- Step 2: Select the best and worst performance indexes among all dams to arrive at two solutions.

$$\text{Solution 1: } MaDam = (v_1^{ma}, v_2^{ma}, v_3^{ma}, v_4^{ma}, v_5^{ma}, v_6^{ma}, v_7^{ma})$$

$$\text{Solution 2: } MiDam = (v_1^{mi}, v_2^{mi}, v_3^{mi}, v_4^{mi}, v_5^{mi}, v_6^{mi}, v_7^{mi})$$

MaDam represents the best possible performance of a dam, whereas *MiDam* shows the worst possible performance of a dam, given the current data.

- Step 3: Calculate the distance.

$$\text{Distance 1: } Dma_i = \left[\begin{aligned} &(v_{i1} - v_1^{ma})^2 + (v_{i2} - v_2^{ma})^2 + (v_{i3} - v_3^{ma})^2 + (v_{i4} - v_4^{ma})^2 \\ &+ (v_{i5} - v_5^{ma})^2 + (v_{i6} - v_6^{ma})^2 + (v_{i7} - v_7^{ma})^2 \end{aligned} \right]^{1/2}$$

$$\text{Distance 2: } Dmi_i = \left[\begin{aligned} &(v_{i1} - v_1^{mi})^2 + (v_{i2} - v_2^{mi})^2 + (v_{i3} - v_3^{mi})^2 + (v_{i4} - v_4^{mi})^2 \\ &+ (v_{i5} - v_5^{mi})^2 + (v_{i6} - v_6^{mi})^2 + (v_{i7} - v_7^{mi})^2 \end{aligned} \right]^{1/2}$$

The two distances above tell how far any dam i is away from the best and worst results. In these two solutions, Dma_i shows how far the water scheduling ability of dam i is away from the best performing composite dam, while Dmi_i indicates how far the scheduling ability of

dam i is away from the worst performing composite dam. Furthermore, v_{ij} is the j^{th} evaluation index of dam i .

- Step 4: Obtain the schedule ability.

$$SA_i = \frac{Dmi_i}{Dma_i + Dmi_i}$$

Step 4 gives the final evaluation result of dam i 's water scheduling ability. The SA_i represents the water resource scheduling capability of dam i evaluated by TOPSIS.

3.2. Fuzzy Comprehensive Evaluation (FCE)

Fuzzy Comprehensive Evaluation (FCE) was developed from the concept of the Fuzzy set [4]. FCE quantifies the fuzzy indexes of evaluation objects through establishing grade fuzzy subsets and utilizes the fuzzy variable principle to integrate each index so as to better solve the fuzzy problem.

FCE involves the following factors: Factor set U ; Comment set V ; Membership Function F ; Fuzzy relation matrix R ; Weight distribution vector W ; and Fuzzy Comprehensive Evaluation Model M .

- Establish factor set $U = \{u_1, u_2, \dots, u_7\}$.

u_1 is the water quantity that a dam is able to handle; u_2 is the water transmitting time of the schedule; u_3 is the status for using water along the river of a dam; u_4 indicates the remains of two pollutants (NH_3-N and COD) after water has passed through the dam; u_5 indicates the dam management status; and u_6 is the construction status of a dam. Finally, a dam's emergency handling capability is represented by u_7 .

- Establish Comment set $V = \{v_1, v_2, v_3\}$.

The measure v_1 shows that the actual value of the factor is in a bad condition, whereas v_2 represents that the actual value of the factor is in a middle condition, and v_3 means that the actual value of the factor is good.

- Membership Function

The key to evaluating the scheduling ability of dams using the fuzzy mathematical method is selecting the Membership Function F . There are many methods that can be selected. The Trichotomy method is used in this paper to identify the membership function of all factors. Although different factors have different physical quantities, data standardization of all factors can eliminate the differences among them.

- Evaluation matrix of a single factor

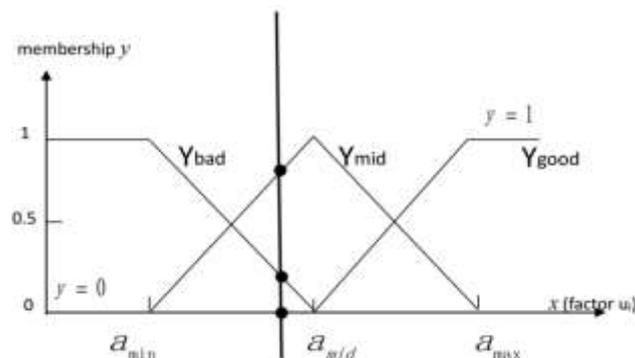


Figure 2. Evaluation matrix of a single factor.

In this part, the membership of each factor is computed, according to the value of the factor. The values of each factor for all dams are listed. For example, for calculating the factor u_1 , a list of numbers is obtained: $a_1, a_2, a_3, \dots, a_n$. Then, the maximum value (a_{max}) of that factor is found as well as the minimum value (a_{min}) of that factor. a_{mid} is set to equal $(a_{max} + a_{min})/2$. The fuzzy distribution is shown as follows:

$$\begin{cases} y_{good} = 0, & x \in [0, a_{mid}) \\ y_{good} = \frac{x - a_{mid}}{a_{max} - a_{mid}}, & x \in [a_{mid}, a_{max}] \\ y_{good} = 1, & x \in (a_{max}, +\infty) \end{cases}$$

$$\begin{cases} y_{mid} = 0, & x \in [0, a_{min}) \\ y_{mid} = \frac{x - a_{min}}{a_{mid} - a_{min}}, & x \in [a_{min}, a_{mid}] \\ y_{mid} = \frac{a_{max} - x}{a_{max} - a_{mid}}, & x \in [a_{mid}, a_{max}] \\ y_{mid} = 0, & x \in (a_{max}, +\infty) \end{cases}$$

$$\begin{cases} y_{bad} = 1, & x \in [0, a_{min}) \\ y_{bad} = \frac{a_{mid} - x}{a_{mid} - a_{min}}, & x \in [a_{min}, a_{mid}] \\ y_{bad} = 0, & x \in (a_{mid}, +\infty) \end{cases}$$

Common fuzzy distributions include y_{good} , y_{mid} , y_{bad} . When a factor is getting a value, there will be three membership values associated with it.

- Fuzzy relation matrix R

$$R = \begin{bmatrix} R_1 \\ R_2 \\ \dots \\ R_7 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ \dots & \dots & \dots \\ r_{71} & r_{72} & r_{73} \end{bmatrix}$$

In this paper, seven factors that influence the scheduling ability of dams are considered. According to the membership function of each factor, the membership degree can be found by using number normalization. All the membership degrees consist of an evaluation matrix R .

- Weight distribution vector W

For each influence factor, the weighing vector $W = (w_1, w_2, \dots, w_m)$ indicates the respective weight, and the sum of all factor weights in this set is 1, which is consistent with the normalization principle. In this work, the expert inquiry method is used. The results are as follows:

Table 2. Weight of factors.

Factor	V ₁	V ₂	V ₃	V ₄	V ₅	V ₆	V ₇
Weight	0.20	0.15	0.11	0.13	0.12	0.16	0.13

- Fuzzy Comprehensive Evaluation Model M

The composite operator is selected. Synthesis of W and R will be S , which means the comprehensive evaluation results are in comment set V . The Fuzzy operator $M(\bullet, \otimes)$ is employed.

$$S = W \circ R$$

3.3. Experiment

This paper takes the Yin Shang ecological control section on the Huai He River basin as an example to illustrate the method. All of the data for this study came from the Key State Science and Technology Project (2014ZX07204-006-05). From the Yin Shang control section, this paper selects five dams as experimental objects: Zhou Kou, Huai Dian, Gen Lou, Fu Yang, and Yin Shang. For each of them, the data for the seven indexes are listed in Table 3.

Table 3. TOPSIS Evaluation Data of Dams.

Dams	V1	V2	V3	V4	V5	V6	V7
Zhou Kou	445	259.3	3	1.00	2	3	3
Huai Dian	82	133.1	2	0.74	2	3	2
Gen Lou	3970.61	143.7	2	0.24	2	2	2
Fu Yang	2875	78.4	1	0.41	3	2	2
Yin Shang	5431.46	0	1	0.07	5	4	5

Firstly, the authors set up the experiment environment. Secondly, a database was devised to store the necessary information. Finally, the evaluation process was conducted by performing the experiment on the environment.

The database was constructed by an SQL Server, and the experiment environment was built by the MyEclipse tool. SQL and MyEclipse are suitable to perform the evaluation process of dams.

4. Results and discussion

The results calculated by the TOPSIS approach are shown in Table 4.

Table 4. Evaluation Results of TOPSIS.

Dams	Yin Shang	Fu Yang	Huai Dian	Zhou Kou	Gen Lou
SA ^a	0.68	0.42	0.42	0.41	0.40

^a SA means scheduling ability of dams.

The results calculated by the FCE approach are summarized in Table 5.

Table 5. Evaluation Results of FCE.

Dams	Bad	Middle	Good
Zhou Kou	0.44	0.41	0.15
Huai Dian	0.44	0.46	0.10
Gen Lou	0.32	0.45	0.23
Fu Yang	0.39	0.36	0.25
Yin Shang	0.13	0.02	0.85

The results show that the Yin Shang dam is the best of the five dams because of its top score in the V1, V2, V3, V5, V6, and V7 indexes. Although the scores of the dams may be different, the tendency of the dams' scores is almost the same, which means that different evaluation approaches could obtain the same results based on the common data. Furthermore, the different results of the specific regulating ability of the dams are caused by the two different evaluation approaches. In addition, it is easy for administrators to choose the dam with the highest water regulating ability to address the urgent problems that are occurring in the ecological control section after ranking the dams.

5. Conclusion

This paper introduces a new model to evaluate the water regulating ability of dams. The paper uses two evaluation methods, TOPSIS and FCE, to implement the model. In the experiment stage, five dams of the Sha Ying ecological control section were selected, and their differences were compared using the assessment results from the TOPSIS and FCE approaches. From the results, it is clear that the Yin Shang dam is the best capable dam for water environment protection in terms of regulating ability.

The next step to extend this study should be to use these evaluation methods to find the best way to conduct water regulation using dams.

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