Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454

Vol. 20 | No.4 | pp. 1585-1591 | 2021

Original Research Paper

https://doi.org/10.46488/NEPT.2021.v20i04.020

Open Access Journal

Water Quality Evaluation of Wenyu River in Beijing by Matter Element Model

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 20-10-2020
Revised: 11-01-2021
Accepted: 22-01-2021

Key Words:
Water resources
Matter element analysis
Multiple super-scale weighting method
Correlation degree
Wenyu river

ABSTRACT

River water quality is an important indicator for identifying river changes and analyzing river health, and has an important impact on the ecological environment of the river basin. In this paper, the matter-element analysis method based on the coupling weight method is used to evaluate the water environment of the water quality measured data of Wenyu River in 2019, which provides a reference for water quality management and protection. Through the establishment of the object element to be evaluated, the classical domain, the section domain, the normalization of the evaluation standard, and the measured data, three representative indicators such as DO, NH_3-N, and COD_{cr} are selected as the object element to be evaluated. The standard value corresponding to the water quality standards of Grade I to V is the classic domain. The weight of river indicators is determined by the coupling of the ordinary objective weighting method and the multiple super-scale weighting method. After the weight is determined, the correlation degree is calculated and the matter-element analysis model for water quality evaluation is established. The results showed that the water quality of the Wenyu River in May 2019 was still mainly Grade V water, which was in line with the actual water quality situation. It shows that the method meets the feasibility and practicability in water quality evaluation and is relatively reliable.

INTRODUCTION

Wenyu River, located in the northeast of Beijing, was once known as the Mother River of Beijing. It is the only river that originated locally in Beijing. It originated from the foothills of Jundu Mountain. Three tributaries, Nansha River, Dongsha River, and Beisha River, meet at the upper reaches of the Wenyu River. In recent years, the population on both sides of the Wenyu River has increased sharply and businesses have been densely populated. Large amounts of domestic sewage and industrial wastewater have been injected into the Nansha River and Beisha River. The Wenyu River, which used to have a clear stream, is no longer clear. At present, there are many methods to evaluate the water environment. The commonly used methods include fuzzy comprehensive evaluation, set pair analysis, attribute recognition, and analytic hierarchy process (Wen 1984). Among them, the fuzzy comprehensive evaluation method uses the membership function to fuzzify the boundary of the evaluation object, although it can objectively reflect the actual situation. This method overemphasizes the extreme value and consumes far too much useful data, and each method for calculating the weight coefficient has its own set of limitations (Ming & Jianqiang 2013). With the improvement of the theory, the matter-element analysis theory established by Chinese mathematician Cai Wen in the 1980s has progressed from the initial matter-element analysis to the current extenics, forming a rigorous theoretical system (Xueqiang et al. 2001, Zhemin 2005). The matter-element analysis method is a multivariate data quantitative evaluation approach that is based on the matter-element model, extension set, and correlation function theory, and can solve the incompatibility problem (Huber 1985). When determining the weights of evaluation indicators, commonly used methods such as expert evaluation method and analytic hierarchy process are highly subjective, and it is easy to cause deviations in results due to differences in the subjective value judgment standards of each person. Whereas in the ordinary objective weighting method, the weights are obtained directly based on the original data of the evaluation indicators and processed by statistical methods. Therefore, the distribution of the weights in this method will be affected by the randomness of the sample data, and cannot reflect the independence of the indicators, nor can it highlight the main influencing factors in the weights. Wang Mingtao mentioned the combination weighting method in his article -A comprehensive analysis method on determining the coefficients in multi-index evaluation (Mingtao 1999). As each weighting method has its own advantages and disadvantages, it is more reasonable to combine the weights obtained by various methods to determine the final weight. Compared with the basic matter-element analysis, this paper improves the calculation method of its weight coefficient. Based on the ordinary objective weighting method, it is supplemented by the multiple super-scale weighting method. These two methods are weighted linearly and corresponding coefficients are given according to the actual conditions, and finally, the weight coefficient of the selected index is obtained. In this paper, the matter-element model based on coupling weight is applied to evaluate the water quality of The matter-element analysis method is a multivariate data quantitative evaluation approach that is based on the matter-element model of the Wenyu River.

MATERIALS AND METHODS

Build a Matter-Element Model

Determination of elements to be evaluated: The ordered triple "R = (P, C, X)" is used as the basic unit to describe things, which is called the matter element. Among them, P represents things, C represents the characteristics of P, and X represents the value of P with respect to C.

If a thing P is described by n features C1, C2,..., Cn and the corresponding values X1, X2,..., Xn, it is called an n-dimensional matter element and expressed as:

$$R = \begin{bmatrix} P & C_1 & X_1 \\ & C_2 & X_2 \\ & \vdots & \vdots \\ & C_n & X_n \end{bmatrix} \quad \ldots(1)$$

For the unit to be evaluated, the data obtained from the actual measurement is expressed in matter elements, which are called matter elements to be evaluated.

Determination of the Level of the Matter Element Set

Determination of the Classic Domain

$$R_j = (N_j, C_i, X_{ji}) = \begin{bmatrix} N_j & C_1 & X_{j1} \\ & C_2 & X_{j2} \\ & \vdots & \vdots \\ & C_n & X_{jn} \end{bmatrix} = \begin{bmatrix} N_j & C_1 & (a_{j1}, b_{j1}) \\ & C_2 & (a_{j2}, b_{j2}) \\ & \vdots & \vdots \\ & C_n & (a_{jn}, b_{jn}) \end{bmatrix} \quad \ldots(2)$$

In the formula, N_j is the j-th level divided; C_i represents the characteristics of level N_j; X_{ji} is the range of values specified by N_j with respect to C_i, that is, the numerical range of each level with respect to the corresponding characteristics.

Determination of Section Domain

$$R_0 = (N_0, C_i, X_{pi}) = \begin{bmatrix} P_0 & C_1 & X_{p1} \\ & C_2 & X_{p2} \\ & \vdots & \vdots \\ & C_n & X_{pn} \end{bmatrix} = \begin{bmatrix} N_j & C_1 & (a_{j1}, b_{j1}) \\ & C_2 & (a_{j2}, b_{j2}) \\ & \vdots & \vdots \\ & C_n & (a_{jn}, b_{jn}) \end{bmatrix} \quad \ldots(3)$$

In the formula, P_0 represents the whole level; X_{pi} is the range of values taken by P_0 with respect to C_i.

Determination of the Degree of Relevance of each Level of the Object to be Evaluated

Establish correlation function based on extension set theory and specific conditions:

$$K_j(x_i) = \begin{cases} \dfrac{-\rho(X_i, X_{ji})}{|X_{ji}|} & x_i \in x_{ji} \\ \dfrac{\rho(X_i, X_{ji})}{\rho(X_i, X_{pi}) - \rho(X_i, X_{ji})} & x_i \notin x_{ji} \end{cases} \quad \ldots(4)$$

Among them,

$$\rho(X_i, X_{ji}) = |X_i - 0.5(a_{ji} + b_{ji})| - 0.5(a_{ji} - b_{ji})$$

$$\rho(X_i, X_{pi}) = |X_i - 0.5(a_{pi} + b_{pi})| - 0.5(a_{pi} - b_{pi})$$

$$|X_{ji}| = |a_{ji} - b_{ji}|$$

For each feature C_i, w_{ij} is the weight coefficient. Let $K_i(P) = \sum_{i=1}^{n} w_{ij} * k_j(X_i)$, and $K_j(P)$ is called the degree of relevance of the unit P to be evaluated at the quality level j.

Calculation of Weight Coefficient

The multiple super-scale weighting method

In the water quality evaluation process, the greater the weight of the evaluation index, the higher the impact of the index on the water quality. The multiple super-scale weighting method can highlight the main influencing factors and assign weights according to the degree of impact of the indicators on the water quality (Lunyan et al. 2018). It can not only avoid subjectivity in the evaluation but also make the evaluation more objective and reasonable. The calculation formula is as follows:

$$w_{1i} = \frac{x_i/s_i}{\sum_{i=1}^{n}(\frac{x_i}{s_i})} \quad \ldots(5)$$

In the formula: w_{1i} is the weight of the indicator; x_i is the monitored value (or evaluation value) of the indicator; S_i is the average value of the indicator in the 5 standard levels.

Ordinary Objective Empowerment Method

For the threshold value x_{ji}(j =1,2, …, n) of the evaluation level N_i(i =1,2 ,…, m), the weight coefficient is

$$w_{2ij} = x_{ij}/\sum_{i=1}^{n} x_{ij} \quad \ldots(6)$$

i = 1,2 …, n j = 1 2 …, m

The calculation is given in Table 1.

Table 1: Weight coefficient calculation table.

x_{ij}	N_1	N_2	…	N_m
c_1	x_{11}	x_{12}	…	x_{1m}
c_2	x_{21}	x_{22}	…	x_{2m}
…	…	…	…	…
c_n	x_{n1}	x_{n2}	…	x_{nm}

Coupling weight method (Fan et al. 2020)

The multiple super-scale weighting method can highlight the role of the most important pollutant factor in water quality assessment while taking into account the difference in standard values of different pollutants (Mingmei et al. 2015). Taking into account the actual water quality of the Wenyu River, this article uses the common objective weighting method, supplemented by the coupling weight method of the multiple super-scale weighting method to assign the weight of the river water quality index. Calculated as follows:

$$w_i = \alpha w_{1i} + \beta w_{2i} \quad \ldots(7)$$

In the formula: w_{1i} and w_{2i} represent the weights of the multiple super-scale weighting method and the common weighting method respectively; α and β represent the corresponding weighting coefficients of the two methods respectively. According to the actual situation of the river, combining the advantages of each method, take α=0.4, β= 0.6; w_i is the coupling weight corresponding to the i-th index.

Conclusion of matter-element analysis

If $k_a = \max(j)\left[k_j(P)\right]$ (j=1, 2, ..., m), then R∈Ra, that is, the unit P to be evaluated belongs to the *a* level.

RESULTS AND DISCUSSION

Application of matter element analysis in water quality evaluation of Wenyu River

According to the actual conditions around the Shahe Reservoir and Wenyu River, combined with the water quality of the study area over the years and existing literature data, five water quality measurement sections and several monitoring indicators are selected: Shahe reservoir (116.335°E, 40.130°N), Mafang (116.397°E, 40.142°N), Lutuan gate (116.470°E, 40.120°N), Xinbao Gate (116.120°E, 40.062°N) and Xinbao Gate sewage outlet (116°, 40°) were selected on the mainstream of Wenyu River, as shown in Fig. 1.

Select three water quality monitoring indicators such as DO, NH3-N, and CODcr, and plot the data obtained from the monthly measurement from March to December 2019, as shown in Fig. 2, 3, and 4.

It can be seen from the measured water quality data that DO is significantly higher in spring and autumn than in summer, and there is no significant difference between different sampling points. The COD index of the water samples from the five sampling sites exceeded the standard more times and showed a rising trend at the sewage outlet of Xinbao Gate. The ammonia nitrogen of the water sample at Xinbao gate is higher than that of the other four water samples during the same period.

Determine the element to be evaluated

There are many surface water environmental quality indicators given in the "Surface Water Environmental Quality Standard" (GB3838-2002). Taking into account the actual measurement results and calculation results and other factors, the following three representative indicators are selected here: COD_{cr}, NH_3-N, DO. The monitored values of Shahe Reservoir on May 19 and the standards at all levels are shown in Table 2.

The object element to be evaluated is:

$$R = \begin{bmatrix} COD_{cr} & 67 \\ NH_3 - N & 1.89 \\ DO & 5.02 \end{bmatrix}$$

Determining the Classical Domain

Take the value range corresponding to the water quality standards of Class I to V to construct the matter element matrix of the classical domain as follows:

Table 2: Water quality monitoring values and standard values.

	Evaluation standard						mg/L
Monitoring indicators							Monitoring value
	I	II	III	IV	V	average	
COD_{cr}	15	15	20	30	40	24	67
NH_3-N	0.15	0.5	1	1.5	2	1.03	1.89
DO	8	6	5	3	2	4.8	5.02

Fig. 1: Location of sampling points.

$$R(1) = \begin{bmatrix} COD_{cr} & (0,15) \\ NH_3-N & (0,0.15) \\ DO & (6,8) \end{bmatrix} \quad R(2) = \begin{bmatrix} COD_{cr} & (0,15) \\ NH_3-N & (0.15,0.5) \\ DO & (5,6) \end{bmatrix}$$

$$R(3) = \begin{bmatrix} COD_{cr} & (15,20) \\ NH_3-N & (0.5,1) \\ DO & (3,5) \end{bmatrix} \quad R(4) = \begin{bmatrix} COD_{cr} & (20,30) \\ NH_3-N & (1,1.5) \\ DO & (2,3) \end{bmatrix}$$

$$R(5) = \begin{bmatrix} COD_{cr} & (30,40) \\ NH_3-N & (1.5,2) \\ DO & (0,2) \end{bmatrix}$$

Determine Section Domain

Generally, the lower limit of the section domain is 0, and the upper limit is the highest standard. So

$$R_P = \begin{bmatrix} COD_{cr} & (0,40) \\ NH_3-N & (0,2) \\ DO & (0,8) \end{bmatrix}$$

Data Normalization Processing

Because the interval of the quantitative value of each evaluation index is not exactly the same, some evaluation indexes (such as CODcr, NH3-N) have a smaller value and a higher grade, while others (such as DO) have the opposite, so normalize each evaluation index and evaluation standard (Yinqin et a. 2013). For CODcr, etc.: $d_i = x_i/x_5$; for DO, etc.: $d_i = 1.0-(x_i - x_5)/x_1$。

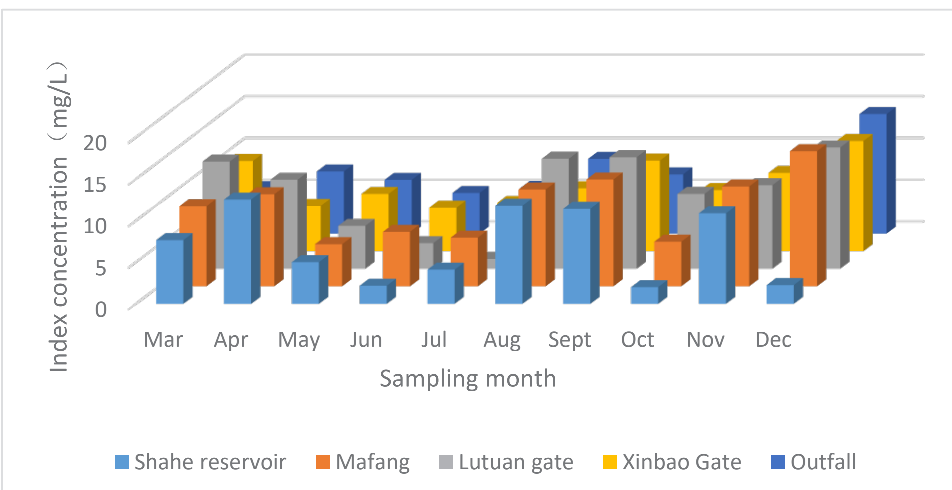

Fig. 2: Statistics of DO monitoring data.

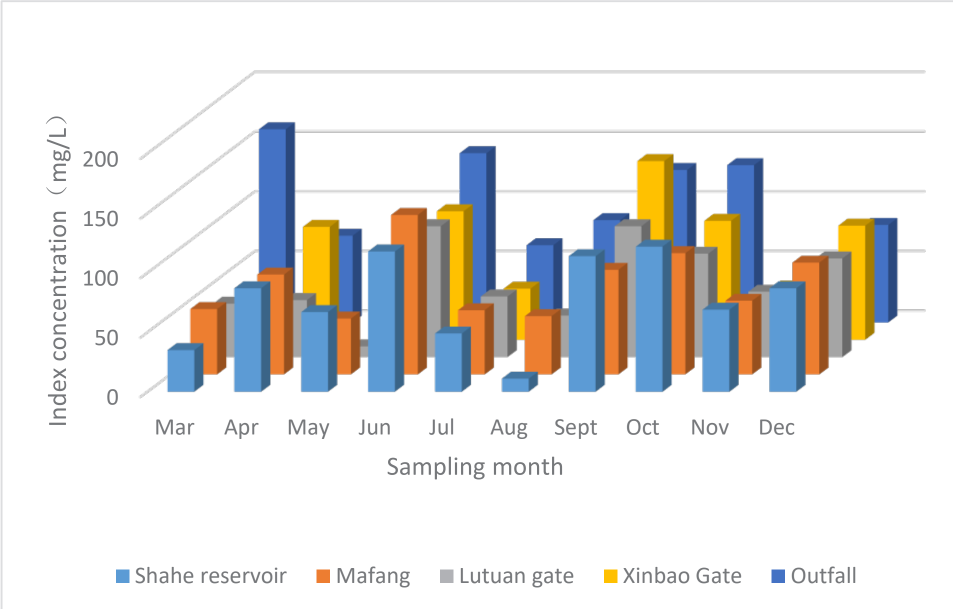

Fig. 3: Statistics of COD_{cr} monitoring data.

In the formula: d_i, x_i, x_1, x_5 are the normalized standard value, unnormalized standard value, and the grade I and V standard value respectively.

The normalization of the grading standards is shown in Table 3.

The normalized classical domain and node domain are as follows:

$$R_{01} = \begin{bmatrix} COD_{cr} & (0,0.375) \\ NH_3-N & (0,0.075) \\ DO & (0,0.25) \end{bmatrix}$$

$$R_{02} = \begin{bmatrix} COD_{cr} & (0,0.375) \\ NH_3-N & (0.075,0.25) \\ DO & (0.25,0.5) \end{bmatrix}$$

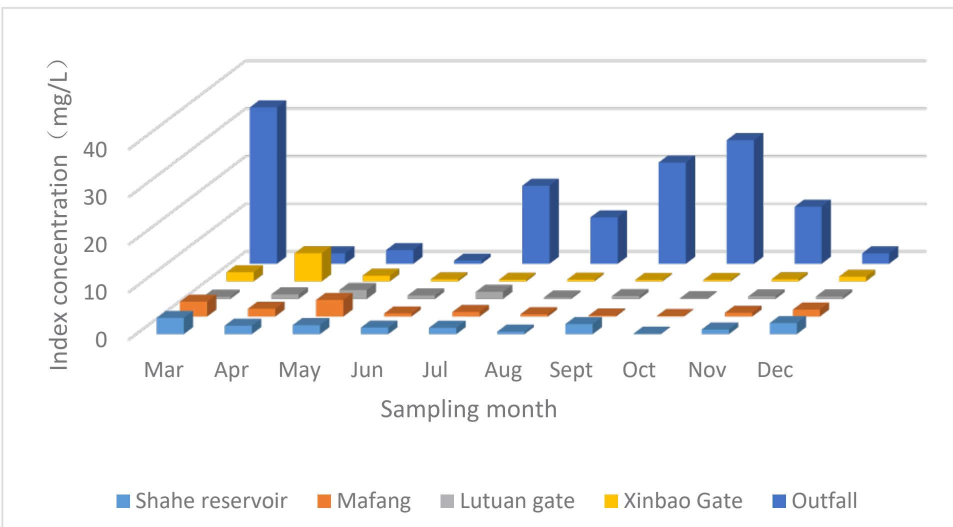

Fig. 4: Statistics of NH_3-N monitoring data.

Table 3: Classification standards after normalization

indicators	COD_{cr}	NH_3-N	DO
Grade I	0.375	0.075	0.25
Grade Ⅱ	0.375	0.25	0.5
Grade Ⅲ	0.5	0.5	0.625
Grade Ⅳ	0.75	0.75	0.875
Grade Ⅴ	1	1	1

$$R_{03} = \begin{bmatrix} COD_{cr} & (0.375,0.5) \\ NH_3 - N & (0.25,0.5) \\ DO & (0.5,0.625) \end{bmatrix}$$

$$R_{04} = \begin{bmatrix} COD_{cr} & (0.5,0.75) \\ NH_3 - N & (0.5,0.75) \\ DO & (0.625,0.875) \end{bmatrix}$$

$$R_{05} = \begin{bmatrix} COD_{cr} & (0.75,1) \\ NH_3 - N & (0.75,1) \\ DO & (0.875,1) \end{bmatrix}$$

The node domain RP of the model is determined according to the value range of normalized standard value and the measured data. Rx is determined according to the measured data after normalization as follows.

$$R_X = \begin{bmatrix} COD_{cr} & 1.675 \\ NH_3 - N & 0.945 \\ DO & 0.6225 \end{bmatrix} \quad R_P = \begin{bmatrix} COD_{cr} & (0,1) \\ NH_3 - N & (0,1) \\ DO & (0,1) \end{bmatrix}$$

Calculation of Weight Coefficient and Correlation

The weight coefficient w_{1i} can be determined according to the multiple super-scale weighting method.

$W_{1\ CODcr}$=0.467; $w_{1\ NH3\text{-}N}$ = 0.260; $w_{1\ DO}$ = 0.273

Determine the weight coefficient w_2 according to the ordinary objective empowerment method, and the results are shown in Table 4.

Table 4: Weight coefficient w_2.

a_{ij}	a_{i1}	a_{i2}	a_{i3}	a_{i4}	a_{i5}
a_{1j}	0.5357	0.3333	0.3077	0.3158	0.3333
a_{2j}	0.1072	0.2222	0.3077	0.3158	0.3333
a_{3j}	0.3571	0.4445	0.3846	0.3684	0.3334

Table 5: Weight coefficient w_i.

a_{ij}	a_{i1}	a_{i2}	a_{i3}	a_{i4}	a_{i5}
a_{1j}	0.5082	0.3868	0.3714	0.3763	0.3868
a_{2j}	0.1683	0.2373	0.2886	0.2935	0.304
a_{3j}	0.3235	0.3759	0.34	0.3302	0.3092

The coupling weight coefficient w_i can be obtained from formula (7), as shown in Table 5.

Using the weight coefficient to calculate the comprehensive correlation degree, K_1(P)=-1.2946, K_2(P)=-1.1165, K_3(P)=-1.1274, K_4(P)=-1.6234, K_5(P)=-0.0571, the evaluation result of this water sample is Grade V water.

CONCLUSIONS

The matter-element analysis method takes the evaluation index and its characteristic value as matter-element, obtains the classic domain, node domain, and weight coefficient of the model to calculate the correlation degree, and establishes a quality evaluation model with multiple index parameters of water quality. The evaluation results can be expressed by quantitative values. Reflect the difference of monitoring values, thereby reflecting the comprehensive level of direct water quality, and classify water quality accordingly. This evaluation method reflects the comprehensive impact of different evaluation factors on water quality.

The coupling weight method effectively highlights the most important pollution factors through two-value coupling and avoids the contingency of data evaluation. The evaluation process is concise and clear. It uses specific numerical calculations and quantitative instead of qualitative, which is closer to the actual situation. Not only can accurately reflect the overall situation of water quality, but also can intuitively show the weight of each measurement index in the water quality pollution factors.

The above-mentioned method was used to evaluate the actual water quality data of the five monitoring sections of the Wenyu River in May. The results showed that the water sample from the Shahe Reservoir at the sampling point on May 19, 2019, was Grade V water. Compared with the actual situation, the evaluation result is close to reality and the evaluation result is credible. In summary, in water quality evaluation, the matter-element analysis method based on coupling weights is an effective method, which can provide a lot of help for the scientific research work of water quality evaluation projects.

ACKNOWLEDGMENTS

This work was supported by the funds for the undergraduate innovative experiment plan of North China Electric Power University, and the Famous Teachers Cultivation planning for Teaching of North China Electric Power University (the Fourth Period).

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