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# Water quality assessment in Qu River based on fuzzy water pollution index method

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## ABSTRACT

A fuzzy improved water pollution index was proposed based on fuzzy inference system and water pollution index. This method can not only give a comprehensive water quality rank, but also describe the water quality situation with a quantitative value, which is convenient for the water quality comparison between the same ranks. This proposed method is used to assess water quality of Qu River in Sichuan, China. Data used in the assessment were collected from four monitoring stations from 2006 to 2010. The assessment results show that Qu River water quality presents a downward trend and the overall water quality in 2010 is the worst. The spatial variation indicates that water quality of Nanbashequ section is the pessimal. For the sake of comparison, fuzzy comprehensive evaluation and grey relational method were also employed to assess water quality of Qu River. The comparisons of these three approaches' assessment results show that the proposed method is reliable.

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## Introduction

Water shortage problem in developing countries is more and more serious in recent years (Ongley, 1998). Especially in China, severe water shortage problems and a large amount of sewage make the situation of surface water pollution exceedingly serious (Lindberg et al., 2014; Zhou et al., 2014). River water quality is becoming an important factor to hinder social and economic development. Therefore, how to analyze and assess water quality accurately is of great significance both to society and economy.

A good water quality assessment method should not only provide the water quality rank, but also accurately reflect the spatial and temporal variations of water quality condition. At the same time, a water quality assessment method which can be widely used in environmental management should be easy to calculate and master, in addition to the scientificity and accuracy. Single factor evaluation method is widely adopted by environmental protection department in China. Water

quality index method (Huang, 2001; Yi and Yu, 2003; Qiu et al., 2013) is used by many provinces and cities hydrology department for water quality assessment of drinking water source, which is proposed by Ministry of Water Resources, Monitoring and Evaluation Center of Water Environment. However, both these two methods have limitations. Single factor evaluation method gives the water quality rank, but is unable to quantify the water quality changes; water quality index method can not only give the water quality rank, but also reflect the spatial and temporal variations of water quality condition. But it needs to consider too many parameters. In recent years, many new methods have been continually applied in the evaluation of water quality, such as multivariate statistical techniques (Shrestha and Karama, 2007; Huang et al., 2010), artificial neural network (Ip et al., 2009; Yan et al., 2010), and grey evaluation method (Shi et al., 2012). Nevertheless, most of these methods' calculation processes are trivial. Then, water pollution index (WPI) method (Liu et al., 2013; Liu and Wu, 2014) is proposed. This method simplifies

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the water quality index method and is extended to general water quality assessment. The method is able to quantify the water quality condition; however, it continues the theory of single factor evaluation method and uses the most polluted indicator as the basis of water quality rank. So the assessment results are relatively conservative. After that, an improved water pollution index method (IWPI) (Li et al., 2014) is presented. In this method, each indicator is given a weight by entropy, and the section IWPI is the weighted sum of all indicators' WPIs. According to the quantitative results, the water quality can not only identify the water quality rank intuitively, but also can reflect the spatial and temporal variations of the water quality.

Methods mentioned above are all deterministic methods. As we all know, it may be not accurate to use deterministic methods deal with complex and changeable environment problems. In view of the limitations and complexities of deterministic models, fuzzy logic, capable of integrating and accounting for the inaccurate, vague, qualitative and fuzzy information, has been increasingly applied to environmental issues in recent years (Chau, 2006). Fuzzy logic was first introduced by Zadeh (1965) and then has been widely used in many fields. It is appropriate for developing environmental indices, due to its ability to reflect human thoughts and expertise, and its capacity to deal with uncertain, ambiguous and subjective information. Furthermore, it is also a reliable method to report the assessment results in linguistic terms for decision-makers with no expertise. Therefore, development of environmental indices based on fuzzy logic have drawn much attention (Karmakar and Mujumdar, 2006; Sowlat et al., 2011), especially in water quality (Chang et al., 2001; Ocampo-Duque et al., 2006, 2007; Zou et al., 2006; Icaga, 2007; Lermontov et al., 2009). For example, Ocampo-Duque et al. proposed a methodology based on fuzzy inference systems to assess water quality (Ocampo-Duque et al., 2006). Gharibi et al. developed a novel water quality index based on fuzzy logic, which is a comprehensive artificial intelligence approach to the development of environmental indices for routine assessment of surface water quality (Gharibi et al., 2012).

Fuzzy water pollution index (FWPI) method is proposed in this article. This method modified the improved water pollution index method using fuzzy inference system. In this method, all indicators' weights are incorporated in setting rules, rather than simply using the heaviest pollution indicator represents the overall water quality condition. The assessment results can be obtained directly by the fuzzy inference. Then this proposed method is used to assess water quality of Qu River in Sichuan, China. The assessment results are compared with those obtained by fuzzy comprehensive evaluation method and grey relational method.

## 1. Materials and methods

### 1.1. Study area

Qu River is a tributary of the Jialing River. It originates from the south of Micang Mountain, which locates at the junction of Sichuan province and Shaanxi provinces. Qu River flows through eight counties and twenty-one towns from north to

**Table 1 – Environmental Quality Standards for Surface Water of China (GB3838-2002).**

Rank	DO (mg/L)	COD <sub>Mn</sub> (mg/L)	BOD <sub>5</sub> (mg/L)	NH <sub>3</sub> -N (mg/L)	TP (mg/L)
I	7.5	2	3	0.15	0.02
II	6.0	4	3	0.50	0.10
III	5.0	6	4	1.00	0.20
IV	3.0	10	6	1.50	0.30
V	2.0	15	10	2.00	0.40

south, then enters Guang'an County, Huaying City, Hechuan County and finally empties into Jialing River. The upstream is called Nanjiang River, next to Enyang River in Bazhong City is called Ba River, and next to Zhou River in Qu County is called Qu River. It runs for 720 km, and covers a watershed area of 39,200 km<sup>2</sup>, with the annual average flow of 663 m<sup>3</sup>/sec. Qu County locates in the southwest of Dazhou City, and is adjacent to Guang'an, Nanchong and Bazhong City. It covers 2013 km<sup>2</sup> with 60 towns. And the population is about 145 million.

Four monitoring stations in Qu County were selected in this study. They are Xipingcun (Station A) in Sanhui Town, Lianhuacun (Station B) in Huinan Town, Jinjikou (Station C) in Qujiang Town and Nanbashequ (Station D) in Qujiang Town. Dissolved oxygen (DO), permanganate index (COD<sub>Mn</sub>), five day biochemical oxygen demand (BOD<sub>5</sub>), ammonia nitrogen (NH<sub>3</sub>-N) and total phosphorus (TP) were selected to assess the water quality of Qu River. Environmental Quality Standards for Surface Water of China (GB3838-2002) is shown in Table 1, and the data of the five parameters at four stations from 2006 to 2010 are shown in Table 2 (Shi et al., 2012).

### 1.2. Water pollution index method

Water pollution index method is based on single factor evaluation method. According to water quality ranks and

**Table 2 – Concentrations of five indicators monitored from four stations from 2006 to 2010.**

Year	Station	DO (mg/L)	COD <sub>Mn</sub> (mg/L)	BOD <sub>5</sub> (mg/L)	NH <sub>3</sub> -N (mg/L)	TP (mg/L)
2006	A	7.63	1.60	1.52	0.16	0.067
	B	6.96	4.31	3.58	0.62	0.142
	C	6.42	3.95	3.07	0.62	0.150
	D	6.98	4.32	3.64	0.39	0.173
2007	A	8.41	1.52	0.98	0.15	0.018
	B	7.16	1.49	1.41	0.17	0.038
	C	6.18	2.56	2.33	0.36	0.024
	D	5.34	2.87	3.24	0.37	0.125
2008	A	6.86	1.95	1.76	0.07	0.095
	B	7.15	1.43	1.39	0.11	0.074
	C	5.47	3.47	3.02	0.18	0.132
	D	5.90	2.58	3.81	0.17	0.127
2009	A	6.51	2.86	1.62	0.09	0.085
	B	6.06	1.98	1.35	0.42	0.064
	C	5.65	4.46	3.76	0.66	0.045
	D	5.97	4.39	3.10	0.53	0.062
2010	A	6.52	2.80	1.33	0.18	0.039
	B	5.36	3.88	3.41	0.57	0.107
	C	5.09	4.12	3.72	0.46	0.115
	D	4.38	3.57	4.26	0.73	0.254

Data sources are from the report by Shi et al., 2012.

their corresponding WPI limiting values (the corresponding WPI limiting values of Rank I, II, III, IV and V are 20, 40, 60, 80, and 100, respectively) (Huang, 2001; Yi and Yu, 2003; Liu and Wu, 2014), all evaluation indicators' WPIs of each section are obtained by interpolation method, then the maximum value of all the indicators' WPIs is selected as the section WPI.

As mentioned by Liu et al. (2013), the concrete calculation process of WPI is as follows.

Each indicator's WPI:

$$WPI(i) = WPI_1(i) + \frac{C(i) - C_l(i)}{C_u(i) - C_l(i)} \times 20 \quad (1)$$

where,  $C(i)$  is the monitoring value of the  $i$ th indicator,  $C_l(i)$  and  $C_u(i)$  are the lower and upper limiting values of the  $i$ th indicator's rank in Table 1 respectively, and  $C_l(i) \leq C(i) \leq C_u(i)$  (for DO,  $C_u(i) \leq C(i) \leq C_l(i)$ ),  $WPI_1(i)$  is the corresponding lower WPI value of the  $i$ th indicator,  $i = 1, \dots, n$ .

Besides, when the standard values of two ranks are the same in Table 1, interpolation on low score value range is used.

Section WPI:

$$WPI = \max(WPI(i)) \quad (2)$$

After that, an IWPI method (Li et al., 2014) is presented. IWPI method improves the section WPI, that is, each indicator's WPI is also calculated according to (1), but the section IWPI is

$$IWPI = \sum_{i=1}^n w_i * WPI(i) \quad (3)$$

where  $w_i$  is the weight of the  $i$ th indicator, which is calculated by entropy method (Zou et al., 2006). The steps of using entropy weight method to determine weight are as follows (Qiu, 2002):

Firstly, normalize the original data matrix. Suppose there are  $m$  evaluation sections for the evaluation river, and each section has  $n$  evaluation indicators, then the judgment matrix is

$$R = (r_{ij})_{n \times m} \quad (4)$$

where  $r_{ij}$  is the  $i$ th evaluation indicator's measured value of the  $j$ th evaluation section. Normalize the judgment matrix and the matrix  $B$  is obtained.  $b_{ij}$  is the element of  $B$ , if the indicator value is the larger the better,  $b_{ij}$  is defined

$$b_{ij} = \frac{r_{ij} - \min_j \{r_{ij}\}}{\max_j \{r_{ij}\} - \min_j \{r_{ij}\}} \quad (5)$$

otherwise,

$$b_{ij} = \frac{\max_j \{r_{ij}\} - r_{ij}}{\max_j \{r_{ij}\} - \min_j \{r_{ij}\}} \quad (6)$$

Second, define the entropy. The  $i$ th evaluation indicator's entropy  $H_i$  is

$$H_i = -k \sum_{j=1}^m f_{ij} \ln f_{ij}, \quad i = 1, 2, \dots, n \quad (7)$$

$$f_{ij} = b_{ij} / \sum_{j=1}^m b_{ij}, k = 1 / \ln m \quad (8)$$

$$\text{If } f_{ij} = 0, f_{ij} \ln f_{ij} = 0.$$

Lastly, the weights are computed. The  $i$ th evaluation indicator's weight  $w_i$  is

$$w_i = (1 - H_i) / \left( n - \sum_{i=1}^n H_i \right) \quad (9)$$

$$\text{where, } 0 \leq w_i \leq 1, \sum_{i=1}^n w_i = 1.$$

### 1.3. Fuzzy water pollution index method

Next fuzzy inference system will be used to improve this method. In a fuzzy inference system, a quantitative numerical value is fuzzified into a qualitative state and processed by an inference engine, through sets and operators, rules in a qualitative sphere, allowing the use of information such as individual knowledge and experience, and permitting qualitative environmental parameters and factors to be integrated and processed. Relevant knowledge of fuzzy inference can be found in many literatures (Yen and Langari, 1998; Ross, 2004; Ocampo-Duque et al., 2006; Gharibi et al., 2012; Turksen, 1991; Karr and Gentry, 1993; Jang and Sun, 1995; Yager and Filev, 1994; Ross, 2004), which will not be described here in detail.

A fuzzy inference system can be divided into three parts: fuzzification, fuzzy inference, and defuzzification (Li, 2006). The fuzzification process involves the transformation of inputs from a numerical value of a variable into a membership grade, which describes a property of the variable. The fuzzy inference includes the fuzzy operations of multiple-part antecedents, the implication methods from the antecedent to the consequent for every rule, and an aggregation method to join the consequents across all the rules. Finally, defuzzification consists in transforming the fuzzy output into a non-fuzzy numerical value which can be used in non-fuzzy contexts (Silvert, 2000; Ocampo-Duque et al., 2006).

Fig. 1 shows the evaluation process of FWPI method. The antecedent sets (DO,  $COD_{Mn}$ ,  $BOD_5$ ,  $NH_3-N$  and TP) and the consequent set (FWPI) were created by trapezoid (I and V sets) and triangular pertinence (all others) functions; the five parameters ranks were as Table 1 and the corresponding five ranks, I, II, III, IV and V were obtained; the FWPI ranks referred to the WPI ranks. That is, the FWPI value ranges from 0 to 100 and water quality can be classified as I(0–20), II(20–40),

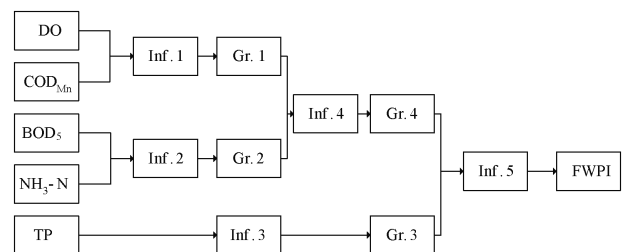


Fig. 1 – Evaluation process diagram of fuzzy water quality index method.

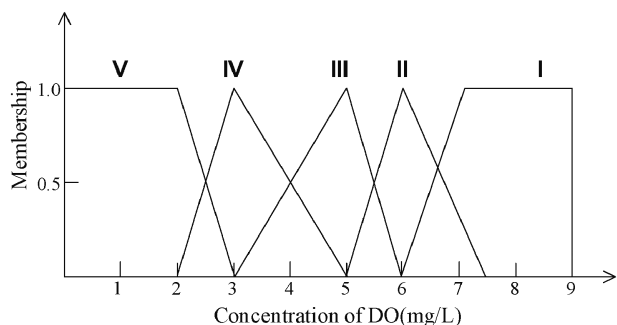


Fig. 2 – Membership functions of DO.

III(40–60), IV(60–80) and V(80–100). Only membership functions of DO (Fig. 2) was given as follows, and for the sake of brevity, membership functions of  $\text{COD}_{\text{Mn}}$ ,  $\text{BOD}_5$ ,  $\text{NH}_3\text{-N}$  and TP were no longer listed here. The output fuzzy sets for inference and FWPI ranks were shown in Fig. 3.

This fuzzy inference system has 125 rules. Weights are embodied in the fuzzy rules. Being impossible to write them all in this paper, some examples are given as below:

If DO is “V” and  $\text{COD}_{\text{Mn}}$  is “I” then Gr.1 is “III”.

If  $\text{BOD}_5$  is “I” and  $\text{NH}_3\text{-N}$  is “I” then Gr.2 is “I”.

If Gr.1 is “III” and Gr.2 is “I” then Gr.4 is “II”.

If Gr.4 is “II” and Gr.4 is “II” then FWPI is “II”.

Defuzzification of the outputs was carried out by using the center of gravity method, which is the most conventionally and physically applicable method for defuzzification. Its derivation is based on the following equation (Ross, 2004):

$$Z = \frac{\int \mu(z)zdz}{\int \mu(z)dz} \quad (10)$$

All the computations were processed using the “fuzzy logic toolbox” in MATLAB2012 (Li, 2006).

## 2. Results and discussion

Table 3 shows the evaluation results of Qu River by FWPI method. According to the FWPI value and Fig. 3, the corresponding ranks can be obtained. The results indicated that from 2006 to 2010, Qu River water quality presents a

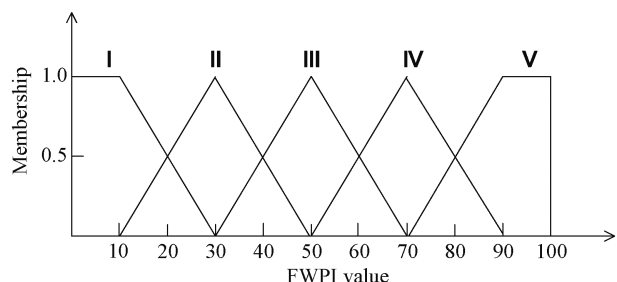


Fig. 3 – Output fuzzy sets for inference and FWPI ranks. FWPI: fuzzy water pollution index.

Table 3 – Evaluation results of FWPI method.

Year	Station	FWPI	Rank
2006	A	14.05	I
	B	37.17	II
	C	29.75	II
	D	36.48	II
2007	A	11.58	I
	B	18.03	I
	C	14.17	I
	D	36.80	II
2008	A	15.19	I
	B	15.02	I
	C	31.70	II
	D	33.19	II
2009	A	14.04	I
	B	25.08	II
	C	21.08	II
	D	24.72	II
2010	A	18.49	I
	B	33.10	II
	C	34.99	II
	D	42.42	III

FWPI: fuzzy water pollution index. Rank I, II, III refer to Table 1.

downward trend. The water quality of Station A retained Rank I in five years, without obvious change. The water quality of Stations B and C have some fluctuation between Rank I and Rank II. The water quality of Station D declines from Rank II to Rank III.

According to the temporal and spatial variations of the four stations from 2006 to 2010, the overall water quality in 2010 and the water quality of Station D were the worst, respectively. That attributes to rapid population increase and fast industrial development, which causes the increase of wastewater discharge. Station D is the place where the population and industrial factories are most intensive of Qu County. A large number of domestic sewage and industrial wastewater are discharged into the river. Therefore the water quality of Station D is the worst.

In order to validate the effectiveness of the FWPI method, the results by fuzzy comprehensive evaluation and grey relational model were compared with those by the FWPI (shown in Table 4). The results of grey relational model method were not computed, but transcribed from reference (Shi et al., 2012). The outcome indicates that the evaluation results get from this method are generally in agreement with the other two methods. However, some differences exist, for example, at Station A in 2009, the results by the proposed method and M3 are both Rank I while that by M2 is Rank II; at Station C in 2009, the results by this method and M2 are both Rank II while that by M3 are Rank I. From the monitoring data of all five indicators at Station A in 2009, it is both reasonable whether the water quality is identified as Rank I or Rank II. At Station C in 2009, according to the principle of fuzzy membership degree,  $\text{BOD}_5$  is in Rank III, TP is in Rank I, and other indicators are all in Rank II, so the water quality should be Rank II. By contrast and careful analysis, the results of FWPI method are almost consistent with other two common water quality assessment methods, so this method is reliable and can provide effective assessment for decision-making in water quality.

**Table 4 – Results and comparison of three methods.**

	2006				2007				2008				2009				2010			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
M1	I	II	II	II	I	I	I	II	I	I	II	II	I	II	II	II	I	II	II	III
M2	I	II	II	II	I	I	I	II	I	I	II	II	II	II	II	II	I	II	II	III
M3	I	II	II	II	I	I	I	II	I	I	II	II	I	II	I	II	I	II	II	III

M1 represents fuzzy water pollution index method; M2 represents fuzzy comprehensive evaluation method; M3 represents grey relational model method.

Rank I, II, III refer to Table 1.

### 3. Conclusions

The fuzzy water pollution index (FWPI) method is developed. This method corrects perceived deficiencies of water quality assessment and water resources management when the conventional, deterministic methods can be inaccurate or conceptually limited. In addition to giving the overall water quality rank, this method also describes the overall water quality condition with a quantitative value, which is convenient for comparison between different sections of the same ranks and making decisions. The proposed method is applied to assess water quality of Qu River in Sichuan, China. Fuzzy comprehensive evaluation and grey relational model are also employed to assess the water quality. It can be seen that the results of this proposed FWPI is almost consistent with those of other two methods, and can be used for water quality assessment in China.

Analysis on the water quality of Qu River suggested that improving the sewage treatment rate, optimizing the city life and rural life layout, and controlling the pollution of industry, and agriculture, should be carried out to prevent and control water pollution, and then the ecological environment of Qu River can be gradually improved.

The fuzzy water pollution index method achieves assessment by setting the fuzzy rules. However a large number of parameters will lead to tremendous increase of inference rules. To solve this problem, it is applicable to reduce the dimension of parameters firstly using some methods such as principal component analysis. The authors are still working in the development of an index with more parameters for a more realistic evaluation of water body.

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