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Application of fuzzy comprehensive evaluation method in water quality evaluation

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Based on the fuzzy transformation principle and principle of maximum degree of membership, the comprehensive evaluation on the monitoring data of Weihe Tongguan drawbridge section in 2015-2016 is conducted by using the fuzzy comprehensive evaluation method. The results show that the water quality pollution levels of this section in 4 seasons of spring, summer, autumn and winter are Class V (seriously polluted) , Class I (unpolluted) , Class IV (heavily polluted) and Class V (seriously polluted) respectively. Compared with the traditional method of single factor assessment, this method can reflect the water quality more comprehensively and reasonably.

Keywords: fuzzy mathematics; comprehensive evaluation method; Weihe River; water quality evaluation

INTRODUCTION

The comprehensive evaluation of water quality is the basic work of water pollution control [1-3], it is an important reference for governance decision-making [4] , therefore, it is important to select a suitable evaluation method [5-7]. The severity of water pollution is fuzzy concept[8,9], and the water quality assessment according to water quality standards is a typical fuzzy pattern recognition problem [10-13]. For fuzzy comprehensive evaluation, the selection of evaluation factor set, the establish of evaluation set and the calculation of weight depend on the characteristics of the statistical data [14-16]. The choice of the combination operator of fuzzy transformation and the principle of judgment are closely related to the error of the fuzzy evaluation model [17,18], around the contents, a lot of literatures have carried on the research [19-23]. The comprehensive evaluations of the Weihe River water quality are carried on in the article, the detailed process of establishing factor set, evaluation [24-27] set, weight, compound operation operator and judgment principle [28-32] is given, make use of the data of the the Weihe river water quality in the Tongguan hanging bridge section during 2015-2016, the fuzzy comprehensive [33-35] evaluation of the water pollution in the four seasons of the year is carried out, the results provide a basis for the Weihe River water pollution control and governance [36]. This evaluation method has the universal significance to the environment pollution statistical data analysis.

EXPERIMENT PART

Overview of contaminated area

The Weihe River is 818 kilometers in length, with a drainage area of 13.43 million square kilometers. The Weihe River Tongguan hanging bridge section is the control station of running into the Yellow River. In recent years, a large sum of industrial wastewater and domestic sewage directly or only after a simple treatment into the Weihe River, excessive discharge of sewage and unreasonable discharge of water cause great damage to the ecological environment. At present, the Weihe River water pollution is serious, and basically lost the ecological function. Therefore, it is of great practical value to make a correct evaluation of the present situation of Weihe River water quality.

Water quality monitoring data

The content of pH, DO, COD_{Mn} and NH3-N in the Weihe river Tongguan hanging bridge section from March 2015 to February 2016 were collected, The data were averaged over every seasons of the year (the first quarter : 3-5 months; the second quarter: 6-8 months; third quarter: 9-11 months; fourth quarter: 12-February the following year), shown in Table 1.

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Table 1. Water quality monitoring data

Time	pH	DO/ $(mg \cdot L^{-1})$	COD_{Mn}/ $(mg \cdot L^{-1})$	NH_3-N/ $(mg \cdot L^{-1})$
First quarter	8.07	4.64	8.32	2.04
Second quarter	8.02	4.78	7.95	0.80
Third quarter	7.87	5.01	7.56	0.96
Fourth quarter	7.78	5.60	7.21	1.37

Table 2. The changing data of BOD_5 and DO.

Time /d	-2	-1	0	1	2	3	4	5	6	7	8	9
DO	7.8	7.7	7.8	4.2	3.6	3.5	4.2	5.5	7.1	8.2	8.0	7.9
BOD_5	3.8	3.9	19.5	16.0	12.5	9.8	6.1	4.9	4.2	3.9	3.9	3.8

Table 3. The commonly used fuzzy synthesizing operators

Detail	Operator			
	$M(\wedge, \vee)$	$M(\cdot, \vee)$	$M(\wedge, \oplus)$	$M(\wedge, \vee)$
Reflects weight	Not obvious	Obvious	Not obvious	Obvious
Integrated degree	Weak	Weak	Strong	Strong
R information utilization	Insufficiency	Insufficiency	More sufficiency	sufficiency
Type	Dominant- factor	Dominant- factor	Weighted average	Weighted average

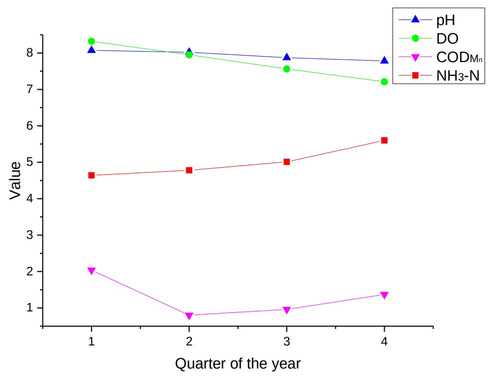

Fig. 1. he changing curve of Water quality monitoring data.

A contaminant zone real-time tracking data

The Table 2 data shows the tracking observations of organic contaminants in a contaminated zone in September 2015. According to Table 2, Fig. 2 is drawn, from the curves, the changes of BOD_5 and DO are observed during biodegradation.

As can be seen from Fig.2, the BOD_5 of the uncontaminated water bodies fluctuates between 3.5 and 4 $mg \cdot L^{-1}$, the dissolved oxygen(DO) varies from 7.5 to 8 $mg \cdot L^{-1}$. the DO of contaminated water bodies has a large decline in the initial 1~2 days, the content of DO in 2 ~ 6 days is relatively gentle , and the DO content is low, the content of DO in 6 ~ 8 days is relatively gentle increase slowly with a less increment; The biochemical demanded oxygen BOD_5 of polluted water increase rapidly in the initial 1~2 days, the peak value of BOD_5 reaches 19.5 $mg \cdot L^{-1}$, and then decreases with a larger amplitude, after about 4 to 5 days, the amplitude is small, and gradually approach the same biochemical demanded oxygen BOD5 of clean water.

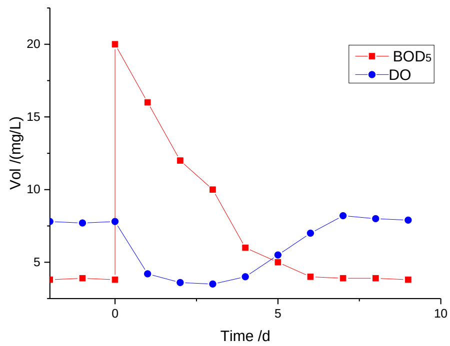

Fig. 2. The variation of BOD5 and DO with time.

RESULTS AND DISCUSSION

Data processing algorithm

The fuzzy comprehensive evaluation method is adopted in the monitoring data processing. Based on the establishment of evaluation factors, factor rating criteria and weight value, the membership function of each factor to the corresponding water quality level was established, And then put the measured values into the corresponding membership function, after fuzzy transformation and integrated operations, get the comprehensive membership degree, and finally determine the water quality level. Generally need the following steps:

- Set the factor set, $U = \{U_1, U_2, \cdots, U_3\}$, U represents the set of evaluation factors;
- Establish evaluation set, $V = \{V_1, V_2, \cdots, V_3\}$, V Represents the set of corresponding rating criteria;
- Make sure membership function. The semi - trapezoid distribution in fuzzy mathematics is used to determine membership function. The indexes which smaller value is better, use Equation 1 for processing; The indexes which large value are better, use Equation 2 for processing.

$$u(x) = \begin{cases} 0 & x \geq a_2 \\ \frac{a_2 - x}{a_2 - a_1} & a_1 < x < a_2 \\ 1 & x \leq a_1 \end{cases} \quad (1)$$

$$u(x) = \begin{cases} 1 & x \geq a_1 \\ \frac{x - a_2}{a_1 - a_2} & a_2 < x < a_1 \\ 0 & x \leq a_2 \end{cases} \quad (2)$$

- Establish the fuzzy relation matrix

Put the measured value into the determined membership function, calculate the membership degree of the i factor to the j-th level, get the fuzzy relation matrix R:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1j} \\ r_{21} & r_{22} & \cdots & r_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ r_{i1} & r_{i2} & \cdots & r_{ij} \end{bmatrix} \quad (3)$$

- Calculate the weight vector of the evaluation factors.

Because the evaluation factors have different effects on water quality, they should be given a different weight. The factors which smaller value are better, use Equation 4 for calculating the corresponding weight; The factors which large value are better, use Equation 5 for obtaining the weight; the weight factor calculation of the value of Ph adopts the Equation 6.

$$P_i = \frac{C_i}{S_2} \quad (4)$$

$$P_i = \frac{S_1}{C_I} \quad (5)$$

$$P_i = \frac{C_i - 6}{9 - 6} \quad (6)$$

Where, C_i is the measured concentration of the i evaluation factor; S_1 is the minimum value of the multi-level concentration standard value of the i evaluation factor; S_2 is the maximum value of the multi-level concentration standard value of the i evaluation factor.

In order to facilitate the operation, normalize d the weight value P_i of each evaluation factor, obtain the weighting set $W = \{W_1, W_2, \cdots, W_i\}$.

- Factor set judgment

The fuzzy synthesizing operators which are commonly used in environmental chemistry are as follows:

① $M(\wedge, \vee)$ (7)

$$b_j = \bigvee_{i=1}^{m} (a_i \wedge r_{ij}) = \max_{1 \leq i \leq m} \{\min(a_i, r_{ij})\},\ j = 1, 2, \cdots, n$$

② $M(\bullet, \vee)$

$$b_j = \bigvee_{i=1}^{m} (a_i, r_{ij}) = \max_{1 \leq i \leq m} \{a_i, r_{ij}\},\ j = 1, 2, \cdots, n \quad (8)$$

③ $M(\wedge, \oplus)$

$$b_j = \min\left\{1, \sum_{i=1}^{m} \min(a_i, r_{ij})\right\}, \quad j = 1, 2, \cdots, n \quad (9)$$

④ $M(\bullet, \oplus)$

$$b_j = \min\left(1, \sum_{i=1}^{m} a_i r_{ij}\right), \quad j = 1, 2, \cdots, n \quad (10)$$

The features of the commonly used fuzzy synthesizing operators are summarized as shown in Table 3:

The weighting set W is compound operation with the fuzzy evaluation matrix R:

$$B = W \cdot R = \{W_1, W_2, \cdots, W_i\} \cdot \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1j} \\ r_{21} & r_{22} & \cdots & r_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ r_{i1} & r_{i2} & \cdots & r_{ij} \end{bmatrix} \quad (11)$$

- Processing method of fuzzy comprehensive evaluation vector $B = (b_1, b_2, ..., b_n)$

The processing of fuzzy comprehensive evaluation vector $B = (b_1, b_2, ..., b_n)$ often uses the following two methods in environmental chemistry:

1. The principle of maximum membership

If the fuzzy comprehensive evaluation result vector meet the Equation 12):

$$\exists b_r = \max_{1 \leq j \leq n} (b_j) \quad (12)$$

The evaluated object belongs to the r-th class as a whole.

2. Weighted average principle

Think a level as a relative position, make it continuous. In order to be able to quantitative processing, use "1,2,3, ..., m" to express the level, calling them as the rank, then the rank of each level is summed with the corresponding component in B, so as to obtain the relative position of the object to be evaluated, which is expressed as follows:

$$A = \frac{\sum_{j=1}^{n} b_j^k \cdot j}{\sum_{j=1}^{n} b_j^k} \quad (13)$$

Where, k is the undetermined coefficient (k = 1 or 2), the purpose is to control the role of the larger b_j. When k-> ∞, the weighted average principle is the principle of maximum membership.

Fuzzy comprehensive evaluation of monitoring data

- Set up the factor set and evaluation set

The values of pH, dissolved oxygen (DO), permanganate index (COD_{Mn}) and ammonia nitrogen (NH3 - N) in Table 1 were selected as the evaluation factors, establish the factor set $U = \{pH, DO, COD_{Mn}, NH3-N\}$; Select the "Surface Water Environmental Quality Standard" (GB 3838-2002) as the evaluation criteria, in the standard of GB 3838-2002, the water quality was divided into five grades: 1-uncontaminated, 2-light pollution, 3-medium pollution,4-heavy pollution, 5-severe contamination, as is shown at the Table 4.

Table 4. The evaluation factors and evaluation criteria.

evaluation factors	1	2	3	4	5
The value of pH	6~9	6~9	6~9	6~9	6~9
DO/ $(mg \cdot L^{-1})$	7.5	6	5	3	2
COD_{Mn}/ $(mg \cdot L^{-1})$	2	4	6	10	12
NH_3-N/ $(mg \cdot L^{-1})$	0.15	0.5	1.0	1.5	2.0

- Make sure the Membership function and the fuzzy relation matrix

According to the Table 2, the membership function of each level is determined by the "semi - trapezoidal formula". For the smaller values of the COD_{Mn} and the NH3 – N denote the better the water quality, the membership function should be selected partial small semi-trapezoidal function, as is shown from Equation 14.

$$u(x)\begin{cases} u_i(x)=\begin{cases}0 & x\ge a_2\\ \frac{a_2-x}{a_2-a_1} & a_1<x<a_2\\ 1 & x\le a_1\end{cases}, i=1\\ u_i(x)=\begin{cases}0 & x\ge a_{i+1}, x\le a_{i-1}\\ \frac{x-a_{i-1}}{a_i-a_{i-1}} & a_{i-1}<x<a_i\\ \frac{a_{i+1}-x}{a_{i+1}-a_i} & a_i\le x\le a_{i+1}\end{cases}, i=2\sim n-1\\ u_i(x)=\begin{cases}1 & x\ge a_n\\ \frac{x-a_{n-1}}{a_n-a_{n-1}} & a_{n-1}<x<a_n\\ 0 & x\le a_{n-1}\end{cases}, i=n\end{cases} \quad (14)$$

For the larger values of the DO denote the better the water quality, the membership function should be selected partial larger semi-trapezoidal function, as is shown from Equation15.

$$u(x)\begin{cases} u_i(x)=\{ , i=1\\ u_i(x)=\begin{cases}0 & x\le a_{i+1}, x\ge a_{i-1}\\ \frac{x-a_{i+1}}{a_i-a_{i+1}} & a_{i+1}<x<a_i\\ \frac{a_{i-1}-x}{a_{i-1}-a_i} & a_i\le x\le a_{i-1}\end{cases}, i=2\sim n-1\\ u_i(x)=\begin{cases}0 & x\ge a_{n-1}\\ \frac{x-a_n}{a_{n-1}-a_n} & a_n<x<a_{n-1}\\ 1 & x\le a_n\end{cases}, i=n\end{cases} \quad (15)$$

Where, x is the measured concentration of an evaluation factor; a_i is the i-level water quality standards.

Put the measured value into the corresponding membership function, get the fuzzy relation matrix of four quarters of the year:

$$R_1=\begin{bmatrix}1&0&0&0&0\\0&0&0.82&0.18&0\\0&0&0.42&0.58&0\\0&0&0&0&1\end{bmatrix} \quad (16)$$

$$R_1=\begin{bmatrix}1&0&0&0&0\\0&0&0.89&0.11&0\\0&0&0.51&0.49&0\\0&0.40&0.60&0&0\end{bmatrix} \quad (17)$$

$$R_1=\begin{bmatrix}1&0&0&0&0\\0&0.01&0.99&0&0\\0&0&0.61&0.39&0\\0&0.08&0.92&0&0\end{bmatrix} \quad (18)$$

$$R_1=\begin{bmatrix}1&0&0&0&0\\0&0.60&0.40&0&0\\0&0&0.70&0.30&0\\0&0&0.26&0.74&0\end{bmatrix} \quad (19)$$

- Calculate the weight vector of the evaluation factors

The weight vector calculation of the evaluation of COD_{Mn} and NH3-N use the equation 4, the weight vector calculation of the evaluation of DO use the equation 5, the weight vector calculation of the evaluation of pH use the equation 5, Normalize the weight calculation, the calculation results in Table 5.

- Water pollution comprehensive evaluation results

Through fuzzy comprehensive operation, according to the principle of maximum membership, it can be determined water qualities of the Weihe River Tongguan hanging bridge section of the four quarter from March 2015 to February 2016. The results are shown in Table 6.

Table 5. The normalized results of the weights.

evaluation factors	First quarter		Second quarter		Third quarter		Fourth quarter	
	P_1	W_1	P_2	W_2	P_3	W_3	P_4	W_4
pH	0.6900	0.2559	0.6733	0.3330	0.6233	0.3106	0.5933	0.2804
DO/ $(mg \cdot L^{-1})$	0.4310	0.1599	0.4184	0.2070	0.3992	0.1990	0.3571	0.1687
COD_{Mn}/ $(mg \cdot L^{-1})$	0.5547	0.2058	0.5300	0.2622	0.5040	0.2512	0.4807	0.2274
NH_3-N/ $(mg \cdot L^{-1})$	1.0200	0.3784	0.4000	0.1978	0.4800	0.2392	0.6850	0.3237
$\sum P_i$	2.6957	1.0000	2.0217	1.0000	2.0065	1.0000	2.1161	1.0000

Table 6. The comprehensive evaluation of Weihe River water quality

Time	I	II	III	IV	V	Fuzzy Evaluation	Single factor evaluation
First quarter	0.2559	0.0000	0.2058	0.2058	0.3784	V	V
Second quarter	0.3330	0.1978	0.2622	0.2622	0.0000	I	IV
Third quarter	0.3106	0.0800	0.2512	0.2512	0.0000	I	IV
Fourthquarter	0.2804	0.1687	0.2600	0.3237	0.0000	IV	IV

CONCLUSIONS

Based on the data of the the Weihe river water quality during 2015-2016, use the fuzzy comprehensive evaluation in the purpose of making an assessment on the water quality in the Weihe River Tongguan hanging bridge section, The evaluation results shows the following contents:

- During 2015-2016, in the Tongguan hanging bridge section, the water quality grades of the four quarters are as follows: in the first quarter, the water pollution is V, it is severe contamination; in the second quarter and the third quarter, the water pollution is I, it is un-pollution; in the fourth quarter, the water pollution is IV, it is heavy pollution, compared with the same period during 2014-2015, the water quality has been significantly improved, But in the first and the fourth quarters , the pollution situation is still more serious, Caused a significant impact on the water quality safety.
- As can be seen from the results of the weight calculation, in the Tongguan hanging bridge section, The main pollutants in the first quarter were NH3 - N and COD_{Mn}; The main pollutants in the second quarter were COD_{Mn} and DO; The main pollutants in the third quarter were COD_{Mn} and NH3 – N; The main pollutants in the fourth quarter were NH3 - N and COD_{Mn}, the different distribution information of major pollutants at different quarters Contribute to the upstream pollution control of major sources of pollution and downstream water purification.
- The analysis of the experimental results verify that Fuzzy comprehensive evaluation method can be used for water quality evaluation which is more reasonable than traditional one-factor evaluation. In terms of the algorithm, the improvement of weight operator and compound operator can help to reduce the error of the evaluation model.

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REFERENCES

1. K.O. Adebowale, F.O. Agunbiade, B.I. Olu-Owolabi *Chem Ecol*, **24**(4), 269 (2008).
2. V. Adriaenssens, B. De Baets, P.L.M. Goethals, N. De Pauw, *Sci Total Environ*, **319**, 1 (2004).
3. F.O. Agunbiade, A.T. Fawale, *Int J Environ Sci Technol*, **6**(2), 267 (2009).

4. F.O. Agunbiade, A.A. Awe, K.O. Adebowale, *Toxicol Environ Chem*, **93**(10), 1856 (2011).
5. F.O. Agunbiade, B.I. Olu-Owolabi, K.O. Adebowale, *Environ Monit Assess*, **184**(1), 89 (2012).
6. O.A. Akintola, A.Y. Sangodoyin, F.O. Agunbiade, *Water Pract Technol*, **8**(2), 244 (2013).
7. O. Akoto, G. Darko, M.A. Nkansah, *Int J Environ Res*, **5**(4), 847 (2011).
8. P. Mitchell, Guidelines for quality assurance and quality control in surface water quality programs in Alberta, W0603, Alberta Environment, 2006, p.67.
9. B. Alo, B. Orgu, A. Abayomi, *Eur J Sci Res*, **40**(2), 279 (2010).
10. APHA, Standard methods for the examination of water and wastewater, 19th edn. APHA, Washington, DC, 1995.
11. T.Y. Fu, Z.H. Zou, X.J. Wang, *Acta Scientiae Circumstantiae*, **34**(2), 473 (2014).
12. P.G.C. Campbell, In: Metal speciation and bioavailability in aquatic systems, A Tessier, D.R. Turner (eds), Wiley, New York, 1996, p. 45.
13. N.B. Chang, H.W. Chen, S.K. Ning, *J Environ Manag*, **63**, 293 (2001).
14. J. Ellith, M.A. Burgman, H. Regan, *Ecol Model*, **157**, 313 (2002).
15. M. Enea, G. Salemi, *Ecol Model*, **135**, 131 (2001).
16. J.N. Houser, W.B. Richardson, *Hydrobiologia*, **640**, 71 (2010).
17. J.G. Jabbra, N.W. Jabbra (eds) Challenging environmental issues: middle eastern perspectives, Brill, Leiden, 1997, p 101.
18. P.E. John–De–Zuane, Handbook of drinking water quality: standards and control, Wiley, New York, 1990.
19. K.S. Low, G.K. Lee, S.C. Liew, *Process Biochem*, **36**, 59 (2000).
20. R.S. Lu, S.L. Lo, *Water Res*, **36**, 2265 (2002).
21. T.E. McKone, A.W. Deshpande, *Environ Sci Tech*, **39**, 42A (2005).
22. W. Ocampo-Duque, N. Ferre´-Huguet, J.L. Domingo, M. Schuhmacher, *Environ Int*, **32**, 733 (2006).
23. G. Onkal-Engin, I. Demir, H. Hiz, *Atmos Environ*, **38**, 3809 (2004).
24. A. Plazinska, In: Microbiological quality of rainwater in selected Indigenous communities in central Australia. Rainwater: quality issuesq (Proc. 10th international rainwater catchment systems conference Germany, 2001), 2001, p. 129.
25. K. Sadegh-Zadeh, *Artif Intell Med*, 21, 1 (2001).
26. E. Sazakli, A. Alexopoulos, M. Leotsinidis, *Water Res*, **41**(9), 2039 (2007).
27. G. Shen, Y. Lu, M. Wang, Y. Sun, *J Environ Manag*, **76**, 355 (2005).
28. W. Silvert, *Ecol Model*, **130**, 111 (2000).
29. T. Thomas, *Waterlines*, **18**(3), 7 (2000).
30. USEPA, Water quality standards handbook, 2nd edn. EPA-823-B-93-002 and EPA-823-B-94-006. Office of Water, Washington, DC, USA, 1993.
31. L.P. Yang, K. Mei, X.M. Liu, *Environmental Science and Pollution Research*, **20**, 5341 (2013).
32. World Health Organization, Guidelines for drinking water quality, 3rd edn, vol 1., RecommendationsWorld Health Organization, Geneva, 2004.
33. S. Yadav, P. Kumar, *Air Qual Atmos Health*, **7**(4), 559 (2014).
34. L.A. Zadeh, *Inform Control*, **8**, 338 (1965).
35. X. Ban, Q.Z. Wu, B.Z. Pan, *Environmental Monitoring and Assessment*, **186**, 4237 (2014).
36. H.M. Bu, X. Tan, S.Y. Li, *Environmental Earth Sciences*, **60**, 1631 (2010).