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Comprehensive Assessment of the Management Mode of Small Water Conservancy Projects based on Matter-Element Extension

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Abstract

Small water conservancy projects are characterized by large quantities, multiple types, and extensive distribution. Therefore, no universal management mode exists for all small water conservancy projects. To disclose the relationship between the management mode and benefits of small water conservancy projects, a new comprehensive assessment model based on matter-element extension was proposed in this study. First, six common management modes of small water conservancy projects were summarized. These management modes were lease management, collective management, joint household management, individual management, auction, and joint stock cooperative management. Second, a comprehensive evaluation indicator system of management mode of small water conservancy projects was constructed, and the weights of different evaluation indicators were determined through the entropy weight method and the analytic hierarchy process. Third, the classical, extensional, and evaluating composite matter-element matrices of four evaluation grades for the management mode of small water conservancy projects were constructed in accordance to the matter-element extension model. The relevance of each evaluation indicator and management mode was calculated by a correlation function, and the evaluation grade was determined. Finally, the proposed comprehensive assessment model was verified using a case study based on a small water conservancy project in Suzhou City, Jiangsu Province, China. Results demonstrate that the relevance between the evaluation indicators and the management modes is higher than -1. The higher the numerical value of relevance of the evaluation indicator is, the more effective it is. Therefore, lease, joint household, and joint stock cooperative management are better than the other management modes and applicable in the management of small water conservancy projects in Suzhou City. Individual management and auction are the second-best management modes, whereas collective management is the least. This study provides references for scientifically and reasonably selecting the appropriate management mode of small water conservancy projects.

Keywords: Small water conservancy project, Management mode, Matter-element extension evaluation

1. Introduction

Small water conservancy projects play an important role in farmland irrigation, living water, aquaculture, and flood and waterlogging prevention. They guarantee food safety, improved living quality for peasants, agricultural development, and improved ecological environment. Thus, the continuously increasing national input into the construction of small water conservancy projects promotes agricultural progress and effectively accelerates water conservancy engineering reform and development. Nevertheless, the management of small water conservancy projects still has many weaknesses, and the demands for ecological environmental improvement are increasing. Management mode is in disharmony with the rural mode of production and management, resulting in increasingly prominent problems, such as poor management and low efficiency. These problems influence the development of benefits and bring great challenges to the management of small water conservancy projects [1]. Therefore, the management mode and efficiency of small water conservancy projects should be given attention.

On this basis, some studies on the management mode and evaluation indicators of small water conservancy projects have been reported [1-3]. The currently applied management modes are summarized and reviewed. For the evaluation of management efficiency, some indicator systems have been proposed. Studies on the management mode assessment of small water conservancy projects are mainly qualitative and have not effectively solved the problem of selecting the management mode of small water conservancy projects. Therefore, evaluating the management mode of small water conservancy projects and recognizing the appropriate conditions and the quality are problems that need urgent solutions.

In this study, a comprehensive evaluation model of management mode of small water conservancy projects was constructed through the matter-element extension evaluation method to analyze the management mode and evaluation indicators and evaluate the weights of different indicators and the evaluation grades of small water conservancy projects. This study aims to disclose the relationship between the management mode and efficiency of small water conservancy projects to provide references for selecting the appropriate management mode.

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2. State of the art

Numerous studies on the matter-element extension method have been reported. The comprehensive assessment method based on matter-element extension was a dynamic evaluation method [4]. Its basic idea was to view evaluation objects as matter-elements, divide matter-elements into several grades, determine the data range of different grades, and then perform a multi-index evaluation based on a correlation function. The evaluation results were compared in terms of relevance with sets of different grades. High relevance implied high conformance between the evaluation results and the sets of different grades [5]. The matter-element extension model has been applied by many researchers. Chen Shouyu [6] applied the matter-element extension model in the evaluation of a water resource system and proposed an optimal decision variable set method for the water resource system, which increased the decision-making level of the water resource system. Zhang Hongbo [7] evaluated the bearing capacity of water resources in China by using the extension evaluation method and proposed a method to improve the extension evaluation model based on the asymmetric close degree and weight of a rough set. This method increased the evaluation accuracy of the bearing capacity of water resources. Liu Chunli [8] constructed a quality evaluation model of ecological environments based on matter-element extension and used the model in the evaluation and empirical analysis of the ecological environmental quality of soil. This model provided a new idea for ecological environmental evaluation. Sun Tingrong [9] applied the improved extension evaluation method based on the asymmetric close degree and rough set theory in drought assessment in irrigated areas. The proposed method was practical and feasible according to a calculation example. Zhou Chaowang [10] evaluated risks in a flood prevention system by using an improved matter-element extension model and found that the model was scientific, reasonable, and simple in calculation. Yu Weijiang [11] constructed an underground water quality evaluation model based on comprehensive weights and an improved matter-element extension method and applied it in underground water quality evaluation in Guxian Town, Pingdu City and achieved good evaluation effects. Dong [12] assessed software quality by using the matter-element extension method and proposed a new perspective for software quality evaluation. Hsieh[13] assessed the validity of a fuel cell diagnosis system by using matter-element extension theory. These studies provided good references for the application of the matter-element extension model.

Many studies on the management mode of small water conservancy projects have been proposed. Bose [14] assessed the construction of water conservancy projects based on the multi-objective decision matrix but not the management mode of water conservancy projects. David [15] assessed the management of WFD river basins in England and Wales from the perspectives of progress, communities, output, and outcomes. He also proposed a highly valuable evaluation perspective. Liziński [16] assessed flood control and sewage treatment projects by using the CVM method and achieved a relatively good evaluation effect. Neves [17] evaluated a watercourse design project by using the gray correlation method, but the computation was relatively complicated. Vizzari [18] constructed a reliable and fast evaluation model by using the multi-index analytic hierarchy process and used the model to evaluate the validity of a sewage project management. Li Yifan [19] studied the management mode of small farmland water conservancy projects based on self-governance and analyzed current problems in various management modes. He proposed that water user association is the management mode with the strongest applicability. Liu Pingping [20] studied the incentive mechanism in a small water conservancy project management in which peasant households suggested an incentive mechanism for them to participate in the management of small water conservancy projects. These studies lay the foundation for the evaluation of the management modes of small water conservancy projects.

In summary, the existing extension evaluation is mainly applied in water resource utilization, drought prevention in irrigation areas, and flood prevention. However, the evaluation has not been used in the management mode of small water conservancy projects yet. Moreover, existing studies on extension evaluation mainly determine the weights of the evaluation model by the AHP method based on the knowledge and experiences of experts. Consequently, the weights of the evaluation model are subjective to some extent. Thus, the objectivity of the evaluation results must be strengthened. In contrast, the weights determined by the entropy weight method are relatively objective. Therefore, the advantages of the AHP and entropy weight methods were combined to evaluate the management mode of small water conservancy projects by an extension model. Furthermore, the weights of the extension model were determined by combining the AHP and entropy weight methods. This step is an innovative application of the extension model.

The reminder of this study is organized as follows. Section 3 describes the principle of the matter-element extension model, the construction method of matter-element and matter-element matrices, the calculation process of association, the calculation process of comprehensive weights, and the determination of evaluation grades. A comprehensive assessment model for the management mode of small water conservancy projects based on matter-element extension is constructed. Section 4 presents a case study based on small water conservancy projects in Suzhou City, Jiangsu Province. Six comprehensive assessment models based on matter-element extension are constructed for six management modes. The evaluation results of the six management modes are obtained by calculation. Section 5 summarizes the conclusions.

3. Methodology

3.1 Matter-element construction

The management modes (*N*), mode characteristics (*C*), and eigenvalues (*V*) of small water conservancy projects together form the matter-element (*R*) of the management mode of small water conservancy projects. They are recorded as *R*= (*N*, *C*, *V*). If *N* has n characteristics ($C_1, C_2, \cdots, C_n$) and the eigenvalues of the characteristics are $V_1, V_2, \cdots, V_n$, respectively, then

$$R = (N, C, V) = \begin{vmatrix} N & C_1 & V_1 \\ & C_2 & V_2 \\ & \vdots & \vdots \\ & C_n & V_n \end{vmatrix} \tag{1}$$

3.2 Determination of classical and extensional matter-element matrices

The classical matter-element matrix (R_N) of the management mode of small water conservancy projects can be expressed as

$$R_N = (N_i, C_n, V_n) = \begin{vmatrix} N_i & C_1 & (a_{i1}, b_{i1}) \\ & C_2 & (a_{i2}, b_{i2}) \\ & \vdots & \vdots \\ & C_n & (a_{in}, b_{in}) \end{vmatrix} \tag{2}$$

where N_i is the evaluation grade of *i*, $C_1, C_2, \cdots, C_n$ are the evaluation indicators; and (a_{in}, b_{in}) is the classical domain of C_n.

The extensional matter-element matrix (R_P) of the management mode of small water conservancy projects is expressed as

$$R_P = (N_P, C_n, V_n) = \begin{vmatrix} N_P & C_1 & (a_{p1}, b_{p1}) \\ & C_2 & (a_{p2}, b_{p2}) \\ & \vdots & \vdots \\ & C_n & (a_{in}, b_{pn}) \end{vmatrix} \tag{3}$$

where N_P is an entirety formed by the comprehensive evaluation grades of the management modes of small water conservancy projects; $C_1, C_2, \cdots, C_n$ are the evaluation indicators; and (a_{pn}, b_{pn}) is the value range of C_n.

3.3 Calculation of correlation coefficient and relevance

The correlation function of indicators in the management mode of small water conservancy projects is defined as

$$K(V_i)_j = \begin{cases} \dfrac{-\rho(V_i, V_{ij})}{|V_{ij}|} & V_i \in V_{ij} \\ \dfrac{\rho(V_i, V_{ij})}{\rho(V_i, V_{ij}) - \rho(V_i, V_{pn})} & V_i \notin V_{ij} \end{cases} \tag{4}$$

Where

$V_{ij} = |(b_{in} - a_{in})|$,

$\rho(V_i, V_{ij}) = \left| V_{pn} - \frac{1}{2}(a_{in} + b_{in}) \right| - \frac{1}{2}(b_{in} - a_{in})$,

$\rho(V_i, V_{pn}) = \left| V_{pn} - \frac{1}{2}(a_{pn} + b_{pn}) \right| - \frac{1}{2}(b_{in} - a_{in})$,

$i = 1, 2, 3, \cdots, n$, and $j = 1, 2, 3, \cdots, n$. $K(V_i)_j$ is the relevance between evaluation indicator *i* and evaluation grade *j* of the management mode of small water conservancy projects. V_i and V_{pn} are the magnitude ranges of the classical and extensional domains of the matter-elements in different management modes, respectively. $\rho(V_i, V_{ij})$ is the distance between point V_i and the finite interval V_{ij} of the corresponding eigenvector. $\rho(V_i, V_{pn})$ is the distance between point V_i and the finite interval V_{pn} of the corresponding eigenvector.

3.4 Calculation of comprehensive relevance and determination of evaluation grades

Comprehensive relevance refers to the degree of coincidence between all evaluation indicators and evaluation grades. It is expressed as

$$K_i(p) = \sum_{i=1}^{n} w_i k(V_i)_j \quad i = 1, 2, 3, \cdots, n \tag{5}$$

where $K_i(p)$ is the relevance between evaluating matter-element *R* and evaluation grade *j*. w_i denotes the weights of different evaluation indicators. $k(V_i)_j$ refers to the single-index relevance between the matter-element and grade *j*. If $K_{ij} = \max\{k_i(p)\}$, then indicator *i* of the evaluation object belongs to comprehensive evaluation grade *j*. The value of $K_i(p)$ reflects the degree of the evaluation object belonging to a comprehensive evaluation grade of the management mode of small water conservancy projects. When $K_i(p) > 0$, the evaluation index is compliant with the requirements of the standard object range and its value reflects the degree of conforming to the requirements. When $-1 < K_i(p) < 0$, the evaluation index is noncompliant with the requirements of standard objects but has the potential to be transformed to a standard object. A high $K_i(p)$ indicates that the evaluation object is easy to transform. When $K_i(p) < -1$, the evaluation object is noncompliant with the requirements of standard objects and cannot be transformed to a standard object.

3.5 Determination of weights

The amount of information gained from evaluation decisions is one of the decisive factors of evaluation accuracy and reliability. Currently, the AHP method is widely used in determining weights. The AHP method [21] considers the knowledge and experiences of experts and the preference of decision-makers, but it has substantial subjective randomness. The entropy weight method [21] is based on information entropy theory. Its principle is that an indicator with a small information entropy has a high degree of variation and can provide more effective information. Therefore, it has a higher weight, otherwise, it has a smaller weight. When evaluation objects have the same value on a certain indicator, the entropy reaches the maximum, indicating that this indicator provides no useful information and can be eliminated from the evaluation indicator system. Therefore, the results of the entropy weight method are relatively objective [22]. However, the entropy weight method cannot reflect the knowledge and experiences of experts and the opinions of decision makers. On the basis of the advantages of the AHP and entropy weight methods, the comprehensive weight (w) of evaluation indicators that combines the subjective and objective weights can be calculated by the following equation:

$$w = \partial w_i + (1 - a) w_i^{'} \tag{6}$$

where w_i is the weights of the indicators determined by the AHP method. a is the discount coefficient of the weights and set to 0.5. $w_i^{'}$ is the weight determined by the entropy weight method and calculated by the following equations:

$$w_i = \frac{(1-H_i)}{n-\sum_i^n H_i} \tag{7}$$

where $H_i = -\frac{1}{\ln m}\sum_{j=1}^{m} f_{ij} / \ln f_{ij}$, $f_{ij} = v_{ij} / \sum_{j=1}^{m} v_{ij}$, $i = 1, 2, 3, \cdots, n$, and v_{ij} is the magnitude of indicator i of evaluation object j.

4. Result analysis and discussion

4.1 Management mode of small water conservancy projects

Water conservancy projects have diversified management modes due to the increasing investment scale and quantity and different policy regulations, investment structures, and construction years. The small water conservancy projects in Suzhou City, Jiangsu Province include five types: 1) small reservoirs, 2) middle- and small-sized rivers and their embankments, 3) small water gates, 4) small farmland water conservancy projects and equipment, and 5) drinking water safety projects and small hydropower stations in rural areas. These small water conservancy projects cover six management modes, including lease management, collective management, joint household management, individual management, auction, and joint stock cooperative management modes. The management system of small water conservancy projects in Suzhou City, Jiangsu Province is shown in Fig. 1.

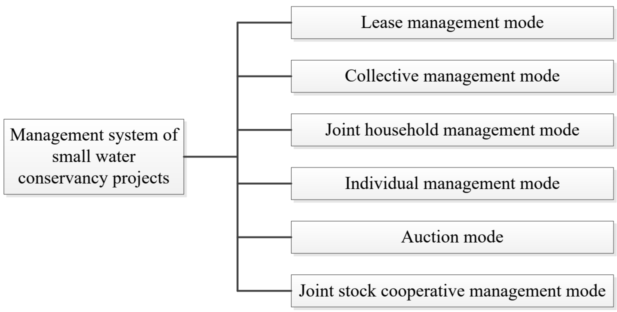

Fig. 1. Management system of small water conservancy projects in Suzhou

(1) Lease management mode
In lease management, an individual and the collective formally sign a lease contract that proposes explicit regulations on renter, project item, time limit, rental fee and rights, and obligations of two parties. The tenant shall operate and manage projects according to the articles stipulated in the contract.

A contract is a common management form. In lease management, small water conservancy projects owned by the collective are contracted to individual management. The contractor pays certain management fees to the collective, or the contractor is in charge of appropriate irrigation to cultivated lands in a certain area by paying water and electricity costs to peasant households.

(2) Collective management mode
Under collective management, the village mainly owns and has the right to use the small water conservancy projects, except for few projects that are managed by the rural town government or the Water Conservancy Bureau. Engineering investment types include national, collective, and state–collective–individual collaborative investments.

(3) Joint household management mode
Under joint household management, joint household financing is the main investment mode of small water conservancy projects, which are assisted by state subsidies. Projects are managed by one household or village.

(4) Individual management mode
Small water conservancy projects under individual management can be divided into three types: (1) projects with state investment and used and managed by individuals, (2) projects with individual investment supplemented with state subsidies and individual use and management, and (3) projects constructed and managed by users.

(5) Auction mode
Ownership and right to use of some projects, which are constructed with state or collective investment, are put up for auction under the organization of a town government or the Water Conservancy Bureau. The auction contract regulates the obligations of the purchaser in addition to the auction amount and recovery mode of the projects.

(6) Joint stock cooperative management mode
Joint stock cooperative management refers to the management of small water conservancy projects, which are constructed with collaborative investments, materials, and labor forces as a corporate enterprise. In recent years, some small water conservancy projects have been constructed with collaborative investments from the state, collectives, and the public and were attempted or planned to be managed by a joint stock cooperation system.

4.2 Comprehensive evaluation indicator system

According to previous research conclusions, characteristics, and practical situations on the management mode of small water conservancy projects in Suzhou City, a comprehensive evaluation indicator system was constructed (Fig. 2). The weights of different indicators were determined by using the abovementioned calculation method. Table 1 shows the results.

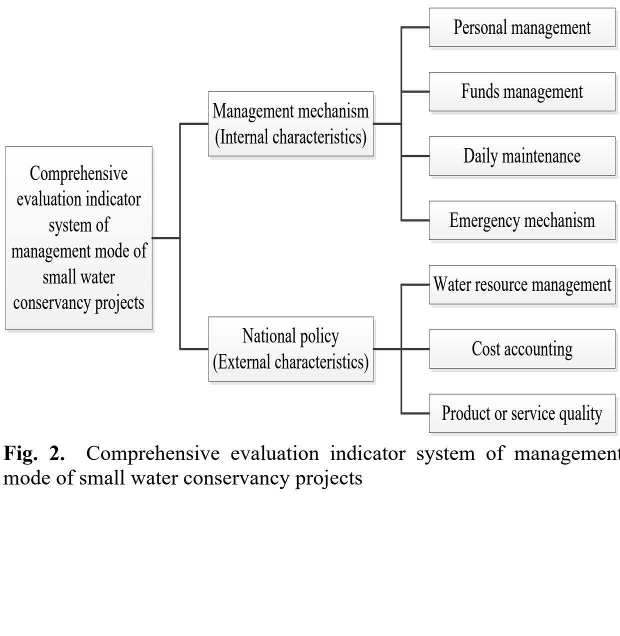

Fig. 2. Comprehensive evaluation indicator system of management mode of small water conservancy projects

4.3 Classical domain and extensional domain in comprehensive evaluation

According to the extension of the management mode of small water conservancy projects, the management mode is divided into four grades, namely, excellent, good, moderate, and poor, which correspond to Grades I, II, III, and IV, respectively. On this basis, classical matter-element matrices (R_{N1} , R_{N2} , R_{N3} , and R_{N4}) and an extensional matter-element matrix (R_P) for the comprehensive evaluation of the management mode of small water conservancy projects were constructed. The details are introduced in the following text.

Table 1. Weights of indicators in the comprehensive evaluation indicator system

Target layer	Criteria layer	Program layer	Symbols	Weights
Comprehensive evaluation of management mode of small water conservancy projects	Management mechanism (internal characteristics)	Personnel management (scores)	C_1	0.42
		Funds management (cost/10,000 RMB)	C_2	0.22
		Daily maintenance (grade)	C_3	0.08
		Emergency mechanism (grade)	C_4	0.04
	National policy (external characteristics)	Water source management (scores)	C_5	0.04
		Cost accounting (budget percentage = %)	C_6	0.13
		Product or service quality (water price)	C_7	0.07

$$R_{N1} = \begin{vmatrix} N_1 & C_1 & (95,100) \\ & C_2 & (6,8) \\ & C_3 & (6,7) \\ & C_4 & (6,7) \\ & C_5 & (80,100) \\ & C_6 & (0,10) \\ & C_7 & (1.5,2) \end{vmatrix}, \quad R_{N2} = \begin{vmatrix} N_2 & C_1 & (85,95) \\ & C_2 & (8,10) \\ & C_3 & (4,6) \\ & C_4 & (4,6) \\ & C_5 & (60,80) \\ & C_6 & (10,20) \\ & C_7 & (2,2.5) \end{vmatrix},$$

$$R_{N3} = \begin{vmatrix} N_3 & C_1 & (70,85) \\ & C_2 & (10,12) \\ & C_3 & (2,4) \\ & C_4 & (2,4) \\ & C_5 & (40,60) \\ & C_6 & (20,30) \\ & C_7 & (2.5,3) \end{vmatrix}, \quad R_{N4} = \begin{vmatrix} N_4 & C_1 & (0,70) \\ & C_2 & (12,14) \\ & C_3 & (1,2) \\ & C_4 & (1,2) \\ & C_5 & (0,40) \\ & C_6 & (30,40) \\ & C_7 & (3,3.5) \end{vmatrix},$$

$$R_P = \begin{vmatrix} N_P & C_1 & (0,100) \\ & C_2 & (6,14) \\ & C_3 & (1,7) \\ & C_4 & (1,7) \\ & C_5 & (0,100) \\ & C_6 & (0,40) \\ & C_7 & (1.5,3.5) \end{vmatrix}$$

4.4 Matter-elements for evaluation

The statistical data and scoring of the six management modes were carried out based on the existing data of small water conservancy projects in Suzhou City, Jiangsu Province. Moreover, a composite matter-element matrix for evaluation (R_d) is constructed according to the comprehensive evaluation indicators of the management modes of small water conservancy projects.

$$R_d = \begin{vmatrix} & \text{m1} & \text{m2} & \text{m3} & \text{m4} & \text{m5} & \text{m6} \\ C_1 & 95.7 & 97.2 & 90.4 & 94.7 & 85.9 & 99.9 \\ C_2 & 7.88 & 15.5 & 15.8 & 14.5 & 8.21 & 9.23 \\ C_3 & 4 & 5 & 4 & 2 & 3 & 4 \\ C_4 & 5 & 4 & 3 & 2 & 2 & 4 \\ C_5 & 93.2 & 95.7 & 87.4 & 82.9 & 90.1 & 89.5 \\ C_6 & 21.4 & 30.3 & 28.6 & 33.8 & 27.6 & 26.1 \\ C_7 & 1.73 & 2.33 & 1.87 & 3.11 & 2.25 & 1.99 \end{vmatrix}$$

where m1 = lease management mode, m2 = collective management mode, m3 = joint household management mode, m4 = individual management mode, m5 = auction mode, and m6 = joint stock cooperative management mode.

4.5 Relevance of evaluation indicators

Relevance between the management modes of small water conservancy projects and evaluation indicators can be calculated by using Eq. (4). Table 2 lists the results.

Table 2. Relevance between management modes and evaluation indicators

Relevance	m1	m2	m3	m4	m5	m6
$K(V_1)_j$	I	I	II	II	II	I
$K(V_2)_j$	III	IV	I	II	I	III
$K(V_3)_j$	II	I	II	II	II	I
$K(V_4)_j$	I	II	III	IV	III	III
$K(V_5)_j$	I	III	III	II	IV	III
$K(V_6)_j$	II	III	I	III	I	II
$K(V_7)_j$	I	IV	I	IV	IV	II

4.6 Comprehensive evaluation grades

Relevance between the management modes and evaluation grades is calculated by using Eq. (5). Table 3 presents the results of relevance and relevant evaluation grades.

Table 3 indicates that lease, joint household, and joint stock cooperative management are the best modes and shall be promoted in small water conservancy projects in Suzhou City, Jiangsu Province. Individual management and auction are the second-best management modes, whereas collective management is the poorest.

Table 3. Comprehensive evaluation results of the management modes of small water conservancy projects

Comprehensive relevance	Grade I	Grade II	Grade III	Grade IV	Comprehensive evaluation grades
m1	-0.005	-0.287	-0.412	-0.649	Grade I
m2	-0.383	-0.353	-0.285	-0.259	Grade IV
m3	0.015	-0.229	-0.385	-0.608	Grade I
m4	-0.319	-0.201	-0.188	-0.312	Grade III
m5	-0.374	-0.315	-0.219	-0.283	Grade III
m6	-0.272	-0.277	-0.373	-0.510	Grade I

5. Conclusions

To explore the relationship between the management modes of small water conservancy projects and the management benefits and improve management performance, six management modes of small water conservancy projects were evaluated comprehensively by combining the indicator evaluation and the case study based on the matter-element extension model. The following conclusions could be drawn:

(1) Lease management mode, joint household management mode and joint stock cooperative management mode are the best modes and shall be promoted in small water conservancy projects in Suzhou City, Jiangsu Province. Individual management mode and auction mode are the second best management modes, whereas collective management is the least.

(2) The evaluation results are basically consistent with the practical situation. These results verify that the constructed matter-element extension model is feasible and can be promoted to evaluate the management modes of small water conservancy projects.

In this study, a comprehensive evaluation model for the management modes of small water conservancy projects based on matter-element extension was proposed by combining theoretical and case studies. This model provided references for deciding on the scientific and reasonable selection of the management modes of small water conservancy projects. Given that the proposed model claims heavy calculation loads, future studies may explore how to compile calculations into a computer program and develop a reusable comprehensive evaluation software for the management modes of small water conservancy projects, providing informatization means for the management of small water conservancy projects.

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