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Coupling Monte Carlo simulation with CRITIC-enhanced water quality assessment for the Weishui Reservoir

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ABSTRACT

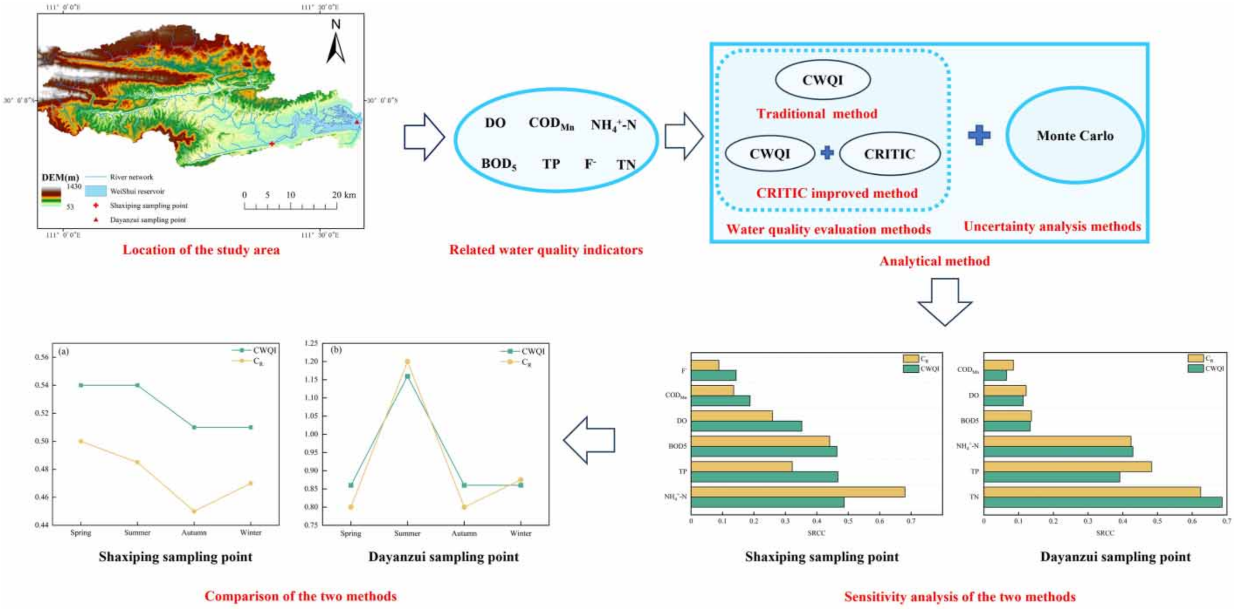
Traditional methods for water quality assessment often overlook the uncertainty of water quality data during the sample collection process, leading to limitations in their application. Therefore, this study combines the comprehensive water quality index (CWQI) method and the improved CWQI method based on CRITIC with the Monte Carlo method to evaluate the water quality in the Weishui Reservoir watershed. The results indicate that (1) there is a noticeable difference in water quality between the Shaxiping and Dayanzui sampling points. The water quality at the Shaxiping sampling point is excellent, with a water quality classification of Class I. In contrast, the water quality at the Dayanzui sampling point is comparatively poorer, with an average water quality classification of Class III. (2) Sensitivity analysis shows that TN, NH_4^+-N, and TP are more sensitive than other indicators, suggesting that they are the primary factors influencing the evaluation results. (3) Compared to the traditional CWQI method, combining the CRITIC-based improved CWQI method with the Monte Carlo method is more scientifically rigorous. It considers the variety of evaluation indicators, allocates weights rationally, and provides evaluation results that align better with seasonal variations, resulting in higher discriminative power.

Key words: comprehensive water quality index, CRITIC, Monte Carlo method, water quality assessment, Weishui Reservoir basin

HIGHLIGHTS

- A new model integrating Monte Carlo simulation, CRITC methods, and CWQI was proposed to assess water quality in Weishui Reservoir.
- Compared with the conventional model (CWQI), the new model leads to more reasonable results.
- The key parameters affecting water quality in Weishui Reservoir are TN, TP, and NH_4^+-N.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water resources are a crucial asset for the economic development of human society and constitute one of the controlling factors in the ecological environment (Wei *et al.* 2020; Tang *et al.* 2022). As important surface water components, reservoirs play a vital role in flood control, irrigation, water storage, power generation, and water supply for urban use (Ji *et al.* 2020). In recent years, with the rapid growth of the population and the swift development of industry and agriculture, a significant amount of wastewater has been discharged into reservoirs, leading to frequent water pollution incidents in reservoirs (Xu *et al.* 2019; Su *et al.* 2022). This severely threatens the ecological health of reservoir ecosystems and the safety of water supplies for people. Water quality assessment is a crucial pillar of watershed water environmental management and holds significant importance in the context of water pollution control (Yang *et al.* 2020).

Commonly used water quality assessment methods include the single pollution index method, principal component analysis method, fuzzy evaluation method, and comprehensive water quality index (CWQI) method (Wang *et al.* 2021; Zhang *et al.* 2021; Zhao *et al.* 2021). These methods each possess distinct characteristics. For instance, the single pollution index method entails comparing the measured values of evaluation indicators with their respective standard values to ascertain the pollution status of individual indicators (An *et al.* 2023). The principal component analysis method involves statistically analyzing data and assigning values rationally to evaluation indicators for comparative water quality analysis (Li *et al.* 2012). They calculate the degree of proximity between the actual concentrations of evaluation indicators and the water quality standards, utilizing fuzzy operators for computation (Liu & Zou 2012). The CWQI method involves the arithmetic mean of the single-factor pollution indices of various evaluation indicators to provide a comprehensive assessment of water quality (Jin *et al.* 2022). The CWQI method is a simple calculation process that reflects the overall pollution status of a water body and is a widely used water quality assessment method worldwide (Xue *et al.* 2023). However, the traditional CWQI method handles the weighting of various evaluation indicators relatively simplistically, failing to emphasize the distinctions among indicators. Furthermore, it assesses water quality from a deterministic perspective based on known sampling data without accounting for variations in natural conditions (such as rainfall) and errors in human operations during the sampling process (Huang *et al.* 2019). This results in uncertainty in the measured indicator concentrations and an inability to accurately reflect the pollution status of the water body. Therefore, it is essential to calculate weights sensibly and thoroughly consider uncertainties in the evaluation process to manage water quality effectively.

The Monte Carlo method is a numerical computation technique based on random numbers and grounded in probability and statistical theory (Seifi *et al.* 2020). It is one of the effective tools for addressing problems involving uncertainty. In recent years, the Monte Carlo method has gradually gained widespread application in the uncertain analysis research of traditional water quality assessment methods. For example, Lin *et al.* (2020) proposed a water quality eutrophication evaluation method based on the preference by similarity to an ideal solution (TOPSIS) method and Monte Carlo simulation (MCS) and identified the most sensitive factors of the method through a global sensitivity analysis. Xi & Zhihe (2023) constructed a water quality evaluation method that combines the Monte Carlo method (MC), criteria importance through intercriteria correlation (CRITIC), and vIseKriterijumska optimizacija i kompromisno resenje (VIKOR) methods. The results indicate the accuracy and reliability of the method and its ability to overcome the uncertainty caused by sampling errors.

Therefore, to understand the current situation and trends of water quality in the Weishui Reservoir, this paper selects the comprehensive pollution index method (CWQI) and the comprehensive pollution index (CWQI) method improved based on the CRITIC method, coupled with the Monte Carlo method, to analyze the spatiotemporal changes of water quality in the Weishui Reservoir. The aim is to provide a certain scientific basis for the water quality management of the Weishui Reservoir.

2. STUDY AREA AND DATA SOURCES

2.1. Study area

The Weishui Reservoir is located southwest of Songzi City, Hubei Province (Figure 1). It is a comprehensive reservoir primarily used for irrigation and flood control while serving navigation, water supply, aquaculture, and power generation functions. The reservoir is 14.5 km long from east to west, with a total area of 37 km^2 and a total storage capacity of 512 million m^3 (Hu *et al.* 2022). The region falls under a subtropical monsoon climate, with an average annual temperature of 17.6 °C and an approximate annual precipitation of 1,100 mm.

2.2. Sampling point and data source

Select two monitoring points within the watershed as the evaluation objects. One of the sampling points is located at the inflow point of Shaxiping (111°24′13.2″E, 29°54′13.2″N) in the Weshui Reservoir. Another sampling point is situated at Dayanzui (111°34′55.9″E, 29°57′41.3″N) within the Weishui Reservoir, serving to monitor the water quality within the reservoir.

A total of 25 biochemical indicators were detected at both sampling points (pH, DO, COD_{Mn}, NH_4^+-N, BOD_5, CN, As, VOC, Cr, Hg, Cd, Pb, Cu, Zn, Se, TP, TN, F^-, Petrol, NO_3^-, Fe, Mn, SD, Chl.a, linear alkylbenzene sulfonates (LAS)). Due to the Shaxiping sampling point being located on the inflow river of the reservoir and the Dayanzui sampling point within the reservoir, there exist differences in the water quality indicators monitored at each location. Moreover, many indicators

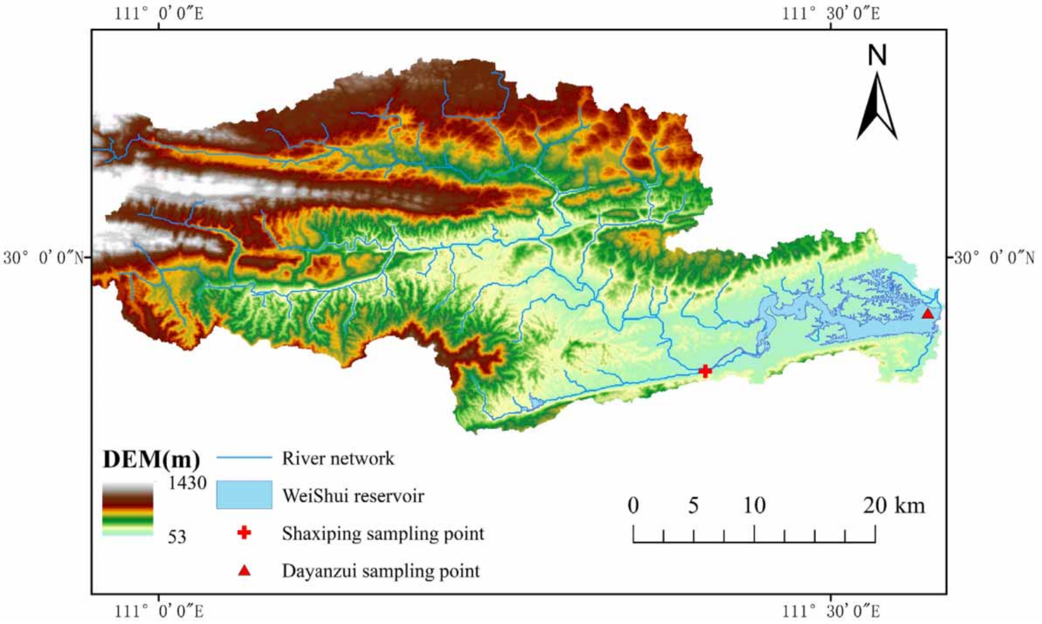


Figure 1 | Location of the study area.

exhibit a lack of data continuity as their concentrations have consistently remained below the detection limit over an extended period. Therefore, in this study, different biochemical indicators were employed for water quality assessment at the Shaxiping and Dayanzui sampling points. The biochemical indicators used for the Shaxiping sampling point include DO, COD_{Mn}, NH_4^+-N, BOD_5, TP, and F^-. The biochemical indicators used for the Dayanzui sampling point include DO, COD_{Mn}, NH_4^+-N, BOD_5, TP, and TN.

Water samples were collected 0.5 m below the surface using a 5 L plexiglass water collector. After collection, the samples were stored in polyethylene plastic bottles and rinsed thrice with distilled water. Subsequently, the samples were refrigerated at 4 °C in insulated boxes until the analysis of water quality parameters. Parameters like DO were examined using a multi-parametric probe with calibrated sensors during field measurements. In the laboratory, COD_{Mn} was analyzed through permanganate titration, BOD_5 was measured via the reduction of DO in the raw water samples after 5 days, total phosphorus (TP) was determined using potassium persulfate molybdenum antimony spectrophotometry, NH_4^+-N was measured through Nessler's reagent spectrophotometry and F^- concentrations were determined using ion chromatography, TN was determined using a HACH DR6000 UV–VIS spectrophotometer.

3. STUDY CASE

3.1. Comprehensive water quality index

The CWQI method involves the statistical computation of relative pollution indices for various pollution indicators, resulting in a numerical representation of the degree of water pollution. This method determines the pollution level, identifies primary pollutants, and comprehensively assesses water pollution status. The CWQI calculation is performed according to the following formula:

$$\mathrm{CWQI} = \frac{1}{n}\sum_{i=1}^{n} P_i \tag{1}$$

where CWQI is the comprehensive water quality index, n is the water quality indicators involved in the evaluation, P_i is the single-factor pollution index, and the larger the value, the higher the pollution degree of the factor.

$$P_i = C_i/C_0 \tag{2}$$

where C_i is the measured value of the water quality indicator, and C_0 is the standard value of the indicator.

According to the Chinese Surface Water Environmental Standards (GB3838-2002), when formulating water quality assessment standards, the standards for Class III water are often used as reference values for evaluation indicators. The water quality grading table using the CWQI method is shown in Table 1.

3.2. CWQI method improved based on the CRITIC method

3.2.1. Weight calculation

The traditional CWQI method can quantitatively analyze the overall pollution level in a particular area. Still, it does not consider the weights of various evaluation indicators during the calculation and cannot classify water quality. Therefore, we chose to improve the CWQI method using the CRITIC method in this study. The CRITIC method is an objective weighting method that comprehensively measures the weights of indicators based on the contrast and conflict between evaluation indicators. Contrast is represented by the standard deviation and is used to indicate the differences in the same indicator among different scenarios. The correlation coefficient represents conflict, and when two indicators have a high positive correlation, their conflict is low, resulting in lower weights (Xi & Zhihe 2023). The CRITIC method considers both the variability of

Table 1 | Comprehensive water quality index grading standards

Monitoring stations	Classification	I	II	III	IV	V
Shaxiping	CWQI	0–0.66	0.66–0.77	0.77–1	1–1.56	>1.56
Dayanzui	CWQI	0–0.52	0.52–0.69	0.69–1	1–1.56	>1.56

indicators and the correlation between them, making it more comprehensive than entropy weighting and standard deviation weighting methods. The specific calculation process of the CRITIC method is as follows (Li *et al.* 2022):

(1) Constructing an assessment matrix.

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \tag{3}$$

where m is the number of influencing factors, n is the number of evaluation indicators, and x_{ij} denotes the j indicator under the i influencing factor.

(2) Normalization

Normalization is required to eliminate the effect of different magnitudes of the data, and the specific formula for normalization is as follows.

If the value of the indicator is higher when it is better:

$$e_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}} \tag{4}$$

If the indicator value is as small as possible:

$$e_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}} \tag{5}$$

where e_{ij} is the normalized dimensionless value, $x_{\max}$ is the maximum value of the evaluation indicator, and $x_{\min}$ is the minimum value of the evaluation indicator.

(3) Indicator variability

$$\bar{x}_j = \frac{1}{n}\sum_{i=1}^{n} x_{ij} \tag{6}$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{n} (x_{ij} - \bar{x}_j)^2}{n-1}} \tag{7}$$

where σ_j is the standard deviation, and $\bar{x}_j$ is the mean value of the evaluation indicators.

(4) Conflicting indicators

$$R_j = \sum_{i=1}^{n} (1 - r_{ij}) \tag{8}$$

where R_j is the indicator conflictive, and r_{ij} is the correlation coefficient.

(5) Weights

$$w_j = \frac{\sigma_j R_j}{\sum_{n}^{i=1} \sigma_j R_j} \tag{9}$$

where w_j is the indicator weight.

The weights of the five pollutants calculated based on Equations (1)–(9) are shown in Table 2.

Table 2 | Weight of various pollutants in the Weishui Reservoir

Monitoring stations	DO	COD_{Mn}	NH_4^+-N	BOD_5	TP	F^-	TN
Shaxiping	0.138	0.132	0.289	0.174	0.140	0.127	–
Dayanzui	0.182	0.164	0.159	0.160	0.191	–	0.144

3.2.2. Improved CWQI method

Combining the weights obtained from the CRITIC method with the single-factor assessment results of corresponding indicators, we obtain the improved CWQI method based on the CRITIC method:

$$C_R = \sum_{i=1}^{n} w_i p_i \tag{10}$$

where C_R is the improved composite pollution index, n is the number of pollutants, and w_i and p_i represent the weight of the ith pollutant and the one-factor index, respectively.

The water quality classification standards for the improved CWQI method based on the CRITIC method are shown in Table 3.

3.3. Monte Carlo method

The Monte Carlo method in this study was conducted using an Oracle Crystal Ball. The main steps involved two phases: determining the distribution functions and distribution parameters of variables and defining variables and conducting sampling. The specific process is as follows:

(1) The Anderson–Darling test in Oracle Crystal Ball was used to determine the best-fitting distribution for the assumed variables and set distribution parameters accordingly.

(2) Using CWQI and C_R as predictive variables, six hypothetical variables were set for each evaluation indicator, P_i and $w_i p_i$. After defining the probability distributions for each hypothetical variable, 20,000 Monte Carlo samples were collected. These samples were then substituted into Equations (1) and (10) for simulation, resulting in 20,000 outcomes representing possible results for various scenarios of water quality indicators.

3.4. Spearman rank correlation coefficients

Spearman's rank correlation coefficients (SRCC) can demonstrate the extent to which various water quality indicators affect water pollution. This study calculated SRCC using the sensitivity analysis feature of the Oracle Crystal Ball's built-in model parameters. The specific formula is as follows:

$$\mathrm{SRCC} = \frac{\sum_{i-1}^{m} (x_i - \bar{x})(y_i - \bar{y})}{\left[\sum_{i-1}^{m} (x_i - \bar{x})^2 \sum_{i-1}^{m} (y_i - \bar{y})^2\right]^{1/2}} \tag{11}$$

where m is the number of simulations, x_i represents the value of the ith input parameter, $\bar{x}$ is the average value of the input parameter, y_i represents the ith output result, and $\bar{y}$ is the average value of the output result.

Table 3 | Water quality classification standards for the improved comprehensive water quality index method

Monitoring stations	Classification	I	II	III	IV	V
Shaxiping	C_R	0–0.59	0.59–0.73	0.73–1	1–1.55	>1.55
Dayanzui	C_R	0–0.54	0.54–0.69	0.69–1	1–1.57	>1.57

3.5. Carlson trophic status index

The trophic state index is a crucial indicator for assessing the water environment of the reservoir. The Carlson trophic status index (CTSI), developed by Carlson (1977), is employed to analyze the trophic status of Lake San Martín. The specific calculation formula for CTSI is as follows (Klippel *et al.* 2020):

$$\mathrm{CTSI_{SD}} = 60 - 14.4\mathrm{Ln(SD)} \tag{12}$$

$$\mathrm{CTSI_{TP}} = 14.42\mathrm{Ln(TP)} + 4.15 \tag{13}$$

$$\mathrm{CTSI_{Chl.a}} = 9.81\mathrm{Ln(Chl.a)} + 30.6 \tag{14}$$

$$\mathrm{CSTI} = \frac{\mathrm{CSTI_{SD}} + \mathrm{CSTI_{TP}} + \mathrm{CSTI_{Chl.a}}}{3} \tag{15}$$

where $\mathrm{CTSI_{SD}}$, $\mathrm{CTSI_{TP}}$, and $\mathrm{CTSI_{Chl.a}}$ represent the Carlson trophic status index for Secchi disk depth, total phosphorus, and chlorophyll-a, SD represents the Secchi disk depth (m), TP represents the concentration of total phosphorus (mg/L), Chl.a represents the chlorophyll-a concentration (μg/L).

The trophic level classification thresholds for CTSI are shown in Table 4.

4. RESULTS

4.1. Analysis of water quality data

The water quality grades are based on China's surface water environmental quality standard GB3838-2002 (Table 5). The water quality objective of the Weishui Reservoir is to achieve Class II.

The selected water quality indicators were evaluated based on the measured data from 2010 to 2020, as shown in Figure 2.

The DO concentration at the Shaxiping (Dayanzui) sampling point ranged from 5.1 to 13.1 mg/L (5.1–11.92 mg/L), with 95% of the samples meeting the Class II. There was no obvious difference in the DO concentrations between the sampling points at Shaxiping and Dayanzui. The $\mathrm{COD_{Mn}}$ levels at the Shaxiping and Dayanzui sampling points were relatively low, with average concentrations of 1.4 and 1.7 mg/L, both meeting Class I standards. There was a noticeable difference in the $\mathrm{NH_4^+}$-N content between the two sampling points. The $\mathrm{NH_4^+}$-N concentration at Dayanzui was significantly higher than that at Shaxiping. The $\mathrm{BOD_5}$ concentration at the Shaxiping (Dayanzui) sampling point ranged from 0.2 to 3 mg/L (0.5–2.9 mg/L), with average concentrations of 1.5 mg/L (1.6 mg/L), both meeting Class I standards. The TP content at

Table 4 | The trophic level classification thresholds

Classification	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Index	$\mathrm{CTSI} \le 40$	$40 < \mathrm{CTSI} < 50$	$50 \le \mathrm{CTSI} < 60$	$\mathrm{CTSI} > 60$

Table 5 | Selected classification criteria for water quality indicators

	Water quality criteria				
Index (mg/L)	I	II	III	IV	V
DO	7.5	6	5	3	2
$\mathrm{COD_{Mn}}$	2	4	6	10	15
$\mathrm{NH_4^+}$-N	0.15	0.5	1.0	1.5	2.0
$\mathrm{BOD_5}$	3	3	4	6	10
TP	0.01	0.025	0.05	0.1	0.2
$\mathrm{F^-}$	1.0	1.0	1.0	1.5	1.5
TN	0.2	0.5	1.0	1.5	2.0

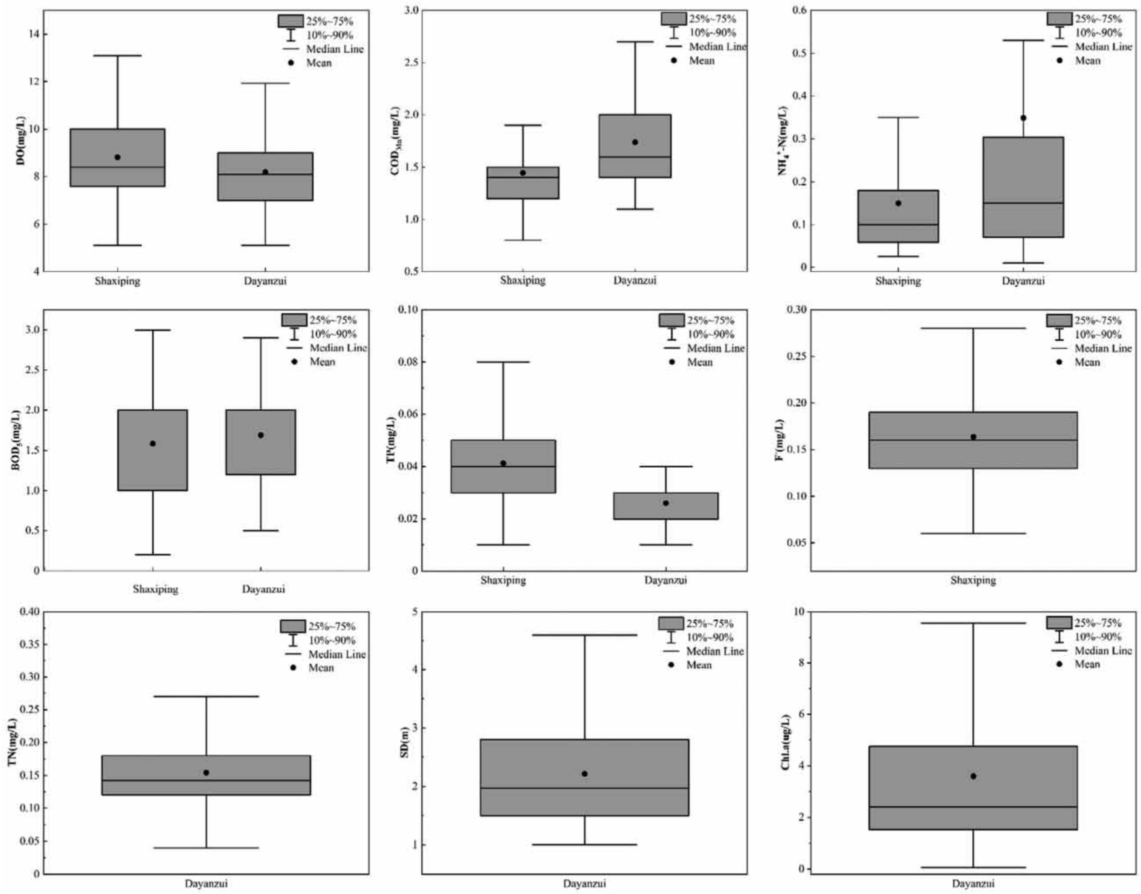


Figure 2 | Box plots of water quality parameters at the Shaxiping and Dayanzui sampling points from 2010 to 2021.

the Shaxiping and Dayanzui sampling points was relatively high, with average values of 0.041 and 0.026 mg/L, belonging to Class III water quality. The F^- content at Shaxiping was low, ranging from 0.06 to 0.28 mg/L, with all samples meeting Class I water quality standards. The concentration of TN at the Dayanzui sampling point is high, with an average concentration of 1.3 mg/L, 94% of the samples meet the Class III water quality standard. The Secchi disk depth at the Dayanzui sampling point has a depth range of 1–4.6 m, with an average value of approximately 2.2 m. The concentration of Chl.a at the Dayanzui sampling point is low, with an average concentration of 3.5 μg/L.

The water quality indicators at the Shaxiping sampling point exhibited noticeable temporal variations throughout the year. Yet, the overall trend remained relatively stable, with no significant deterioration in water quality indicators (Figure 3). The situation at the Dayanzui sampling point was similar to that at the Shaxiping sampling point. However, the COD_{Mn} concentration showed an upward trend from 2019 to 2021, indicating a potential for further deterioration (Figure 4).

Overall, the water quality characteristics at the Shaxiping and Dayanzui sampling points were similar. Both TP and TN values exceed the specified water quality standards among the selected parameters.

4.2. Water quality assessment of the Weishui Reservoir watershed

4.2.1. CWQI method

Seasonal evaluation results of the CWQI method are shown in Table 6. There is evident seasonal variation in water quality at both the Shaxiping and Dayanzui sampling points. The probability of water quality exceeding II standards at the Shaxiping sampling point follows spring > summer > winter > autumn. The probability of water quality exceeding II standards at the Dayanzui sampling point follows the order of summer > spring > winter > autumn.

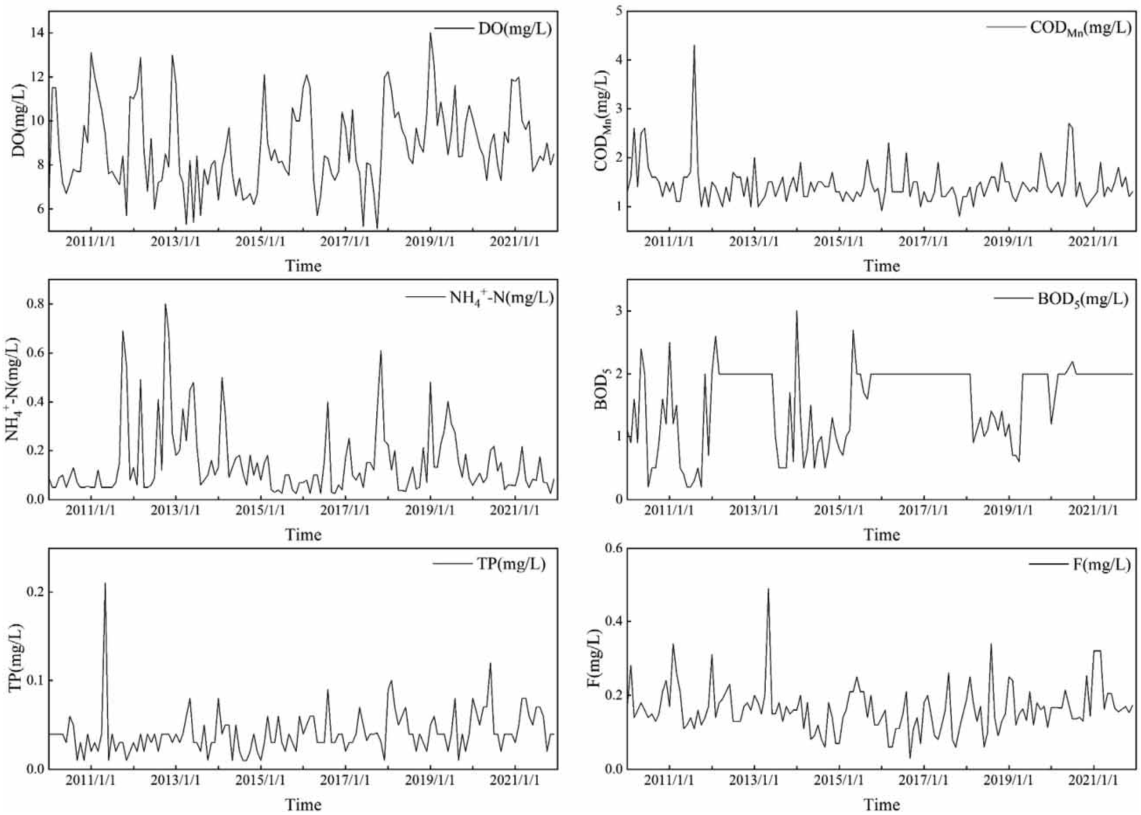


Figure 3 | Monthly average concentration changes of pollutants at Shaxiping from 2010 to 2021.

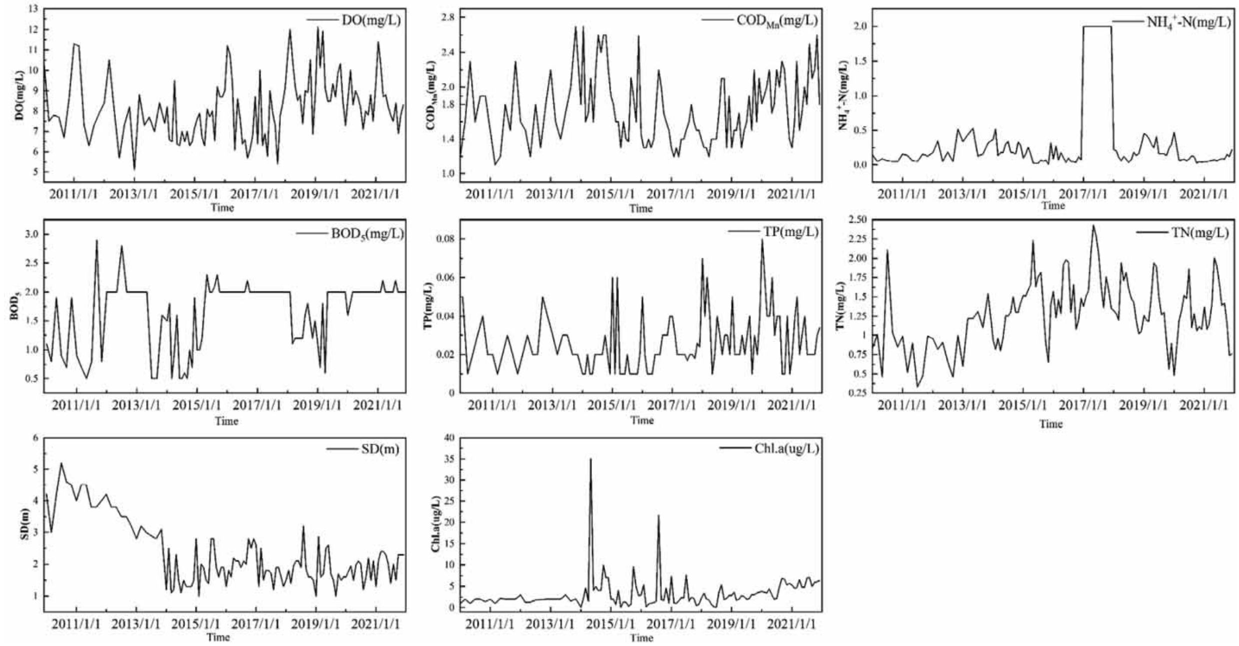


Figure 4 | Monthly average concentration changes of pollutants at Dayanzui from 2010 to 2021.

Table 6 | Probabilities of water quality grades at each sampling point in different seasons (%)

Monitoring stations	Seasons	I	II	III	IV	V
Shaxiping	Spring	50.26	21.72	21.26	6.58	0.18
	Summer	59.86	19.85	16.27	3.92	0.10
	Autumn	82.35	13.97	3.14	0.52	0.02
	Winter	72.85	15.05	9.96	2.08	0.06
Dayanzui	Spring	0.60	6.58	48.15	41.38	3.29
	Summer	0.74	2.53	30.53	60.74	5.46
	Autumn	0.64	7.76	61.45	26.41	3.74
	Winter	0.09	3.79	47.26	45.94	2.92

The probability of water quality reaching Grade II at the Shaxiping sampling point is significantly higher than at the Dayanzui sampling point (Table 7). At the Shaxiping sampling point, the probability of water quality being classified as Grade I is maximized, whereas at the Dayanzui sampling point, the probability of water quality being categorized as Grade III is maximized. This is mainly because the Shaxiping sampling point is located at the reservoir inflow, where the water flow is fast, making it difficult for pollutants to accumulate. The Dayanzui sampling point is located within the reservoir, where the water flow is slow, making accumulating pollutants easier.

4.2.2. Improved CWQI method based on CRITIC

The improved method considers the weights of different water quality indicators, balancing the influence of both low-concentration and high-concentration indicators on the results. Therefore, compared to the traditional CWQI method, the evaluation results of the CWQI method based on the CRITIC method show more pronounced seasonal variations (Table 8). The probability of exceeding Class II standards in each season has also changed. The probability of water quality exceeding II standards at the Shaxiping sampling point follows spring > summer > autumn > winter. The probability of water quality exceeding II standards at the Dayanzui sampling point follows the order of summer > winter > spring > autumn.

Overall, the improved method shows similar evaluation results to the traditional method, the probability of Grade I water quality is highest at the Shaxiping sampling point, while the probability of Grade III water quality is highest at the Dayanzui sampling point. Moreover, it is more evident that the probability of the water quality level at the Shaxiping sampling point reaching Class II is higher than at the Dayanzui sampling point (Table 9).

Table 7 | Probabilities of water quality grades at sampling points (%)

Monitoring stations	I	II	III	IV	V
Shaxiping	98.78	0.77	0.33	0.10	0.02
Dayanzui	0.81	4.87	48.87	43.00	2.45

Table 8 | Probabilities of water quality grades at each sampling point in different seasons (%)

Monitoring stations	Seasons	I	II	III	IV	V
Shaxiping	Spring	50.81	28.04	18.27	2.71	0.17
	Summer	56.85	26.63	14.47	2.02	0.03
	Autumn	77.49	13.02	5.75	2.36	1.38
	Winter	70.97	20.03	7.84	1.09	0.07
Dayanzui	Spring	0.89	8.08	53.14	35.25	2.64
	Summer	0.69	2.55	41.01	52.87	2.88
	Autumn	1.02	8.32	66.24	23.23	1.19
	Winter	0.20	4.87	50.04	42.51	2.38

Table 9 | Probabilities of water quality grades at sampling points (%)

Monitoring stations	I	II	III	IV	V
Shaxiping	95.12	3.00	1.40	0.39	0.09
Dayanzui	0.95	5.55	55.06	36.60	1.84

4.3. Sensitivity analysis

To examine the influence of various water quality indicators on water pollution. We calculated the SRCC for the water quality indicators of CWQI and CR at the Shaxiping (Figure 5) and Dayanzui (Figure 6) sampling points. A higher SRCC value indicates a greater impact of the corresponding indicator on water quality.

In Figure 5, the SRCC variations for the water quality indicators of CWQI and CR show similarities at the Shaxiping sampling point. Among them, TP has the highest SRCC values, which are 0.49 and 0.68, while the SRCC values for F^- are the smallest, being 0.14 and 0.09, respectively. This indicates that at the Shaxiping sampling point, TP is the most influential indicator of water quality, while F^- has the least impact.

In Figure 6, the water quality indicators with relatively high SRCC values for CWQI are TN and NH_4^+-N, with SRCC values of 0.55 and 0.49, respectively. Following them are TP, BOD_5, and DO, with SRCC values of 0.39, 0.13, and 0.11, respectively. The indicator with the least impact is COD_{Mn}, with an SRCC value of 0.07. For C_R, TN and TP are the indicators with relatively high SRCC values, with SRCC values of 0.62 and 0.48, respectively. NH_4^+-N, BOD_5, and DO are followed, with SRCC values of 0.42, 0.13, and 0.12, respectively. The indicator with the least impact is COD_{Mn}, with an SRCC value of 0.09.

From the sensitivity analysis results, it can be concluded that the main pollutants affecting the water quality in the Weishui Reservoir basin are TN, TP, and NH_4^+-N. Therefore, controlling TN, TP, and NH_4^+-N is crucial for improving the water environmental quality of the Weishui Reservoir.

4.4. Comparison of two water quality assessment methods

Overall, the results of the two evaluation methods are similar. To explore the disparity between the two water quality assessment methods, the seasonal average values of CWQI and CR for the Shaxiping and Dayanzui sampling points are shown in Figure 7.

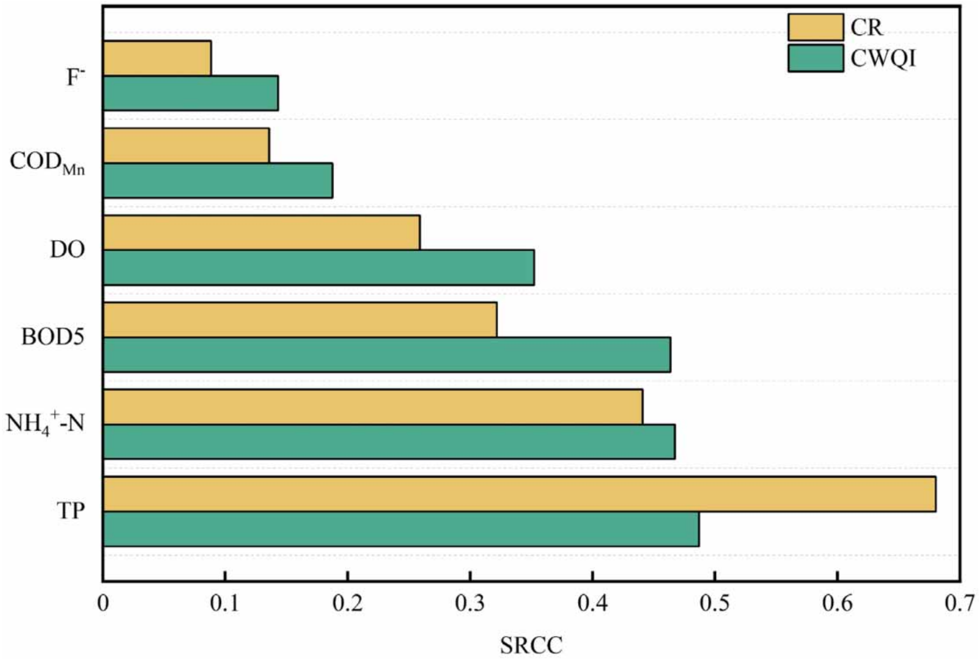


Figure 5 | Sensitivity analysis for the Shaxiping sampling point.

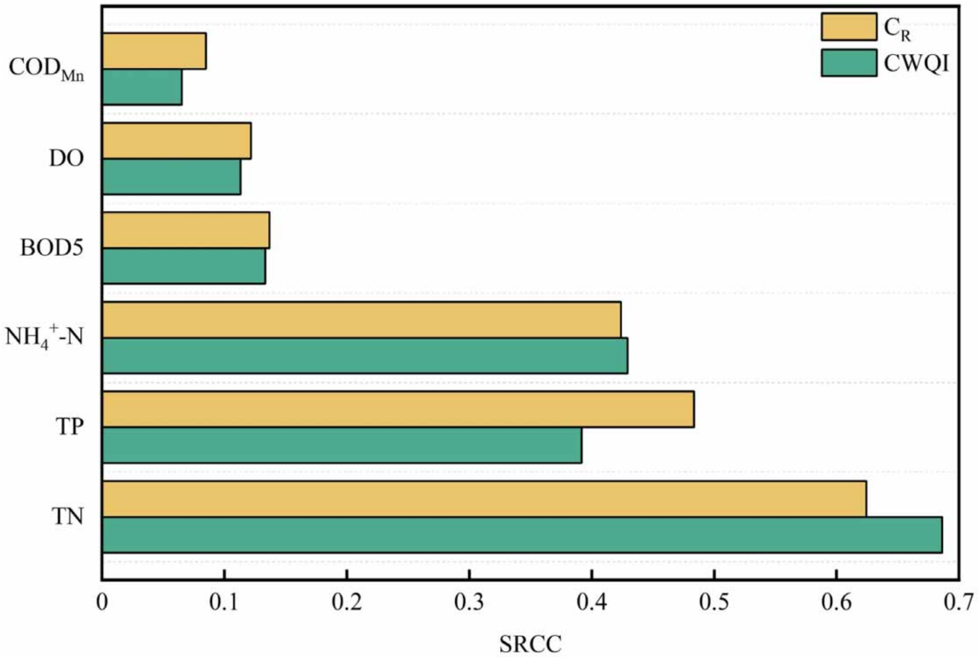


Figure 6 | Sensitivity analysis for the Dayanzui sampling point.

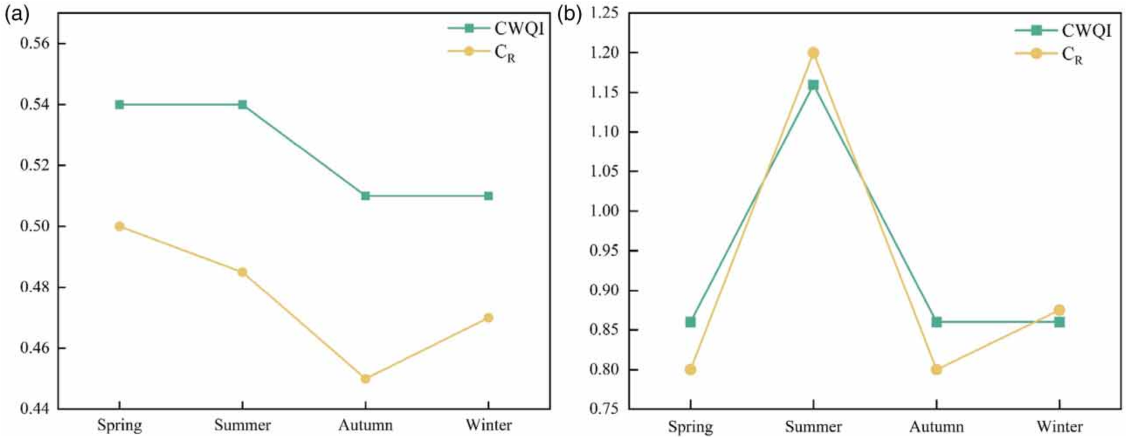


Figure 7 | The seasonal average water quality assessment results for the Shaxiping sampling point (a) and for the Dayanzui sampling point (b).

In Figure 7(a), the CWQI and the modified CWQI (CR) were utilized to assess the Shaxiping sampling point. The water quality assessment results for each season were categorized as Class I. In Figure 7(b), the water quality at the Dayanzui sampling point is poorest in the summer, categorized as Class IV, while in the remaining seasons, it is classified as Class III.

Overall, the results of the two evaluation methods are similar. The seasonal variations in the evaluation results of the CWQI are relatively small. In contrast, the modified comprehensive pollution index based on the CRITIC method exhibited significant seasonal variations, better reflecting the diverse pollution levels at different sampling points across seasons. Furthermore, this evaluation method combines the local area's specific pollutants and pollution levels, enabling a targeted analysis of the water quality situation. This facilitates the provision of more targeted environmental management policies and recommendations.

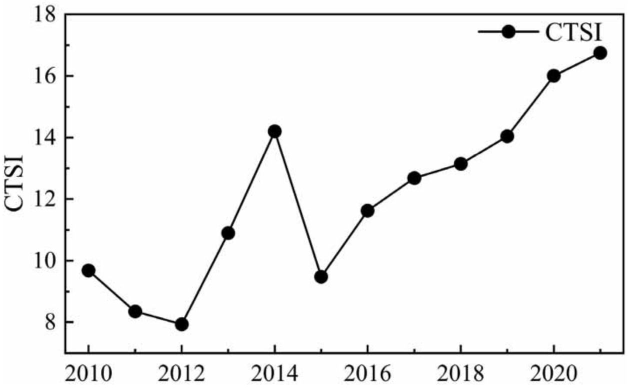


Figure 8 | The average value of the Carlson trophic status index at the Dayanzui sampling point from 2010 to 2021.

Table 10 | Average value according to the Carlson trophic status index for the season that classifies the trophic status of Dayanzui sampling points

Season	Spring	Summer	Autumn	Winter
CTSI	11.25	12.67	13.25	14.00
Trophic state	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic

4.5. Evaluation of trophic state indices

The trophic status at the Dayanzui sampling point has consistently remained oligotrophic ($CSTI < 40$) from 2010 to 2021(Figure 8). Except for significant fluctuations in carlson trophic status index (CSTI) values in 2013 and 2014, the average CSTI at the Dayanzui sampling point has been gradually increasing year by year. This change is related to the increase in chlorophyll-a and total phosphorus concentrations within the reservoir in recent years. The trophic status of the Dayanzui sampling point remains oligotrophic across all seasons (Table 10). The average values of CSTI show a small difference across all seasons, with the highest value observed in winter at 14.00 and the lowest in spring at 11.25.

5. CONCLUSIONS

(1) Based on the water quality data from 2010 to 2021, it can be observed that, in the Weishui Reservoir, only the average concentration of TN and TP exceeds the Class III water quality standard, while the concentrations of other water quality indicators meet the Class II water quality standards.

(2) The water quality at the Shaxiping sampling point is excellent, with a water quality classification of Class I consistently across all seasons. The water quality at the Dayanzui sampling point is relatively poor, particularly during the summer, with a water quality classification of Class IV. Therefore, it is necessary to develop specific water quality management plans tailored to different seasons.

(3) This study's water quality assessment method combines the CRITIC, Monte Carlo, and CWQI methods. The evaluation system is rendered more scientifically sound by establishing pollutant weights through the CRITIC method and reducing the uncertainty of water quality data through the Monte Carlo method.

(4) According to the analysis using Spearman's rank correlation coefficient (SRCC), it was found that TN, TP, and NH_4^+-N, are the key indicators affecting the water quality of the Weishui Reservoir. Consequently, it is imperative to implement stringent control measures for these indicators.

DATA AVAILABILITY STATEMENT

The relevant data has been uploaded to the public database, and the link is https://doi.org/10.6084/m9.figshare.25009520.v1.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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