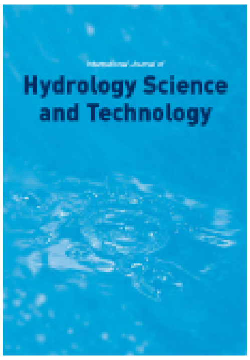

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A software for water pollution treatment technology evaluation by supporting customisable indicator systems for specific scenarios

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A software for water pollution treatment technology evaluation by supporting customisable indicator systems for specific scenarios

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Abstract: Determining the best water pollution treatment technology (WPTT) is one of the biggest challenges in water pollution management. We proposed the point of 'specific evaluations for specific scenarios' to select appropriate technologies that can improve the efficiency of water pollution treatment. This point refers to establishing specific indicator systems for water pollution treatment technology evaluation (WPTTE) for specific scenarios. A software was developed to achieve 'specific evaluations for specific scenarios' by supporting the rapid construction of customised indicator systems. The functions of this software include data management, indicator system matching, visualising construction of indicator systems, comprehensive evaluation and graphic display. In addition, the software was demonstrated by an example of ammonia nitrogen wastewater treatment technology selection. The software can meet the demands of multi-scene and multi-role evaluation and make the establishment of indicator systems more straightforward and effective. The study provides a solid foundation for 'specific evaluations for specific scenarios'.

Keywords: water pollution; treatment technology; technology evaluation; specific evaluations for specific scenarios; indicator system; analytic hierarchy process; AHP; evaluation software.

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1 Introduction

Different water pollution treatment technologies (WPTT) are suitable for different water pollution scenarios (Travanca et al., 2017; Yao et al., 2020). Selecting the right WPTT is one of the biggest challenges in water pollution management (Khan et al., 2022; Mahjouri et al., 2017; Yuan et al., 2019; Zhang et al., 2020). Water pollution treatment technology evaluation (WPTTE) is the current mainstream method of selecting the best WPTT (Ali et al., 2020; Ren and Liang, 2017). Different indicator systems may lead to different conclusions (Shi et al., 2019). Thus, determining the indicator system is key to WPTTE (Silva and Rosa, 2020). In previous studies, some WPTTEs use the same indicator system, which may ignore specific evaluation scenes and evaluators' selection preferences, thus resulting in different evaluation results (Qu et al., 2016b). In practice, the indicator system cannot be invariable (Mahjouri et al., 2017; Qu et al., 2016b; Sharma et al., 2021). For example, even with the same type of water pollution event, the WPTT selection may be influenced by various factors such as water source and pollution concentration (Selihin and Tay, 2022; Varjani et al., 2020). Hence, customisable indicator systems for WPTTEs should be established for specific water pollution scenes and evaluation roles, such as different geographical regions, water quality characteristics, management policies, development stages, researchers, users, investors and decision-makers. This evaluation demand is termed 'specific evaluations for specific scenarios' in this study.

In recent decades, domestic and foreign scholars have solved WPTTE for different scenarios by determining weights. For example, Liu et al. (2020) developed three sets of indicator weights for selecting the optimal wastewater treatment technology based on the specific geography of three counties. Qu et al. (2016a) determined four sets of indicator weights according to the four threat degrees of water pollution. Sadr et al. (2015) established four sets of weights to select the most appropriate WPTT for unrestricted and restricted non-potable reuse applications in South Africa's cities and suburban areas. Nevertheless, they ignore that different scenarios may also affect the indicator topology structure and scoring criteria. Therefore, the research on the 'specific evaluations for specific scenarios' is far from adequate and has plenty of room for improvement.

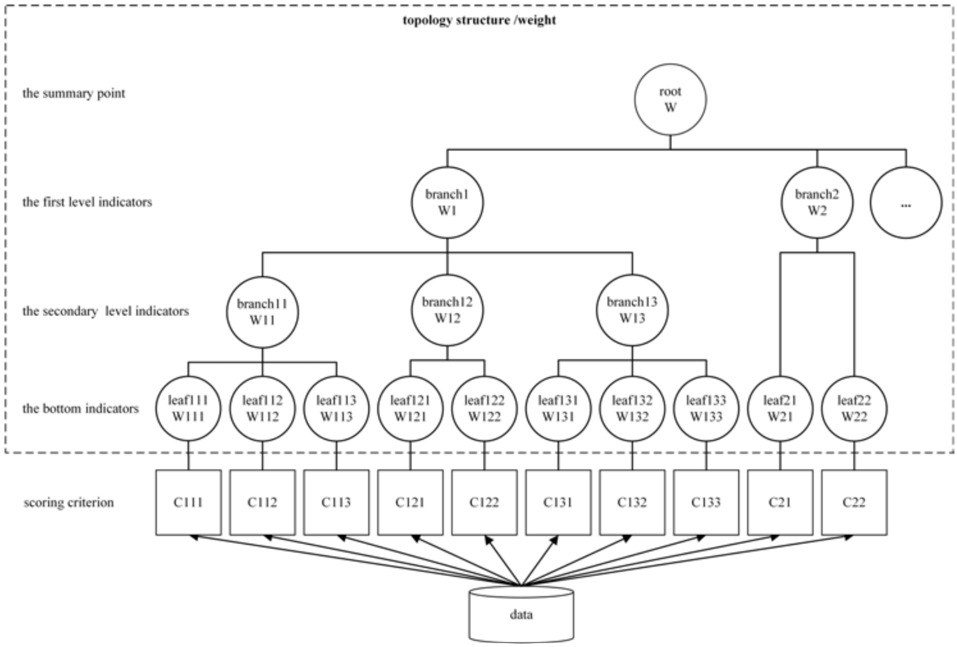
In the face of complex and substantial evaluation demands, using existing methods to establish indicator systems of the 'specific evaluations for specific scenarios' is costly, laborious and time-consuming. At this point, with the help of software technology, achieving 'specific evaluations for specific scenarios' is particularly important. However, software development research has currently reported little on constructing the indicator system of WPTTE. The existing studies still have some deficiencies. For example, the Liaohe River Basin's WPTTE software (Li et al., 2011; Xiang et al., 2013) used fixed indicators to evaluate the same type of water pollution events. Wongburi and Park (2018) developed an expert system in Excel ® program to determine the best WPTT, which has difficulty coping with the complex and variable evaluation. Liu et al. (2017) developed a decision-making platform that uses the same indicators to evaluate emergency disposal technologies for water pollution. The software by Ishak et al. (2020) is only used for palm oil wastewater treatment technology evaluation. In addition, some common decision software such as yet another analytic hierarchy process (YAAHP), yet another analytic network process (YAANP), super decision and expert choice have been developed at home and abroad. These applications can support the construction of indicator systems and calculate evaluation results. However, they are not perfect in comprehensiveness, compatibility, ease of use, openness and efficiency, particularly the browser/server (B/S) network architecture, database and open application programming interface. Therefore, the existing software has difficulty meeting the evaluation demand of 'specific evaluations for specific scenarios'.

For this purpose, on the basis of a wide-ranging investigation of existing WPTTE indicator systems and supporting tools, this study proposed to construct customisable indicator systems for WPTTE according to specific scenarios, namely, 'specific evaluations for specific scenarios'. Moreover, we developed WPTTE software to help achieve 'specific evaluations for specific scenarios'.

2 Indicator system construction

The definition of the indicator system is not clear in academia. Most scholars believe that the indicator system consists of indicators and a topology structure (Liu et al., 2021; Wang et al., 2021). Some scholars believe that the weight should be increased based on the above (Xu et al., 2021). Moreover, some scholars believe that scoring criteria should also be added to the indicator system research (Zhou et al., 2021). We analysed 81 WPTTE cases during the 11th and 12th Five-Year Plans of the China Major Science and Technology Project for Water Pollution Control and Treatment. We found that the above three views were reflected. The study agrees with the third view that the indicator system contains three parts: topology structure, weight and scoring criterion (see Figure 1).

Figure 1 Composition of the indicator system



2.1 *Indicator topology structure*

The indicator topology structure reflects the tree topology relations of each indicator. Nodes can be divided into three types. The first type is the root node, the summary point located at the topology structure's highest level. The second type is the branch node distributed in the topology structure's middle level, which corresponds to all levels of indicators except the bottom level. The third type is the leaf node, located at the bottom level of the topology structure, which corresponds to the bottom indicators. Each leaf node can transform the data in the database into dimensionless scores by scoring criteria.

2.2 *Weight*

The weights reflect each indicator's importance (branch nodes, leaf nodes). The main methods for determining the weights are the subjective weighting method, objective weighting method and combination weighting method (Shi et al., 2018). The subjective weighting method means that the experts determine weights based on their empirical knowledge, such as the analytic hierarchy process (AHP) and the Delphi method. The objective weighting method determines weights by the relationship between the basic data, such as the entropy weight method and variance coefficient. Furthermore, the combination weighting method combines subjective and objective methods to determine weights. The AHP or the expert scoring method determined the indicator weight in this study.

2.2.1 Analytic hierarchy process

The AHP has been widely studied and applied since its introduction by Saaty (1977). In the AHP, the weights are exported by building judgement matrixes. The main steps to determine the indicator weights using AHP are as follows (Feng et al., 2014; Sun et al., 2016):

Step 1 Construction of judgement matrix: Experts and scholars use the 1–9 scaling method to compare indicators under the same node and at the same level with each other to form a judgement matrix.

$$A = \left(a_{ij}\right)_{n\times n} \tag{1}$$

where n is the judgement matrix order, a_{ij} denotes the importance value of nodes i and j relative to the parent node and follows the following criteria:

$$a_{ij} > 0;\ a_{ij} = \frac{1}{a_{ji}}(i \neq j);\ a_{ii} = 1 \tag{2}$$

Step 2 Calculate the weights: Use the square root method to calculate the weights of the nodes relative to their parent node.

$$M_i = \prod_{j=1}^{n} a_{ij},\ i = 1, 2, \ldots, n \tag{3}$$

$$\bar{w}_j = \sqrt[n]{M_i} \tag{4}$$

$$w_i = \frac{\bar{w}_i}{\sum_{i=1}^{n} \bar{w}_i} \tag{5}$$

$$W = \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} \tag{6}$$

Step 3 Consistency testing: The consistency ratio (CR) is used to determine the consistency of the judgement matrix. The calculation formula is as follows:

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n} \frac{(AW)_i}{w_i} \tag{7}$$

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{8}$$

$$CR = \frac{CI}{RI} \tag{9}$$

where CI is the consistency index, $\lambda_{\max}$ is the largest eigenvalue of the judgement matrix, and RI is the average random consistency index. The RI value is obtained by querying the table (Wei et al., 2020). If $CR < 0.1$, the degree of consistency is considered satisfactory. Otherwise, the judgement matrix must be adjusted.

2.2.2 Expert scoring method

The expert scoring method refers to experts or expert groups scoring each indicator on the basis of the specific scenarios and their own experience. Under the same node, the ratio of each indicator score to the total score of indicators at the same level is the weight value of the indicator. The method is simpler and easier to understand but requires more overall perception abilities from the expert.

2.3 Scoring criterion

The scoring criterion intends to eliminate the dimensional difference between the indicators. Different indicators are treated according to standardisation guidelines. The scoring criterion is determined on the basis of national, regional and industry standards, relevant research literature and expert consultation. This study used four scoring criterion calculation methods: direct proportion, inverse proportion, piecewise function and one-vote veto. The direct proportion means that the indicator value is positively correlated with the target value, which cannot be 0. The inverse proportion means that the indicator value is negatively correlated with the target value, and its value cannot be 0. Piecewise scoring maps the indicator values to irregular lines according to user requirements. When the line segmentation is thin enough, it can support various shapes of mapping functions in theory. The one-vote veto setting can reflect some special rules, such as the country or industry setting a strict limit value for a specific indicator. When the technology indicator exceeds or falls below the limit value, technology should be ‘vetoed’.

3 Software development

3.1 Function design

On the basis of the above study, we used Microsoft SQL Server 2008 as the database and Java as the development language to develop a software of B/S model for constructing indicator systems rapidly. The software consists of seven main functions: basic data management, indicator data extraction, indicator system matching, indicator system construction, comprehensive evaluation, graphic display and system management (see Figure 2):

1 Basic data management: The software provides the operations of adding, deleting, modifying and querying required for basic data management.

2 Indicator data extraction: The software provides two means of data filtering and subtotal for extracting the evaluation data needed from the basic data.

3 Indicator system matching: When evaluators are familiar with each indicator system in the indicator system database, they can select the indicator system by themselves for inheritance. However, with the further development of the evaluation work and the accumulation of indicator systems, the evaluators have difficulty familiarising

themselves thoroughly with the existing indicator systems. For this situation, the software provides two additional methods, statistical matching and neural network matching, to help evaluators quickly select indicators and indicator systems. Statistical matching uses statistical algorithms to compare the extracted indicators with the indicator system database. Then, the matching results are presented in descending order for evaluators to select and inherit the indicator system. After the number of indicator systems accumulates to a certain level, the evaluators can use the neural network matching method. This approach can screen out the indicators that the evaluators care about by mining the possible implicit relationships between information such as indicators, evaluation roles and application scenes.

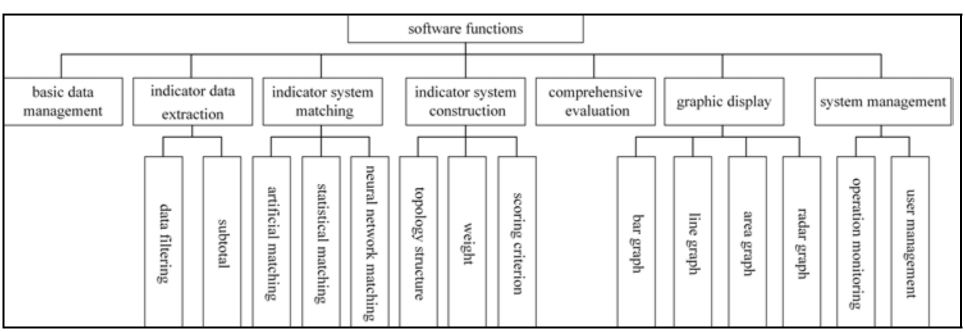
4 Indicator system construction: Indicator system construction includes creating and modifying the indicator topology structure, weight and scoring criterion. Evaluators can quickly edit the indicator topology structure based on the what you see is what you get (WYSIWYG) interactive interface. The interface supports various operations, such as whole inherit, partial copy, drag and drop, add, delete and modify. Evaluators can select the AHP or the expert scoring method to determine the indicator weight. They can design the scoring criteria by choosing direct proportion, inverse proportion, piecewise and one-vote veto. In addition, the evaluators can construct single or multiple indicator topology structures, weights and scoring criteria that constitute one or more indicator systems to evaluate from different perspectives.

5 Comprehensive evaluation: The software uses the constructed indicator topology structure, weights and scoring criteria to calculate the evaluation results.

6 Graphic display: After the evaluation is completed, the software provides the bar graph, line graph, area graph and radar graph to show the evaluation results.

7 System management: The system administration mainly includes operation monitoring and user management functions.

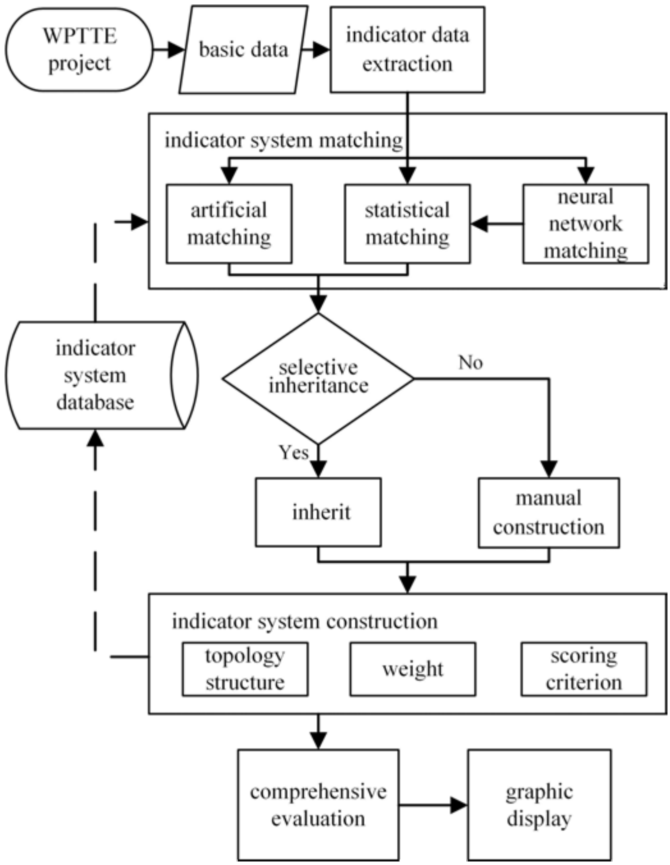
Figure 2 Software functions



3.2 Core business process

The core business process of the software for constructing the WPTTE indicator system is shown in Figure 3.

Figure 3 Software core business process



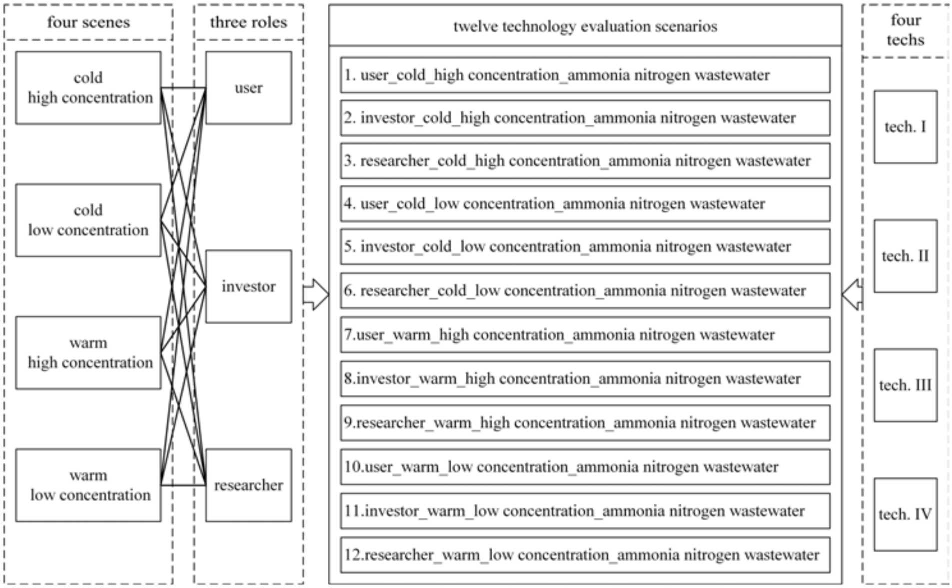
In addition, the software provides sensitivity analysis, historical tracking, intelligent data completion and multi-user group evaluation functions to meet the diverse evaluation needs of evaluators.

4 Application demonstration

4.1 Case situation

In this study, an example of selecting ammonia nitrogen wastewater treatment technology was designed to demonstrate the effect of using software to construct the indicator systems. This case includes four scenes, three evaluation roles and four alternative technologies (see Figure 4). In particular, the four scenes are formed by combining two climatic factors (cold and warm) and two water quality factors (high and low concentration). The three evaluation roles are user, decision-maker and researcher. Finally, these four scenes and three evaluation roles were combined to form 12 evaluation scenarios.

Figure 4 Ammonia nitrogen wastewater treatment technology evaluation analysis



For the 12 scenarios, 12 sets of indicator systems should be established. For instance, in cold areas, evaluators need to consider the low-temperature resistance of technology. For different ammonia nitrogen concentrations, treatment ammonia nitrogen wastewater of high concentration may be more concerned about technology's removal rate and control rate. For different evaluation roles, users, investors, and researchers are more focused on indicators of operation, market demand and pollutant removal rate, respectively.

4.2 Technology evaluation

Here, only Scenario 1 (the user selects the treatment technology of high concentration ammonia nitrogen wastewater in a cold area) and Scenario 12 (the researcher selects the treatment technology of low concentration ammonia nitrogen wastewater in a warm area) are described in detail. The indicator systems of the two scenarios used manual and inherited constructed, respectively.

4.2.1 Manual construction of scenario1 indicator system

1 Basic data entry and indicator data extraction. Firstly, the software entered the basic data of the four ammonia nitrogen wastewater treatment technologies. Secondly, the user used the data filtering method to extract 14 indicators as pre-evaluation indicators, namely, 'ammonia nitrogen removal rate', 'ammonia nitrogen control rate', 'equipment life', 'influent water quality requirements', 'low-temperature resistance', 'operation way', 'automation degree', 'noise', 'odour', 'innovation height', 'innovation difficulty', 'innovation results', 'technology maturity' and 'market demand'.

2 Indicator system construction: The user opted to build the indicator system of Scenario 1 using manual construction and did not inherit the existing indicator systems. According to the extracted indicators, the user constructed the indicator topology structure by mouse dragging, dropping, clicking, and keyboard entry (see Figure 5, this figure and Figures 6, 7 and 9 were translated from Chinese interface). The expert scoring method was used to determine indicator weights (see Figure 6). Moreover, the basic data were converted into standardised scores through direct, inverse and piecewise scoring methods (see Figure 7).

Figure 5 Visual interface for indicator system construction

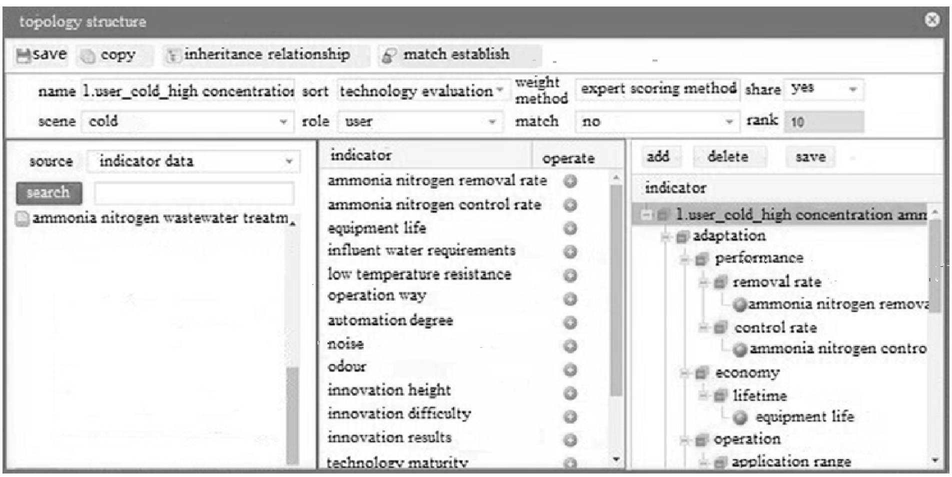


Figure 6 Visual interface for determining weights by expert scoring method

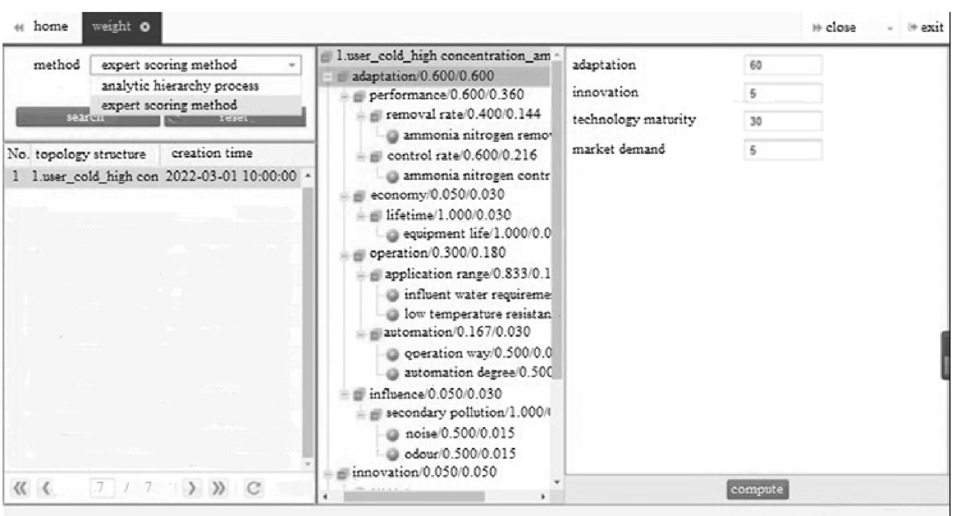
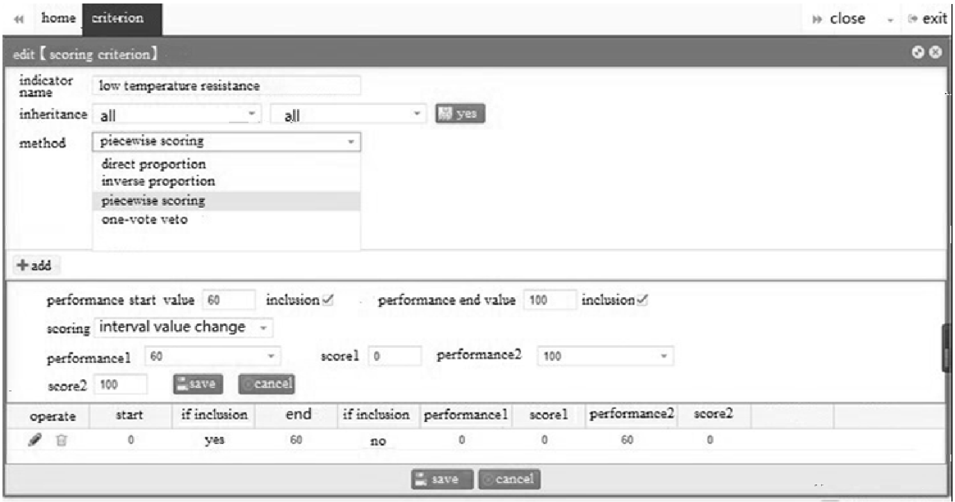
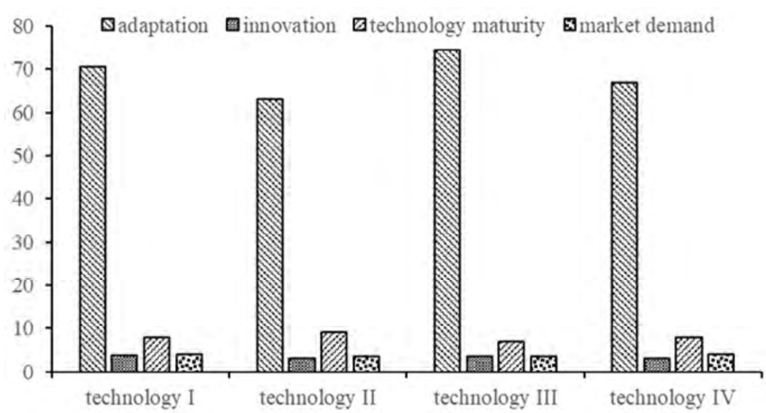


Figure 7 Visual interface for developing scoring criterion of 'low-temperature resistance' by piecewise scoring method



3 Completion of comprehensive evaluation and graphic display: The user used the newly constructed indicator system for comprehensive evaluation. Each level indicator score was calculated and the results are displayed in a bar graph (see Figure 8).

Figure 8 Evaluation results of four technologies in Scenario 1 (first level indicators)



4.2.2 Inheritance construction of Scenario 12 indicator system

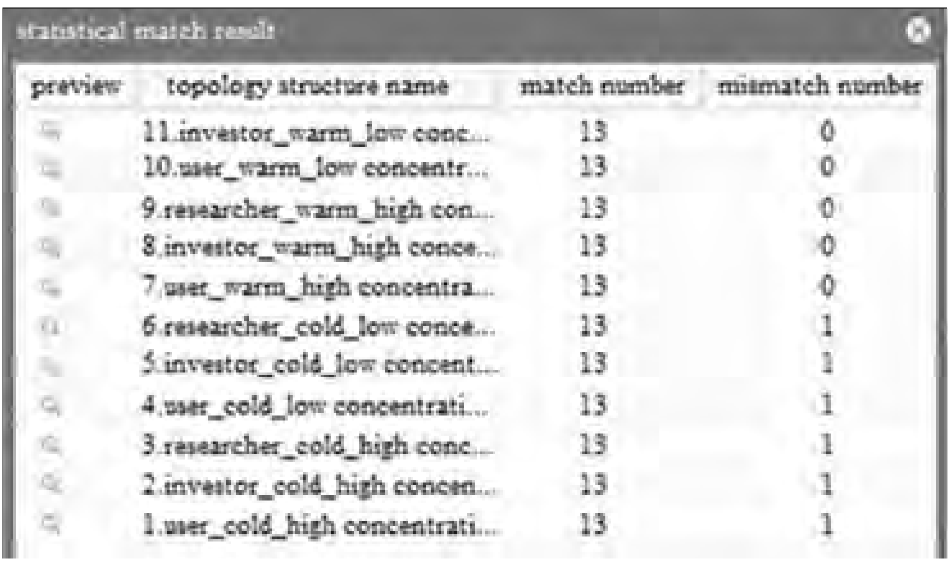
1 Indicator data extraction: Based on the basic data of four ammonia nitrogen treatment technologies, the researcher extracted 13 indicators as pre-evaluation indicators, namely, 'ammonia nitrogen removal rate', 'ammonia nitrogen control rate', 'equipment life', 'influent water quality requirements', 'operation way', 'automation degree', 'noise', 'odour', 'innovation height', 'innovation difficulty', 'innovation results', 'technology maturity' and 'market demand'.

2 Indicator system matching: The researcher used statistical matching to construct the indicator system for Scenario 12. The software presented the matching results (see Figure 9). Ultimately, the researcher inherited the indicator system of Scenario 11 (the investor selects the treatment technology of low concentration ammonia nitrogen wastewater in a warm area) by previewing the matching results.

3 Indicator system construction: The researcher modified the weight value of the 'ammonia nitrogen removal rate' and innovation indicators based on the inherited indicator system. The researcher was satisfied with the inherited topology structure and scoring criteria, which were not modified.

4 Completion of comprehensive evaluation and graphic display: Similar to Scenario 1, the new indicator system was used for a comprehensive evaluation and displayed by a graph.

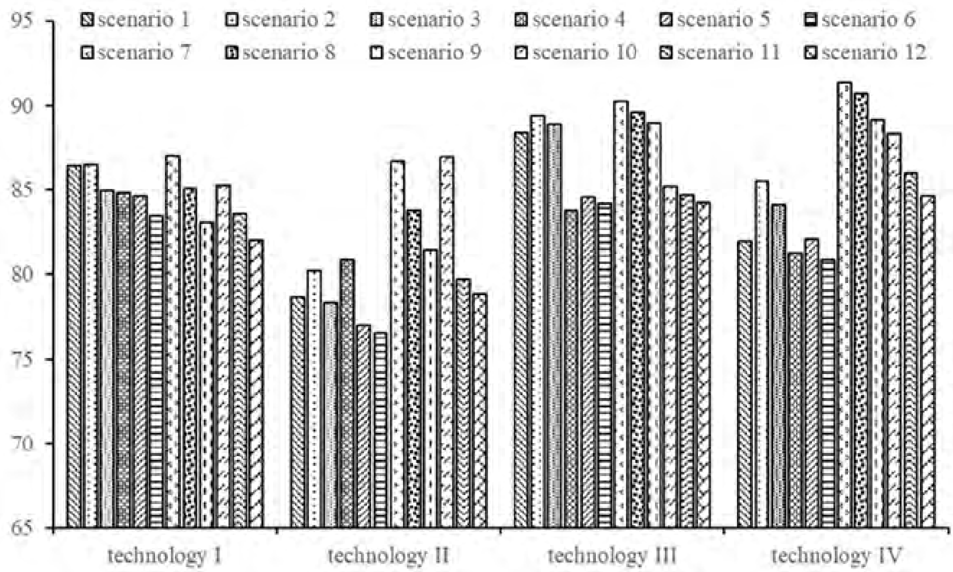
Figure 9 Indicator system statistical matching results


statistical match result

preview	topology structure name	match number	mismatch number
	11.investor_warm_low conc...	13	0
	10.user_warm_low concentr...	13	0
	9.researcher_warm_high con...	13	0
	8.investor_warm_high conce...	13	0
	7.user_warm_high concentra...	13	0
	6.researcher_cold_low conce...	13	1
	5.investor_cold_low concent...	13	1
	4.user_cold_low concentrati...	13	1
	3.researcher_cold_high conc...	13	1
	2.investor_cold_high concen...	13	1
	1.user_cold_high concentrati...	13	1

The evaluation results of ammonia nitrogen treatment technology in 12 scenarios were exported to make a bar graph (see Figure 10). Among the 12 scenarios, technology I scores were more consistent. The scores of technologies II, III and IV showed a significant variation across scenarios. In Scenario 1, technology III was preferred. In Scenario 12, technologies III and IV won. Technology III had a slightly lower technology maturity, while high low-temperature resistance and ammonia nitrogen removal rate met the treatment technology demands of Scenario 1. Both technologies III and IV had a high ammonia nitrogen removal rate and innovation, which met the needs of Scenario 12. The evaluation results were consistent with the actual situation.

Figure 10 Evaluation results of four technologies in 12 scenarios (root node)



5 Conclusions

The point of 'specific evaluations for specific scenarios' was proposed to select the best WPTT by establishing specific indicator systems to WPTTE for specific evaluation scenarios. Each indicator system includes three parts: the indicator's topology structure, weights and scoring criteria. The evaluator constructs the indicator topology structure based on the specific scenario and their preferences, determines the weight values by AHP or the expert scoring method and chooses direct proportion, inverse proportion, piecewise function or one-vote veto as scoring criteria. When the evaluation cases are accumulated to a certain degree, a new indicator system can be constructed by modifying the indicator system of similar cases. The 'specific evaluations for specific scenarios' offer a new reference for solving the challenge of selecting the right WPTT.

The WPTTE software was developed to achieve 'specific evaluations for specific scenarios' by supporting the rapid construction of customised indicator systems. On the one hand, the software visualises the indicator system construction, such as the indicator system's creation, deletion and modification by mouse click, drag and drop and keyboard entry. On the other hand, the software uses artificial, statistical or neural network matching methods to filter out indicator systems of similar cases quickly. Moreover, the software offers functions such as data management, comprehensive evaluation and graphic display. At the same time, it supports network environment and database access, which can be used by multiple people online simultaneously and data sharing. The software meets most evaluation demands, makes constructing indicator systems more straightforward and provides a good support tool for selecting the appropriate WPTT.

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