Evaluation of reservoir management modernization under the concept of coordinated development
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ABSTRACT
The modernization of reservoir management is of great significance to the coordinated development of the region. There are many factors affecting the modernization of reservoir management, and there is a certain degree of ambiguity, randomness and uncertainty among the factors. It is difficult to evaluate the modernization of reservoir management comprehensively by traditional methods. This study first studies the connotation of reservoir management modernization under the concept of coordinated development; that is, securitization, economization, scientificalization and greenization. On this basis, a modernization evaluation system and AHP-Fuzzy evaluation model for reservoir management are constructed. Then, an empirical study is conducted with six large reservoirs in Jiangxi Province of China. The results show that the modernization level of large-scale reservoir management in Jiangxi Province is generally above the middle level, and the economic management and engineering management level of some reservoirs is relatively low, resulting in a low scientific and economic level of reservoir management, which is a key factor restricting the process of reservoir management modernization.

Key words | coordinated development, evaluation, modernization, reservoir management

HIGHLIGHTS
- Studies the connotation of reservoir management modernization under the concept of coordinated development.
- Constructs a modernization evaluation system and AHP-Fuzzy evaluation model for reservoir management.
- Conducts an empirical study with six large reservoirs.
- The modernization level of large-scale reservoir management in Jiangxi Province is generally above the middle level.
- Scientificalization of reservoir management.

INTRODUCTION
The concept of coordinated development is the same as the four development concepts of innovation, greenness, openness and sharing. In the context of the new normal state of China’s economic development, these concepts are important, rich in connotations and of great significance. Coordinated development requires the process of development to reflect more balanced characteristics and requirements. In the new era, guided by the concept of coordinated development, reservoir management should keep pace with the new direction. According to the ‘13th Five-Year Plan for Water Conservancy Development in China’, ‘Reservoir Dam Safety Management and Monitoring System Planning Report’, ‘Interpretation of Standardization Management Assessment Standards for
Large and Medium-sized Reservoirs’ and other materials in China, it can be seen that the modernization of reservoir management has rich connotations.

The modernization of reservoir management is based on the market economy system theory and scientific development concept. It adopts advanced technology, thinking, and concepts to change, transform, and reform the traditional water conservancy technology, water management ideas, and dynamic processes of water management. Modernization of reservoir management requires the establishment of a hydraulic engineering management system that includes management systems, mechanisms, concepts, methods, and management talents. It finally realizes the process of modernization and sustainable social and economic development.

Reservoir management modernization is not only an important basis for a country’s modernization, but also a guarantee for national modernization. At present, objective and scientific evaluation index systems and evaluation methods are the core content and key work of evaluating the level of modernization. Scientific evaluation of reservoir management modernization is of great significance to guide the construction of reservoir management modernization. The rest of this article is organized as follows. The second part is a review of the literatures related to reservoir management. The third part builds an evaluation index system based on management systems, mechanisms, and management talents. It finally realizes the process of modernization and sustainable social and economic development.

LITERATURE REVIEW

Many scholars have carried out quantitative, qualitative, and comprehensive evaluations of modernization of water conservancy management from multiple perspectives. They are mainly divided into the following four categories.

The first category is the research on the construction of an index system in reservoir management. Some scholars constructed an evaluation index system in terms of security, infrastructure, technological development, and ecological environment based on the characteristics and basic connotation of water conservancy modernization (Wang et al. 2013). Tan et al. (2013) established a management modernization evaluation system with a case study of a reservoir in Hubei, China. Some scholars built an index system and meanwhile carried out a comprehensive evaluation of the reservoir of Lu’an in China using the single factor evaluation method (Zhao 2014).

The second category is research on emergency management of reservoir safety. Gong (2011) constructed a GIS-based reservoir information management system and applied it to the evaluation of the Chuanshan reservoir in Suining, China. Some scholars established an evaluation index system for reservoir emergency management capabilities and conducted the empirical study (Zheng 2012). Zhu (2005) conducted a scientific evaluation of the operation status of irrigation districts using grey theory and principal component analysis. By comparing and analyzing the applicability and accuracy of each method, it will help to improve the scientificity and objectivity of the evaluation results. Some scholars analyzed the factors of dam risk under standardized management, constructed an index system of dam risk management, and evaluated it with the data from some dams in China (Zhou et al. 2019).

The third category is research on the ecological aspects of reservoirs. Jorgensen (1995) proposed a preliminary evaluation procedure for reservoir ecosystem health, which is a good method for evaluating a reservoir ecosystem and has sparked an upsurge in related research. Some scholars proposed for the first time that the main characteristics of a healthy ecology are its ability to maintain its organizational structure, self-regulation, and resilience to stress over time. And the degree of health is defined by vitality, organizational structure and resilience (Costanza et al. 1998).

The fourth category is research on reservoir sedimentation, which focused on the applications of models. Some scholars evaluated the sedimentation management of Sanmenxia Reservoir, China by using the RESCON model (Wang et al. 2011). Some scholars used the HEC-RAS model to analyze and evaluate the sedimentary management of Tarbel Reservoir (Rashid et al. 2014).

The above research mainly focuses on a certain aspect of reservoir management, and there are fewer studies involving the entire system of reservoir management. Under the concept of coordinated development in the new period, in
In order to better evaluate the modernization of reservoir management, this article combines the connotation and characteristics of modern management to build an evaluation system. There are many factors affecting the modernization of reservoir management, and the factors have randomness and uncertainty characteristics. Therefore, the fuzzy comprehensive evaluation method has significant advantages in dealing with these problems. This paper attempts to construct a new and more scientific evaluation index system and fuzzy comprehensive evaluation model in order to provide a new method for reservoir scientific management.

EVALUATION INDEX SYSTEMS FOR MODERNIZATION OF RESERVOIR MANAGEMENT

In this part, this article will elaborate the connotation of modernization of reservoir management, and build an evaluation index system based on the connotation of modernization of reservoir management.

Connotation of reservoir management modernization

With reference to existing research results, it can be seen that the modernization of reservoir management has rich connotations under the concept of coordinated development.

Firstly, securitization. Security is the most important things in reservoir management modernization under the concept of coordinated development. It should meet the development requirements of a harmonious society. Therefore, in the process of management, it need to further improve the thinking in light of the new problems and new situations faced by water conservancy projects, accelerate the change of development speed and model, and comprehensively promote the safety management of reservoirs.

Secondly, economization. The modernization of reservoir management should be represented by automation and modernization of monitoring, forecasting, and high-level decision-making. Therefore, in the process of reservoir management, it should improve the existing water management conditions, replace or modify existing equipment by introducing new equipment, new technologies and other means, and actively promote the construction of informationization and automatic monitoring systems.

Finally, greenization. The modernization of reservoir management should be based on the concept of coordinated and sustainable development, adhere to the scientific concept of development in the process of reservoir management, and ensure the greening of the reservoir ecology based on the ecological concept that society is advocating.

Construction of evaluation index system

There are many indices that reflect the individual characteristics of reservoir management modernization under the concept of coordinated development, and some indices are highly relevant. Although some indices are important, accurate data is not easy to obtain. In order to reflect objectively, accurately, and comprehensively the development level of modernization of reservoir management, this study combines with the above-mentioned modern connotation of reservoir management and the suggestions of relevant experts to form an index system that can basically reflect all aspects of reservoir management.

In the process of concrete construction, this paper adopts the Analytic Hierarchy Process (for short, AHP) to design a modern index system of reservoir management in three layers, and establish a hierarchical structure, including a target layer, a criterion layer, and an index layer. The target level is the comprehensive evaluation target; that is, the modernization level of reservoir management. The standard layer includes 4 sub-objectives, namely securitization, economization, scientification, and greenization. Among them, securitization corresponds to the development of a harmonious society in the connotation of modernization of reservoir management. Economization corresponds to the
market economy system theory in the connotation of modernization of reservoir management. Scientificization corresponds to the automation and modernization monitoring and forecasting in the connotation of modernization of reservoir management. Greenization corresponds to the concept of coordinated and sustainable development in the modernization of reservoir management.

What is more, this study follows the principle of harmonizing advancedness, systematicness, and feasibility; the principle of combining hierarchy and comparability; the principle of combining representativeness and comprehensiveness; the principle of combining operability and orientation. The 18 indicators in the index layer are determined based on the above principles, which can comprehensively reflect all aspects affecting the modernization of reservoir management. The specific index system structure is shown in Table 1.

Some complex indices are described below.

Administrative capacity refers to a responsibility structure arrangement and personnel arrangement constituted according to certain rules. It mainly includes two aspects: organization setting and operation mechanism, and management personnel. The goal is to effectively allocate resources.

Emergency flood prevention capacity refers to the establishment of a professional, regular, and technical flood prevention and rescue system, including the level of flood prevention materials storage and management, team building and support capabilities, and the establishment of a sound dispatch team. Accident execution and planning capabilities refers to the establishment of an efficient emergency management mechanism, which mainly includes daily and special inspections, the full implementation of the dispatch operation responsibility system, the promotion of operational safety knowledge, the construction and implementation of emergency plans, the timeliness and accuracy of statistical reporting, etc. The ability to implement maintenance management funds mainly refers to the implementation of maintenance funds, including reasonable maintenance and operation management expenses, and strict implementation of financial accounting systems.

Automated office level includes data collection, engineering automatic monitoring systems, network construction, and information management agencies. The integrity of auxiliary management facilities mainly refers to the integrity of various engineering management signs and labels.

The green coverage rate refers to the percentage of the total area occupied by the green area within the project management scope. Rainfall area refers to the area of the watershed within the watershed above the dam site of the reservoir.

**CONSTRUCTION OF AHP-FUZZY MODEL**

In this part, this article first introduces the AHP-Fuzzy model, and then builds an AHP-Fuzzy model suitable for...
this article, including the process of determining weights and comprehensive evaluation.

AHP-fuzzy model

The AHP-Fuzzy model first uses AHP to construct an index system and treats multi-objective decision problems as a system. Then it is divided into target layer, criterion layer and indicator layer. Experts from academia are invited to make a pair-wise comparison and evaluation of each factor of the same level of indicators according to the 1-9 scale method. By constructing a judgment matrix, and after consistency check, the single sort weight value and total sort weight value of each level are obtained.

Assume that the total set composed of several evaluation indicators is \( U = \{u_1 \ u_2 \ \cdots \ u_m\} \), and the total set of several evaluation level combinations is \( V = \{v_1 \ v_2 \ \cdots \ v_m\} \). The evaluation index is quantified, and the membership degree of the single evaluation index to the evaluation level is calculated by using the membership function formula, and then the fuzzy relation membership matrix \( R \) is obtained. Then, a multi-level fuzzy comprehensive evaluation \( B = W \times R \) is performed, and the fuzzy evaluation of the index layer is finally obtained. That is, the fuzzy comprehensive evaluation is:

\[
B = W \times R = \begin{pmatrix}
  r_{11} & \cdots & r_{1m} \\
  \vdots & \ddots & \vdots \\
  r_{n1} & \cdots & r_{nm}
\end{pmatrix}
= \begin{pmatrix}
  b_1 \\
  b_2 \\
  \vdots \\
  b_m
\end{pmatrix}
\]

Finally, according to the principle of maximizing membership, the maximum value in the fuzzy comprehensive evaluation \( B \) corresponds to the evaluation level \( v_i \) in the evaluation set \( V \).

Determination of evaluation index weights

Firstly, this paper constructed a judgment matrix. Experts were invited to continue to compare each indicator in the same indicator layer. Twenty valid questionnaires were issued and retrieved. To ensure the rigor and rationality of the research, the data were integrated and averaged, and then a judgment matrix was constructed. When constructing a judgment matrix, first compare the influence of \( n \) factors \( A = \{a_1, a_2, \cdots, a_n\} \) were first compared on its upper factors \( P \), then its relative importance was judged, and finally a judgment matrix \( K = (k_{ij})_{n \times n} \) was established between \( P \) and \( A \), where \( k_{ij} \) is the ratio of the influence of factors \( a_i \) and \( a_j \) on \( P \). This paper uses the 1-9 scale method to calculate \( k_{ij} \) and construct a judgment matrix.

Then, weights were calculated and a consistency test performed. According to the constructed judgment matrix, the corresponding weight of each indicator was calculated. The calculation formula is:

\[
w_i = \sqrt[\prod_{i=1}^n a_{ij}} \sum_{i=1}^n \sqrt[\prod_{i=1}^n a_{ij}}
\]

Because the judgment matrix contains strong human subjective judgment factors, a consistency test is required. If the consistency check index is less than 0.1, the judgment matrix is consistent. The specific calculation method is as follows:

\[
CR = \frac{CI}{RI}; \quad CI = \frac{\lambda_{max} - N}{N - 1}; \quad \lambda_{max} = \frac{1}{N} \sum_{i=1}^n \left( \sum_{i=1}^N a_{ij}w_i \right) \frac{1}{w_i}
\]

where \( N \) represents the number of factors of this level; \( RI \) represents the average random consistency index, which is a fixed value. \( RI \) can be obtained from the \( RI \) table of the consistency check. The \( RI \) value table of the consistency test is shown in Table 2.

\( CI \) represents the consistency index. If \( CI = 0 \), it means that the matrix has complete consistency. \( CR \) represents the relative consistency index. If \( CR < 0.1 \), the questionnaire can be used directly. If \( CR > 0.1 \), the questionnaire cannot be used directly and needs to be adjusted.

Comprehensive evaluation of the modernization level of reservoir management

Here the level of reservoir management modernization is divided into five levels. They are excellent, good, medium,
qualified, and unqualified. The evaluation set is:

\[ V = \{\text{excellent, good, medium, qualified, unqualified}\} \]

The membership functions constructed in this paper are:

\[
\begin{align*}
 r_1(x) &= \begin{cases} 
 1 & x \geq d_1 \\
 0 & d_2 \leq x < d_1 
\end{cases} \\
 r_2(x) &= \begin{cases} 
 (x - d_2)/(d_1 - d_2) & d_2 \leq x \leq d_1 \\
 0 & x > d_1, x < d_2 
\end{cases} \\
 r_3(x) &= \begin{cases} 
 (d_3 - x)/(d_2 - d_3) & d_3 \leq x \leq d_2 \\
 0 & x > d_3, x < d_2 
\end{cases} \\
 r_4(x) &= \begin{cases} 
 (d_4 - x)/(d_3 - d_4) & d_4 \leq x \leq d_3 \\
 0 & x > d_4, x < d_3 
\end{cases} \\
 r_5(x) &= \begin{cases} 
 x/d_5 & x < d_5 \\
 0 & x > d_5 
\end{cases}
\]

where \( x \) represents the score of the indicator. \( d_1, d_2, d_3, d_4 \) and \( d_5 \) represent the endpoints of the interval, and they are set to 100, 90, 80, 70 and 60 in this paper.

The comprehensive evaluation of reservoir management modernization level is a multi-level and multi-index comprehensive evaluation problem, and the evaluation results are affected by multiple factors. In comprehensive evaluation, most scholars use the prominent main factor type or the main factor determining type. The result is to focus on major factors or completely ignore minor factors. In order to ensure the scientific rationality of the evaluation results of reservoir management modernization, this paper constructs a weighted average synthetic operator, which can take into account the effects of the main and secondary factors on the results. The calculation formula is:

\[ b_j = \min \left( 1, \sum_{i=1}^{n} w_i r_{ij} \right) \]

where \( 1 \leq i \leq n, j = 1, 2, \cdots, m, w_i \) represents the weight value of the index, \( r_{ij} \) represents the degree of membership of the index \( i \) to the level \( j \).

After the fuzzy comprehensive evaluation result \( B = [b_1, b_2, \cdots, b_m] \) is obtained, the weighted average principle is adopted to make the fuzzy vector single value, and then a comprehensive conclusion is drawn. To facilitate the calculation, the subjective evaluation is quantified. The elements in the evaluation set are assigned in order to obtain the value set \( D = \{90, 80, 70, 60, 50\} \) corresponding to the evaluation set. The calculation formula for the final evaluation score \( F \) is:

\[ F = BD^T \]

Finally, according to the evaluation criteria established in Table 3, the level of reservoir management modernization is judged.

### EMPIRICAL ANALYSIS OF TYPICAL RESERVOIRS

Since the founding of the People's Republic of China, China has built a large number of reservoirs throughout the country. Jiangxi Province is located in central China with

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**Table 2** | RI value table for consistency check

<table>
<thead>
<tr>
<th>n</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0.00</td>
<td>0.00</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
<td>1.52</td>
</tr>
</tbody>
</table>

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**Table 3** | Evaluation criteria for modernization level of reservoir management

<table>
<thead>
<tr>
<th>Grade</th>
<th>Excellent</th>
<th>Good</th>
<th>Medium</th>
<th>Qualified</th>
<th>Unqualified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation score</td>
<td>( F \geq 90 )</td>
<td>( 80 \leq F &lt; 90 )</td>
<td>( 70 \leq F &lt; 80 )</td>
<td>( 60 \leq F &lt; 70 )</td>
<td>( F &lt; 60 )</td>
</tr>
</tbody>
</table>
heavy rainfall and high forest coverage. Therefore, many places in Jiangxi are suitable for the construction of reservoirs. According to statistical data in 2019, Jiangxi Province of China has completed or basically completed 9,782 reservoirs of various types, including 25 large reservoirs, 238 medium reservoirs, 1,439 small (first) reservoirs.
and 8,080 small (second) reservoirs. It can be seen that there are many reservoirs in Jiangxi Province, and all types of reservoirs are included. Therefore, the reservoirs in Jiangxi Province are representative. The huge reservoirs have become an important part of the flood control engineering system and water conservancy infrastructure in Jiangxi Province. These reservoirs have played a huge role in ensuring China’s food and drinking water safety, developing the rural economy, improving farmers’ production and living conditions and the ecological environment, and stabilizing rural social order. In particular, it has an irreplaceable role in the development of major grain producing areas and the construction of a new socialist countryside. Under the concept of coordinated development, this article constructs an evaluation index system for the modernization of typical reservoir management in Jiangxi Province, with a view to conducting a comprehensive and objective evaluation of the modernization of reservoir management in Jiangxi Province and guiding the construction of modernization of reservoir management.

Based on the principle of combining representativeness and comprehensiveness, this article selects six reservoirs in Jiangxi Province as the research object. They are Baiyunshan Reservoir, Tuolin Reservoir, Qiyi Reservoir, Hongmen Reservoir, Longtan Reservoir and Jiangkou Reservoir. These six reservoirs are all large reservoirs with a storage capacity of more than 100 million cubic meters. They are distributed in Jían, Jiújiāng, Shángráo, Fúzhōu, Gánzhōu, and Xíníu in Jiangxi Province. They play an important role in flood prevention, irrigation, and power generation. The distribution of these six reservoirs is shown in Figure 1.

According to the steps of the weight and consistency test, based on the above evaluation index system of reservoir management modernization, the weight of each judgment matrix was obtained, and the consistency test was carried out one by one, all of which were passed. The weight calculation results are shown in Table 4.

According to the membership degree of the evaluation index, the fuzzy comprehensive evaluation model established above in this paper is used to calculate step by step. Finally, the final comprehensive evaluation scores of the six reservoirs were obtained, as shown in Table 5.

From Table 5, it can be seen that among the six reservoirs, the management modernization ratings of Baiyunshan Reservoir, Tuolin Reservoir, and Longtan Reservoir are good, and the management modernization ratings of Qiyi Reservoir, Hongmen Reservoir, and Jiangkou Reservoir are medium. Of the six reservoirs, Tuolin Reservoir located in Jiújiāng has the highest level of modern management. This is closely related to its investment in modern management. The economicization of Tuolin Reservoir is better.
and more funds are used in scientific management, safety management and green management.

Specifically, the specific scores of the six reservoirs in the four criteria layers of security, economical, scientific, and green are shown in Table 6. From Table 6, it can be seen that the Baiyunshan Reservoir, Tuolin Reservoir, and Longtan Reservoir performed well in the four criterion levels, which is also the direct reason for the good final score.

The economic management and engineering management level of Hongmen Reservoir and Jiangkou Reservoir are not high, which is the key to restricting the modernization of management. In the future, the development potential of Hongmen Reservoir and Jiangkou Reservoir is huge, and should focus on continuously improving the level of economic and scientific management, so as to bring the overall level of management modernization to a new level.

For the Tuolin Reservoir, its safety, economics and scientific aspects are at the highest level among the six reservoirs. Therefore, Tuolin Reservoir needs to maintain the advantages of management modernization, play a benchmark role, and lead the development of other reservoir management modernizations. It is worth noting that the management modernization of the six reservoirs has performed well in terms of security. This is inseparable from the importance China has attached to the level of reservoir rescue and flood prevention, accident implementation and plan formulation.

In general, the level of modernization of reservoir management in Jiangxi Province is medium or above, which is consistent with the actual management level, and the evaluation results have certain credibility. Therefore, in a certain period of time in the future, Jiangxi Province reservoir management workers should recognize the current level of reservoir management modernization, and ideologically realize the importance of reservoir modernization management. And based on the existing foundation, the quality and level of modernization of reservoir management should be effectively improved in light of the connotation of modernization of reservoir management.

### CONCLUSION

In order to understand objectively and comprehensively the status of the reservoir in terms of engineering construction, utilization of water and land resources, management system reform, social and economic development, and ecological environment, this study carried out a comprehensive evaluation of modernization. Based on a detailed analysis of the basic requirements and connotation of water conservancy modernization under the concept of coordinated development, this paper constructs a modernization evaluation system for reservoir management with 16 indicators from four aspects: securitization, economization, scientificalization, and greenization. This paper verifies the scientificality and feasibility of the fuzzy comprehensive evaluation method by case study of six typical reservoirs in Jiangxi Province, China. The main conclusions and innovation are as follows:

An evaluation model for modernization of reservoir management was established based on the AHP-Fuzzy method. This study evaluates six typical reservoirs in Jiangxi Province comprehensively by using this model. It concludes that the level of modernization of reservoir management in Jiangxi Province was moderate or higher.

Using the Analytic Hierarchy Process to calculate the weight of each evaluation index, the Fuzzy comprehensive evaluation method is used to evaluate the management modernization level. The weighted average fuzzy synthesis operator is selected, taking into account the effects of the
main and secondary factors. A numerical set is constructed based on the weighted average principle to make the fuzzy vector single value, which is convenient for the judgment of the level of reservoir management modernization.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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