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Research on Safety Evaluation of Municipal Sewage Treatment Plant Based on Improved Best-Worst Method and Fuzzy Comprehensive Method

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Abstract: With the rapid development of urbanization and industrialization, water resources are in increasingly short supply, and the construction of sewage treatment plants can ensure the sustainable development of water resources. To eliminate the potential safety hazards of municipal sewage treatment plants and prevent safety accidents from the source, this paper takes a municipal sewage treatment plant in Changchun as the research object, puts forward the evaluation method of the "improved Best-Worst Method (BWM)—fuzzy comprehensive evaluation method", and carries out safety evaluation research on the research object. Firstly, combined with the technological process of sewage treatment plants, the evaluation index system is constructed from four factors: human factors, material factors, environmental factors, and management factors. Secondly, the improved BWM is used to calculate the weights. Finally, the fuzzy comprehensive evaluation method is used for safety evaluation, and the evaluation of safety status is obtained: the safety level.

Keywords: safety evaluation; municipal sewage treatment plant; improved best-worst method; fuzzy comprehensive evaluation; group decision-making

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1. Introduction

Water is one of the most important resources on Earth, supporting the survival of animals, plants, and microorganisms. Due to the rapid development of the economy and urbanization, the demand for water resources is increasing day by day and water is polluted, resulting in the inefficient use of water resources. Globally, water demand and consumption are expected to increase significantly, especially in the industrial sectors [1]. According to a 2018 United Nations projection, nearly 900 million people in the world could face severe water scarcity by 2050 [2]. Not only is water scarcity a problem, but water quality is also affected by human activities [3]. The development of industrialization has increased the population, resulting in a large amount of industrial wastewater and domestic sewage increasing the pollutant load of water bodies [4]. The extensive use of medications during bacterial or viral pandemics can harm aquatic organisms [5] and affect the sustainability of water resources [6]. Wastewater treatment is crucial to the sustainable development of water resources. In 2021, the United Nations set "clean water and sanitation for all" as the global Sustainable Development Goal [7]. The construction of sewage treatment plants is one of the effective solutions.

Sewage treatment plants are places where sewage or water with high pollutant levels are converted into water bodies with low pollutants. This process is mainly divided into the following stages: (1) pretreatment—mainly the filtration of larger garbage or sand and gravel [8]; (2) primary treatment—the treatment of smaller solids and suspended solids by physical methods [9]; (3) secondary treatment—the removal of non-precipitable suspended

solids [10] and dissolved biodegradable organic matter by biological/chemical [11] and physical [12,13] methods; (4) tertiary treatment—desalination [14] and the removal of nitrate/nitrite [15]; and finally, (5) quaternary treatment—the removal of remaining organic matters/chemicals/drugs [16], viruses [17], protozoa [18], bacteria [19], fungi spores [20] and parasites [21]. Urban sewage treatment plants are under more pressure to treat sewage as a result of the growth in urban population and industry. Additionally, safety accidents (electric shock, drowning, poisoning and suffocation, explosion, etc. [22]) frequently occur in these facilities, reducing the efficacy of sewage treatment and impacting the long-term sustainability of water resources.

Many scholars have put forward research methods and evaluation models for the safety evaluation of sewage treatment plants. Lin [23] used the Analytic Hierarchy Process (AHP) to evaluate the risk of a sewage treatment plant. Shinta et al. [24] used a fishbone diagram to analyze potential risks and Failure Mode Effect Analysis (FMEA) to evaluate risks. Alizadeh et al. [25] used the Fuzzy Failure Mode Effect Analysis (FFMEA) method to identify, evaluate and prioritize the risks of screening and sand removal unit operations in a municipal sewage treatment plant in Iran. Mohammad et al. [26] established a fault tree diagram with ultra-admisable water output BOD as the top-level event, identified the defects of the system using the fault tree analysis method and calculated the probability of basic events using Monte Carlo simulation. Mohsenzade et al. [27] used the FMEA method for risk assessment of chlorination units in four wastewater treatment plants in Mashhad. Kumari et al. [28] used a fuzzy analytic hierarchy process to calculate weights and used fuzzy TOPSIS to rank risks in a risk assessment of common effluent treatment.

In safety evaluation, the weight of each criterion is extremely important to the evaluation results, reflecting that the weight of the indicators is a key factor affecting the accuracy of the evaluation results. Pairwise comparison weighting methods are widely used in index weighting, including AHP, Analytic Network Process (ANP), and BWM. AHP is a hierarchical analysis method that combines qualitative and quantitative research issues [29,30]. ANP is a method developed on the basis of AHP [31–33]. However, ANP constructs the matrix and calculates the weights, and the operation process is complicated and tedious. Rezaei [34] proposed a new pairwise comparison method, BWM, in 2014, which reduces 0.5 (n − 2) (n − 3) times compared with AHP when the number of indicators is the same. BWM is a process for finding the optimal solution through the simple linear model, with unique and reasonable results [35,36]. The analysis presented above reveals that: (1) Subjective considerations have a significant impact on the AHP approach. (2) The ANP method primarily needs a lot of calculations and specialized software. (3) The BWM approach uses fewer calculations and easy-to-follow calculation stages.

However, it seems impossible to quantify each individual level of influence on sewage treatment plant safety. The industry does not have a single standard for calculating weight. As a result, this article also analyzes the factors that affect sewage treatment plant safety, as well as the current state of those facilities; The evaluation of the safety of sewage treatment plants is based on a fuzzy comprehensive evaluation structure, and an improved BWM is suggested to determine the weight and lessen the impact of subjective factors influenced by experts. An example municipal sewage treatment plant in Changchun City is used to demonstrate the model's accuracy and use.

2. Materials and Methods

2.1. Research Object

A municipal sewage treatment plant in Changchun, Jilin Province, China, was constructed in 2011 and put into operation in 2012. It has a daily capacity of 50,000 m^3 of wastewater. Final discharge of the tailwater into Yitong River is subject to the first-class A standard in *Discharge Standard of Pollutants for Municipal Waste-Water Treatment Plant* [37]. The main processing structures include coarse screens and inlet pumping room, fine screens and aerated grit chamber, primary sedimentation tank, biological tank, secondary sedimen-

tation tank, advanced treatment workshop, dosing room, dehydration room, transformer and distribution room, etc. The process flow is shown in Figure 1:

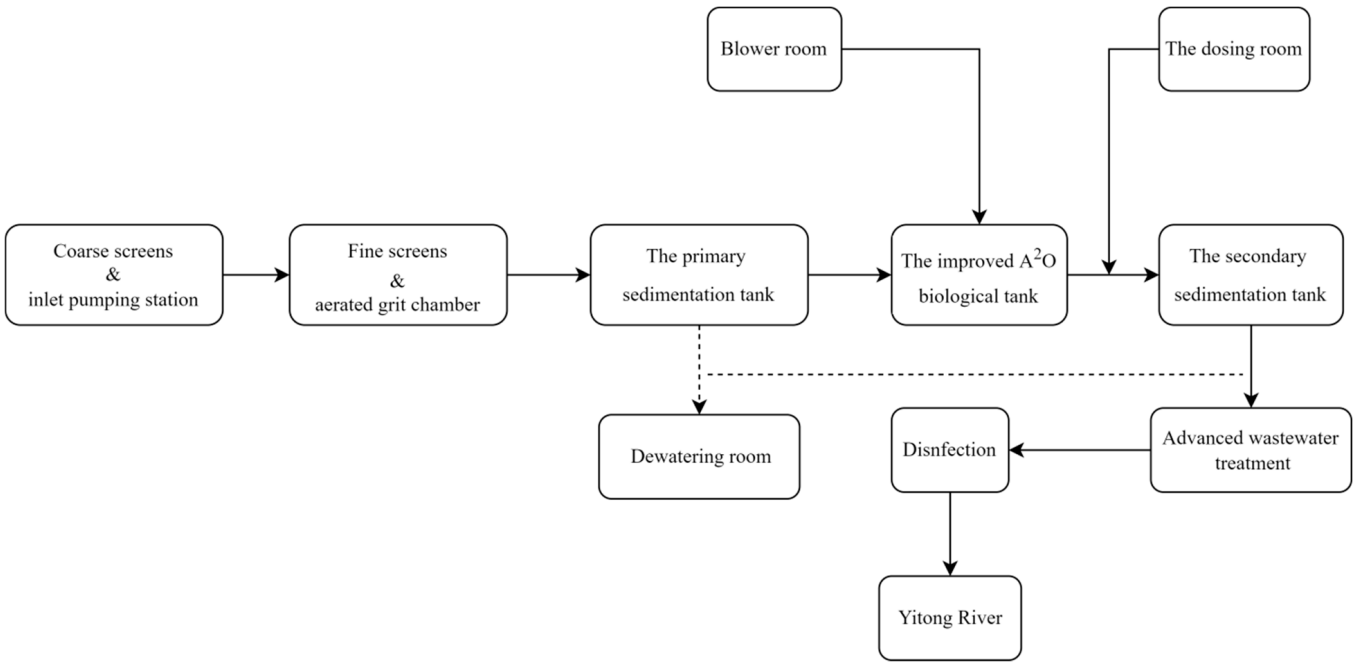


Figure 1. Process flow chart of a municipal sewage treatment plant in Changchun.

2.2. Evaluation Framework

A fuzzy mathematics comprehensive evaluation method based on improved BWM was suggested to assess the status quo safety of municipal sewage treatment plants. First, a model of fuzzy comprehensive assessment structure was constructed in accordance with the field investigation and relevant literature. Second, each expert chose the best and worst indexes, and other indicators scored the degree to which the best and worst indexes were preferred. Through the use of mathematical programming, the weight was determined, and the final weight value was determined using a cluster analysis of the expert weight value. The fuzzy thorough evaluation of the municipal sewage treatment facility was completed, and Figure 2 depicts the evaluation flow chart.

2.3. Fuzzy Comprehensive Evaluation Index System

After field investigation, comprehensive analysis of the relevant literature [38–40], *Classification and Code for the Hazardous and Harmful Factors in Process* [41] and *Technical Specification for Operation, Maintenance and Safety of Municipal Wastewater Treatment Plant* [42], taking the safety evaluation of municipal sewage treatment plant as the target layer, four first-level indicators U_i of human factors, material factors, environmental factors and management factors and 17 second-level indicators U_{ij} will be selected, as shown in Figure 3. In order to facilitate the subsequent quantitative calculation and result analysis, the safety evaluation index system and risk classification table of a municipal sewage treatment plant in Changchun were obtained, as shown in Table 1.

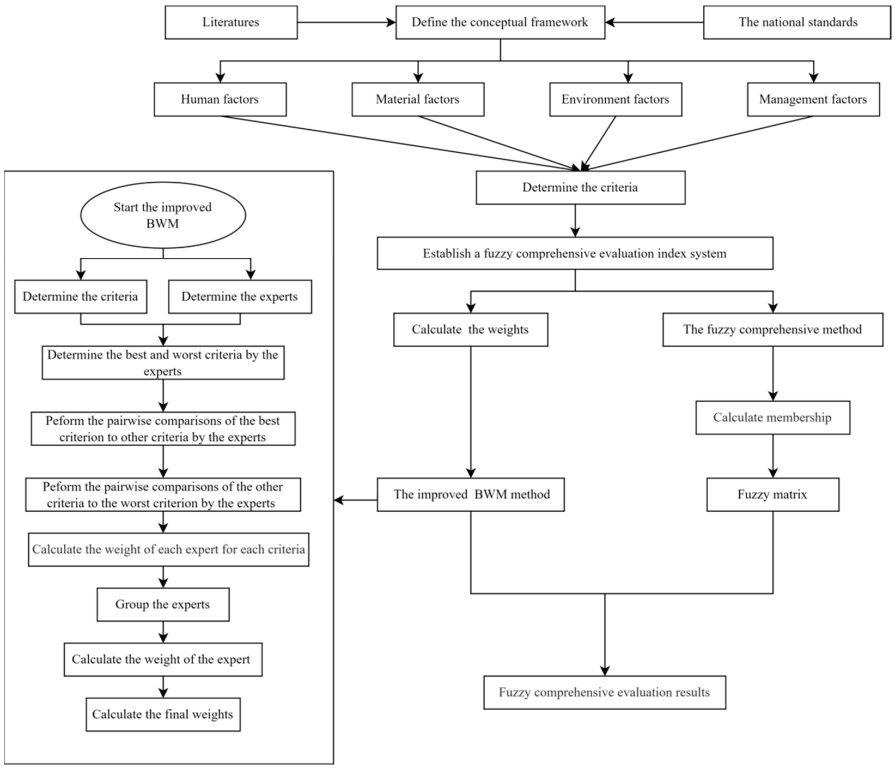


Figure 2. Flowchart of the fuzzy comprehensive evaluation of a municipal sewage treatment plant.

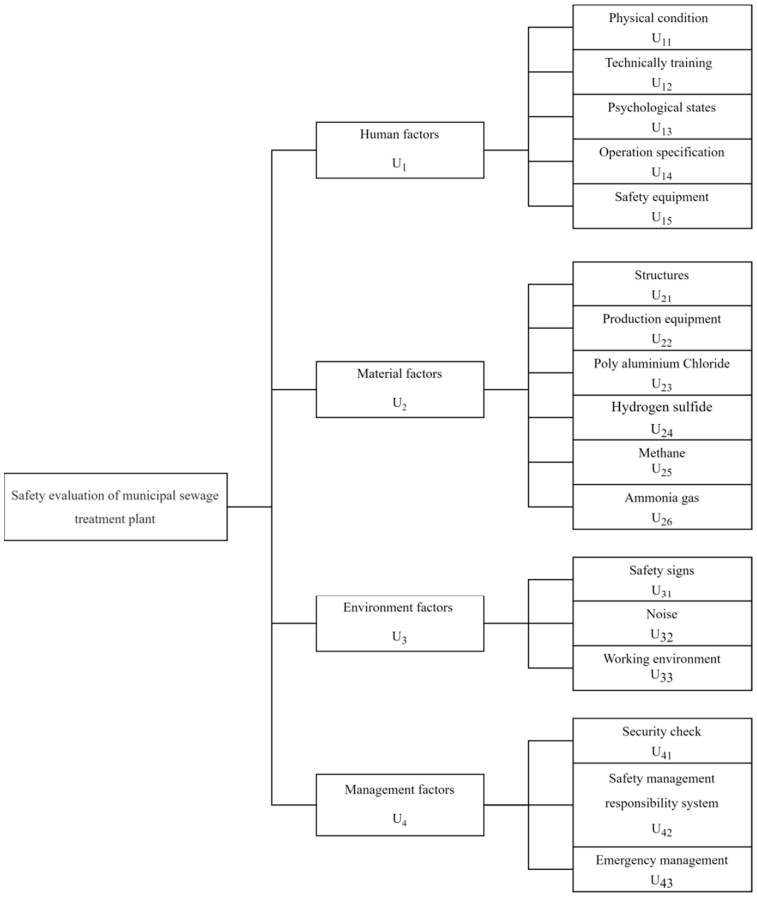


Figure 3. The fuzzy comprehensive evaluation system of a municipal sewage treatment plant.

Table 1. Safety index evaluation index and risk classification of a municipal sewage treatment plant.

Criterion		Risk Grade Standard of Each Criterion				
		Safe	**Relatively Safe**	**Fair**	**Relatively Dangerous**	**Dangerous**
Human factors U_1	Physical condition U_{11}	The proportion of regular physical examinations of workers is greater than 90%.	The proportion of regular physical examinations of workers is greater than 80%.	The proportion of regular physical examinations of workers is greater than 70%.	The proportion of regular physical examinations of workers is greater than 60%.	The proportion of regular physical examinations of workers is greater than 50%.
	Technically training U_{12}	After training, all employees hold certificates and pass regular assessment.		Some employees hold certificates after training and fail to pass the regular assessment.		Some employees do not hold certificates and fail to pass the regular assessment.
	Psychological states U_{13}	Employees are emotionally stable during working hours.		Some employees have big mood swings during working hours.		Some employees experience psychological abnormalities during working hours.
	Operation specification U_{14}	All employees master the operation specification of this position and are able to handle faults skillfully.	Some employees master the operation specification of this position and can handle the faults skillfully.	Some employees basically master the operation specification of this position and can handle the faults.	Some employees fail to master the operating specifications of this position but are able to handle faults.	Some employees fail to master the operation specification of this position and fail to handle the faults.
	Safety equipment U_{15}	The safety protection device is fully equipped, and the damaged and old equipment is regularly updated, and the wearing rate is 100%.	The safety protection device is equipped with sound, regularly updated damaged and old equipment, and the wearing rate is high.	Sound configuration of safety protection equipment, high wearing rate.	Safety and protection equipment is well equipped.	Incomplete configuration of safety protection equipment.
Material factors U_2	Structures U_{21}	No damage to the main structure.	From 1 to 3 main structures are in disrepair.	From 4 to 5 main structures are in disrepair.	From 6 to 7 main structures are in disrepair.	8 or more main structures are damaged.
	Production equipment U_{22}	The appearance of the production equipment is clean and tidy, and the integrity rate is more than 95%.	A small part of the appearance of the production equipment is not clean, and the integrity rate of more than 95%.	Part of the production equipment looks untidy, the integrity rate of more than 95%.	Part of the production equipment looks untidy, the integrity rate is less than 95%.	Most of the production equipment is not neat in appearance, and the integrity rate is less than 95%.
	Poly aluminium Chloride U_{23}	The packaging is complete and lossless, no moisture, pollution, character, or color meets the product requirement.		Some of the packaging is damaged, but there is no moisture, the character and color meet the product requirement.		Some of the packaging is damaged, wet, and the character and color do not meet the product requirement.
	Hydrogen sulfide U_{24}	Concentrations below 10 mg/m^3.				Concentrations above 10 mg/m^3.
	Methane U_{25}	Volumetric concentration below 1%.				Volumetric concentration above 1%.
	Ammonia gas U_{26}	Concentrations below 20 mg/m^3.				Concentrations above 20 mg/m^3.

Table 1. *Cont.*

Criterion		Risk Grade Standard of Each Criterion				
		Safe	**Relatively Safe**	**Fair**	**Relatively Dangerous**	**Dangerous**
Environment factors U_3	Safety signs U_{31}	Very complete.	Complete.	Generally.	Incomplete.	Very incomplete.
	Noise U_{32}	Take measures to reduce noise, all kinds of equipment in operation noise should be less than 85 dB.		Measures are taken to reduce noise, and the noise of some equipment is greater than 85 dB in operation.		No measures are taken to reduce noise, and most of the equipment has noise greater than 85 dB in operation.
	Working environment U_{33}	The platform is flat, the light is good, and the traffic road meets the transportation requirement.	The platform is slightly flat, the light is good, and the traffic road meets the transportation requirement.	The platform is uneven, the light is good, and the traffic road meets the transportation requirement.	The platform is uneven, the poor light, and the traffic road is generally designed.	The platform is uneven, the light is poor, and the traffic road is poorly designed.
Management factors U_4	Security check U_{41}	The safety inspection program is complete and comprehensive and can be implemented.	The safety inspection program is complete and well established and can be largely implemented.	The safety inspection program is basically complete and complete and can basically be implemented.	Safety inspection program complete, some not implemented.	Inadequate safety checks and failure to implement.
	Safety management responsibility system U_{42}	The system is well-established and can be implemented	The system has been improved and basically implemented	The system has been basically improved and implemented	The system is basically perfect but fails to be implemented	The system needs to be improved and fails to be improved
	Emergency management U_{43}	Very complete.	Complete.	Generally.	Imperfect.	Very imperfect.

2.4. The Fuzzy Comprehensive Evaluation

The fuzzy comprehensive evaluation method is a comprehensive evaluation method based on fuzzy mathematics [43–45].

Determine the set of evaluation criteria. All conclusions obtained from the evaluation project constitute the evaluation standard set. According to the evaluation results, the evaluation standard set is generally divided into n levels, as shown in Equation (1):

$$V = (V_1, V_2, \cdots, V_{\mathrm{n}}) \tag{1}$$

where V_n represents the evaluation results, such as "good", "good", "average", "poor", "very poor", etc.; n is the number of factors in the secondary index layer.

Determine the factor weight set $w_i : w_i = \{w_{i1}, w_{i2}, \cdots, w_{ik}\}$, where $w_{ik} > 0$ and $\sum_{i=1}^{k} w_i = 1$. The weight of the improved BWM method is adopted in this paper.

Calculate and evaluate membership. First, the membership function is established, and then the matrix is established according to the actual value of each index:

$$R = (R_1, R_2, \cdots, R_{\mathrm{n}}) = \begin{bmatrix} \mathrm{r}_{11} & \cdots & \mathrm{r}_{1\mathrm{n}} \\ \vdots & \ddots & \vdots \\ \mathrm{r}_{\mathrm{n}1} & \cdots & \mathrm{r}_{\mathrm{nn}} \end{bmatrix} \tag{2}$$

where R_i is the exponential fuzzy relation matrix of the ith secondary index layer.

Fuzzy comprehensive evaluation. Suppose the weight set of m second-level indicators of U_i: $W_i = (w_1, w_2, \cdots, w_n)$; then, the fuzzy synthesis method of the target layer is as follows:

$$\begin{cases} C_i = W_{\mathrm{i}} R_{\mathrm{i}} \\ C = \{C_1, C_2, \cdots, C_{\mathrm{n}}\} \\ B = W \times R = (b_1, b_2, \cdots, b_{\mathrm{n}}) \end{cases} \tag{3}$$

where C_i is the fuzzy comprehensive evaluation result of the U_i index; C is a fuzzy comprehensive evaluation matrix with n first-level indexes; W is the weight of n first-level indicators; B is the final result of fuzzy comprehensive evaluation.

Obtain the evaluation data of the evaluation object, and $\sum_{i=1}^{n} b_i = 1$. According to the principle of maximum membership, the maximum value is taken to determine the evaluation result.

2.5. Improved BWM to Determine the Weight

BWM is a multi-criteria decision-making method based on pairwise comparison [46]. It evaluates the priority of each criterion according to the preferences of experts. The evaluation process is simple and efficient. Since the subjective opinions of experts may produce some differences, it is necessary to form a group of experts with the same or similar opinions, assign different weight coefficients, and propose a method to improve BWM, which consists of the following eight steps:

1. Determine experts and decision criteria.

   A collection of criteria $U = \{u_1, u_2, \cdots, u_n\}$ to be defined by experts $\{DM_1, DM_2, \cdots, DM_{\mathrm{n}}\}$.

2. Experts determine the best and worst criteria.

   Each expert chooses the best criterion u_B and the worst criterion u_W.

3. Using Table 2 as the assessment scale, the preference of uB over the other criteria is determined and the vector $A_{BO} = (a_{B1}, a_{B2}, \cdots, a_{Bn})$ is obtained.

Table 2. BWM evaluation scale.

Sore a_{uv}	Standard
1	This means that, compared with u_u and u_v two criteria, the former is equally important as the latter
2	This means that, compared with the two criteria of u_u and u_v, the former ranges from equally important to moderately important
3	This means that u_u is moderately important compared with u_v
4	This means that, compared with the two criteria of u_u and u_v, the former is between moderately important and highly important
5	This means that, compared with u_u and u_v, the former is more important than the latter
6	This means that, compared with the two criteria of u_u and u_v, the former is between highly important and very important
7	This means that, compared with the two criteria of u_u and u_v, the former is more important than the latter
8	This means that, compared with the two criteria of u_u and u_v, the former is between very important and completely important
9	This means that, compared with u_u and u_v two criteria, the former is more important than the latter

4. The preference degree of all criteria compared with u_W is determined, and the vector $A_{OW} = (a_{1W}, a_{2W}, \cdots, a_{nW})^{\mathrm{T}}$ is obtained, where a_{BW} is u_B's preference degree compared with u_W.
5. Calculate the weight of each expert for each criterion.

The weight value $W^k = \left\{ w_1^k, w_2^k, \cdots, w_n^k \right\}$ of the criterion is solved by mathematical programming, where W^k is the weight of the kth expert.

To solve mathematical programming, Rezaei [35] proposed a linear model, as shown in Equation (4) below:

$$\begin{aligned} &\min\max\left\{ \left| w_B - a_{Bj} w_j \right|, \left| w_j - a_j w_w \right| \right\} \\ &s.t. \sum_j w_j = 1, w_j \geq 0 (j = 1, \cdots, \mathrm{n}) \end{aligned} \tag{4}$$

where w_B is the weight of u_B; w_W is the weight of u_W; w_j is the weight of u_j; a_{Bj} is the preference degree of u_B over uj; a_{jW} is the preference degree of u_j over u_W.

The weight of the criterion is solved after transformation, as shown in Equation (5):

$$\begin{aligned} \min \quad & \xi \\ s.t. \quad & \left| w_B - a_{Bj} w_j \right| \leq \xi \ (j = 1, \cdots, \mathrm{n}) \\ & \left| w_j - a_{Wj} w_W \right| \leq \xi \ (j = 1, \cdots, \mathrm{n}) \\ & \sum_j w_j = 1, w_j \geq 0 \ (j = 1, \cdots, \mathrm{n}) \end{aligned} \tag{5}$$

6. Group the experts

To eliminate the influence of individual factors of experts on the results, the system clustering method is adopted to gather the individual weight of experts into the group decision weight by weighted average. The similarity of the evaluation results of various

experts is used as the standard for cluster analysis [47], and the formula for calculating the similarity d_{xy} is:

$$d_{xy} = \cos\theta_{xy} = \frac{(X,Y)}{|X|\bullet|Y|} = \frac{\sum_{i=1}^{n} x_i y_i}{\sqrt{\sum_{i=1}^{n} x_i^2 \sum_{i=1}^{n} y_i^2}} \left(0 < \cos\theta_{xy} < 1\right) \quad (6)$$

where the closer the similarity d_{xy} is to 1, the more similar the expert evaluation results are [48]. X and Y are the feature vectors $X = (x_1, x_1, \cdots, x_n)$ and $Y = (y_1, y_2, \cdots, y_n)$ in which two experts evaluate indicators at the same level.

7. Calculate the weight of the expert.

d_{xy} is used as the standard to cluster experts. The weight coefficients of different categories of experts are different. The category containing more experts represents the opinions of most experts, so it is assigned a larger weight coefficient; otherwise, it is assigned a smaller weight coefficient [49]. The calculation formula of the expert weight coefficient is:

$$\lambda_k = \frac{\phi_k}{\sum_{k=1}^{m} \phi_k} \quad (7)$$

where λ_k is the weight coefficient of the kth expert, satisfying $\sum_{k=1}^{m} \lambda_k = 1$; ϕ_k is the number of experts in the category of the kth expert; m is the number of experts who participated in the rating.

8. Calculate the final weights.

The weight summation of the individual weight of experts and the expert weight coefficient is carried out to obtain the group decision weight w_i of each evaluation index:

$$w_i = \sum_{k=1}^{m} \left(\lambda_k \bullet w_i^k\right) \quad (8)$$

3. Results

3.1. Single-Factor Membership Calculation

Five industry experts were invited to conduct a safety inspection, and the grade results of a single factor were determined according to the inspection results. The grade was divided into "safe, relatively safe, fair, relatively dangerous, dangerous", which was expressed as V_{ij} = (safe, relatively safe, fair, relatively dangerous, dangerous). The fuzzy membership degree of single factor was summarized in Table 3:

3.2. Improved BWM Method to Determine the Weight

Five industry experts were consulted according to the index system above. Each expert designated the best indicator and the worst indicator, and the other indicators scored the preference degree of the best indicator and the worst indicator, respectively. Then, according to Equation (5), the weight of each expert on each level of indicators was determined. The clustering analysis was carried out through Equations (6)–(8), and the results are shown in Figure 4. Expert 1, 2, 3, and 4 are in the first category, and Expert 5 is in the second category.

Table 3. Single factor fuzzy membership summary table.

Criterion		Order of Evaluation				
		Safe	**Relatively Safe**	**Fair**	**Relatively Dangerous**	**Dangerous**
Human factors U_1	Physical condition U_{11}	0	1	0	0	0
	Technically training U_{12}	0.4	0.6	0	0	0
	Psychological states U_{13}	0.8	0.2	0	0	0
	Operation specification U_{14}	0.2	0.6	0.2	0	0
	Safety equipment U_{15}	0.4	0.6	0	0	0
Material factors U_2	Structures U_{21}	0	1	0	0	0
	Production equipment U_{22}	0	1	0	0	0
	Poly aluminium Chloride U_{23}	0	0.6	0.4	0	0
	Hydrogen sulfide U_{24}	1	0	0	0	0
	Methane U_{25}	1	0	0	0	0
	Ammonia gas U_{26}	1	0	0	0	0
Environment factors U_3	Safety signs U_{31}	0.2	0.4	0.2	0.2	0
	Noise U_{32}	0	0	0.8	0.2	0
	Working environment U_{33}	0	0	0.8	0.2	0
Management factors U_4	Security check U_{41}	0	0	1	0	0
	Safety management responsibility system U_{42}	0.6	0.2	0.2	0	0
	Emergency management U_{43}	0.8	0	0.2	0	0

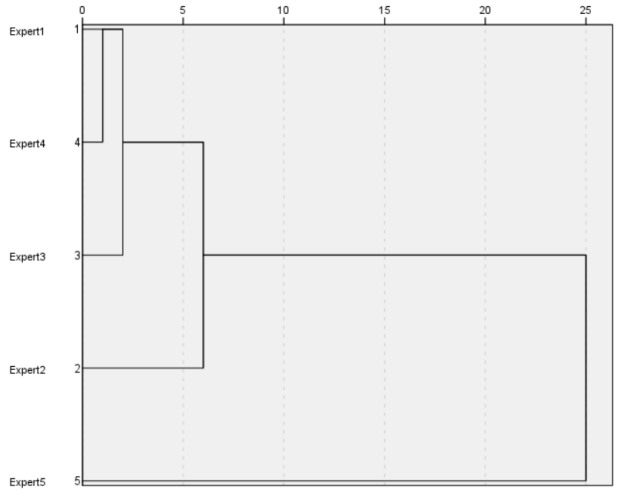


Figure 4. Cluster analysis result graph.

As shown in Table 4, the weight vector is as follows:

$$W = (0.264, 0.161, 0.079, 0.496)^T \tag{9}$$

Table 4. The weights of indicators at all levels.

First-Order Index	The Weight of the First-Order Index	Secondary Index	The Weight of Improved BWM
U_1	0.264	U_{11}	0.169
		U_{12}	0.076
		U_{13}	0.205
		U_{14}	0.087
		U_{15}	0.463
U_2	0.161	U_{21}	0.047
		U_{22}	0.102
		U_{23}	0.110
		U_{24}	0.317
		U_{25}	0.237
		U_{26}	0.187
U_3	0.079	U_{31}	0.613
		U_{32}	0.091
		U_{33}	0.296
U_4	0.496	U_{41}	0.268
		U_{42}	0.152
		U_{43}	0.580

According to Table 4, the weights of indicators at all levels, and the weights of each secondary index are as follows:

$$\begin{cases} w_1 = (0.169, 0.076, 0.205, 0.087, 0.463) \\ w_2 = (0.047, 0.102, 0.110, 0.317, 0.237, 0.187) \\ w_3 = (0.613, 0.091, 0.296) \\ w_4 = (0.268, 0.152, 0.580) \end{cases} \tag{10}$$

3.3. Fuzzy Comprehensive Evaluation of Municipal Sewage Treatment Plant

The fuzzy comprehensive evaluation result C_i of the U_i index is calculated as follows:

$$C_1 = w_1 R_1 = \begin{pmatrix} 0.169 \\ 0.076 \\ 0.205 \\ 0.087 \\ 0.463 \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0.4 & 0.6 & 0 & 0 & 0 \\ 0.8 & 0.2 & 0 & 0 & 0 \\ 0.2 & 0.6 & 0.2 & 0 & 0 \\ 0.4 & 0.6 & 0 & 0 & 0 \end{pmatrix} = (0.397\ 0.586\ 0.017\ 0\ 0) \tag{11}$$

$$C_2 = w_2 R_2 = \begin{pmatrix} 0.047 \\ 0.102 \\ 0.110 \\ 0.317 \\ 0.237 \\ 0.187 \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0.6 & 0.4 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{pmatrix} = (0.741\ 0.215\ 0.044\ 0\ 0) \tag{12}$$

$$C_3 = w_3 R_3 = \begin{pmatrix} 0.613 \\ 0.091 \\ 0.296 \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} 0.2 & 0.4 & 0.2 & 0.2 & 0 \\ 0 & 0 & 0.8 & 0.2 & 0 \\ 0 & 0.8 & 0.2 & 0 & 0 \end{pmatrix} = (0.123\ 0.245\ 0.432\ 0.2\ 0) \tag{13}$$

$$C_4 = w_4 R_4 = \begin{pmatrix} 0.268 \\ 0.152 \\ 0.580 \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} 0 & 1 & 0 & 0 & 0 \\ 0.6 & 0.2 & 0.2 & 0 & 0 \\ 0.8 & 0 & 0.2 & 0 & 0 \end{pmatrix} = (0.555\ 0.031\ 0.414\ 0\ 0) \tag{14}$$

As can be obtained from the above, the fuzzy comprehensive evaluation matrix C of the four first-level indicators is shown in Equation (15):

$$C = \begin{pmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{pmatrix} = \begin{pmatrix} 0.397 & 0.586 & 0.017 & 0.000 & 0.000 \\ 0.741 & 0.215 & 0.044 & 0.000 & 0.000 \\ 0.123 & 0.245 & 0.432 & 0.200 & 0.000 \\ 0.555 & 0.031 & 0.414 & 0.000 & 0.000 \end{pmatrix} \tag{15}$$

According to Equation (3), the fuzzy matrix calculation was carried out to obtain the fuzzy comprehensive evaluation results of the safety of the municipal sewage treatment plant, as follows:

$$B = WC = \begin{pmatrix} 0.209 \\ 0.130 \\ 0.087 \\ 0.574 \end{pmatrix}^{\mathrm{T}} \begin{pmatrix} 0.397 & 0.586 & 0.017 & 0.000 & 0.000 \\ 0.741 & 0.215 & 0.044 & 0.000 & 0.000 \\ 0.123 & 0.245 & 0.432 & 0.200 & 0.000 \\ 0.555 & 0.031 & 0.414 & 0.000 & 0.000 \end{pmatrix} = \begin{pmatrix} 0.509 \\ 0.224 \\ 0.251 \\ 0.016 \\ 0 \end{pmatrix}^{\mathrm{T}} \tag{16}$$

According to the results of the fuzzy comprehensive evaluation, the safety status of the municipal sewage treatment plant belongs to the membership degree of "safe, relatively safe, fair, relatively dangerous, dangerous". According to the principle of maximum membership, the safety status of the municipal sewage treatment plant belongs to the safety level.

3.4. Analysis of Weighting Values

The improved BWM in this paper is compared with the BWM arithmetic mean method and the method in the Reference [50]. Figure 5 shows that the three curves have roughly the same shape, trend, and fluctuations, but the differences in the weight values of individual factors are relatively large (U_{41} and U_{42}). This is due to the fact that different experts have different opinions on the same factor; as a result, the differences in the final weight values derived from the three different methods are also relatively large.

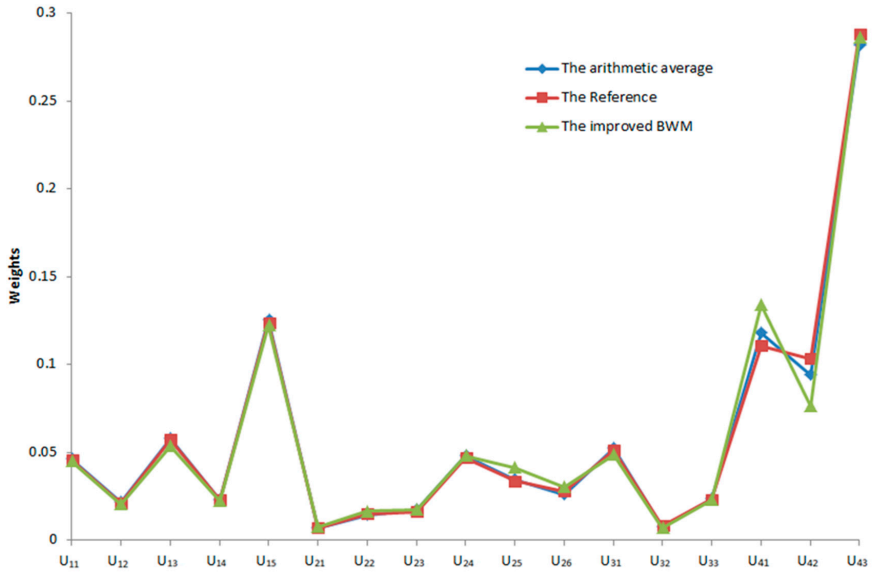


Figure 5. Comparison of the arithmetic average, Reference [50], and improved BWM.

The Pearson correlation coefficient method was used to perform additional correlation analysis on these three curves. Table 5 shows that the three curves' correlation coefficients were greater than 0.9 [51], demonstrating the three curves' considerable and positive correlation with one another. The arithmetic mean is still within a respectable range even though it is closer to Reference [50] (0.99889 > 0.99544 > 0.99102).

Table 5. Correlation analysis.

	The BWM Arithmetic Mean Method	Reference [50]	The Improved BWM
The BWM arithmetic mean method	1		
Reference [50]	0.99889	1	
The improved BWM	0.99544	0.99102	1

It may be demonstrated that the improved BWM is justifiable based on the above analysis.

4. Conclusions

1. This paper evaluates the safety status of municipal sewage treatment plants from the four aspects of human factors, material factors, environmental factors, and management factors, as well as the corresponding 17 secondary indexes, and combines the improved BWM method and fuzzy comprehensive evaluation method. The safety status of the municipal sewage treatment plant is safe.
2. The improved BWM and the fuzzy comprehensive method are combined to take full advantage of their strengths. The improved BWM reduces the subjective element by classifying experts. The fuzzy comprehensive method fuzzes quantitative and qualitative indicators, combining the two to produce more objective and reliable evaluation results.
3. The improved BWM is compared and analyzed with the BWM arithmetic average and the method in Reference [51], and the results show that the improved BWM is an acceptable alternative to the two other approaches when compared.
4. This paper focuses on the safety evaluation within a sewage treatment plant. In future work, a sewage treatment plant may pose a number of risks to the surrounding environment: (1) Air pollution, such as formaldehyde, benzene and other harmful gases, can damage the respiratory system of the surrounding residents. (2) Light pollution. The strong light from the sewage treatment plant at night may cause disturbances to the surrounding nocturnal animals, and may also affect the growth and development of plants. (3) Water pollution, such as chemicals and heavy metal ions, poses a threat to the surrounding land and human health.

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