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FUZZY SYNTHETIC EVALUATION OF WEIHE WATER QUALITY

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Abstract

Based on the fuzzy logic principle, a modified Fuzzy Synthetic Evaluation (FSE) is proposed to assess water quality status of Weihe River (Baoji, China). The potential application of the FSE has been tested in a case study. Twelve sampling locations of Weihe River and its tributaries in Baoji area were selected and seven water quality parameters of BOD₅, COD, fluoride, ammonia, total phosphorus (TP), total nitrogen (TN) and permanganate index, were monitored from 2008 to 2009. The findings clearly indicated that the methodology adopted in this study was reasonably close to the official reports published by the local Environmental Protection Agency (EPA) on the pollution problems in the study area. The water quality of Weihe River in Baoji area showed the Class II and III according to the Chinese classification standard. More importantly, this provides a good showcase of the modified FSE in river water quality evaluation.

Key words: Fuzzy Synthetic Evaluation, river water quality, water management, water quality criteria

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1. Introduction

Pollutants to compromise the health of river ecosystems can be very notable, depending on the economic and social characteristics of the riparian societies (Lekkas et al., 2004). Increasing dearth of water in developing countries has made river water quality evaluation an important issue in recent years (Ongley, 1998; Wang et al., 2009). River water quality evaluation is one of the safety problems of water resources in China, especially among major rivers, such as Yellow River and Yangtze River etc. It has been well noted that the methodology to effectively evaluate water quality and the concrete evaluation criteria to assess the security and the risk of water resources must be developed to ensure sustainable development and to protect public health (Ungureanu et al., 2010). Indeed, river water quality evaluation has been extensively studied in recent years (Benchea et al., 2011; Graca et al., 2002; Yilmaz, 2007; Liu, 2010). However, discrepancies

frequently arise from: 1) the lack of clear boundary distinctions between each water quality parameter; 2) short samples and incomplete information; 3) the uncertainty in the quality criteria employed and 4) the imprecision, vagueness, or fuzziness in the decision-making output values (William et al., 2006). This caused some cases of invalid river water quality evaluation in practice.

Traditionally, reports on water quality only present monitored data on individual substances, without providing an entire and interpreted profile of water quality. To bridge this gap, various water quality evaluation approaches have been developed to integrate water quality variables, such as water quality index (WQI) (Debels et al., 2005; Lumb et al., 2006; Pesce and Wunderlin, 2000), Fuzzy synthetic evaluation (FSE) (Chang et al., 2001; Liou et al., 2003; Lu et al., 1999; Luo et al., 2003; Zou et al., 2005), Fuzzy water quality index (Lermontov et al., 2009), Fuzzy Neural Network (Chen and Li, 2005), comprehensive water quality identification index

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(WQII) (Xu, 2005a). These approaches provide useful information towards decision-making for water environmental management and pollution control (Merdun and Çinar, 2010; Wotawa et al., 2010).

Fuzzy set theory (Zadeh, 1965) has been established to deal with uncertainty problems. It has been widely applied in decision-making and evaluation processes in imprecise situations (Dahiya, 2007; Mujumdar and Sashikumar, 2002). Many applications of Fuzzy set theory have been quoted in the last two decades, such as surface water and groundwater remediation (Cheng et al., 2002; Nasiri et al., 2007; Tzionas et al., 2004) soil amendments (Busscher et al., 2007), air pollution management (Fisher, 2003), and diverse air, water and terrestrial ecosystem environmental studies (Astel, 2007). An evaluation approach has been developed based on Fuzzy logic and Fuzzy set theory, which has been demonstrated to be effective in solving problems of fuzzy boundaries and controlling the effect of monitoring errors on assessment results (Wang, 2002). The Fuzzy logic and Fuzzy set theory-based evaluation model can be used to describe fuzzy character of classified bounds for water quality and it could reflect the actual water quality on objectives (Istrate and Grigoras, 2010; Pislaru et al., 2011).

In this study, a modified Fuzzy synthetic evaluation is proposed based on fuzzy logic to estimate water quality status of the Weihe River in Baoji city, Shannxi Province, China, using the data collected from 2008 to 2009.

2. Methodology

In FSE, the fuzzy boundary of various factors is described using membership grade. Fuzzy evaluation matrix is then established about membership function. The class of evaluation objects is determined using composite operators of the layers. The Fuzzy evaluation process is divided into six main steps:

Step 1: Determine an evaluation factor set U (Eq. 1), based on the data of monitored water quality parameters:

$$U = \{u_i\}, i = 1, 2, \dots, n \tag{1}$$

where, n is the number of selected evaluation parameters, u_i is the i^{th} water quality parameter.

Step 2: Build evaluation criteria set V (Eq. 2), based on the data of water quality criterion of the Chinese standard (GB3838, 2002), as shown in Table 1.

$$V = \{v_j\}, j = 1, 2, \dots, m \tag{2}$$

where, m is the number of evaluation criteria categories, v_j is the j^{th} evaluation criteria category.

Table 1. Water quality criteria applicable to river systems in Baoji (GB3838, 2002)

Water quality parameter	Water quality classification				
	I	II	III	IV	V
BOD ₅ mg/L ≤	3	3	4	6	10
COD mg/L ≤	15	15	20	30	40
Permanganate index mg/L ≤	2	4	6	10	15
Fluoride mg/L ≤	1.0	1.0	1.0	1.5	1.5
Ammonia mg/L ≤	0.15	0.5	1.0	1.5	2.0
TP mg/L ≤	0.02	0.1	0.2	0.3	0.4
TN mg/L ≤	0.2	0.5	1.0	1.5	2.0

Step 3: Establish membership functions and form the fuzzy relationship matrix R (Eq. 3), depending on the relation of U and V:

$$R = \begin{pmatrix} r_{11} & K & r_{1m} \\ M & O & M \\ r_{n1} & L & r_{nm} \end{pmatrix} \tag{3}$$

where, r_{ij} is the quality degree (membership grade) of the i^{th} water quality parameter observed in the j^{th} water quality criteria. In this step, three membership functions are used, namely:

(1) $j=1$, the function being expressed as Eq. (4):

$$r_{ij} = \begin{cases} 1(X_i \leq S_{ij}) \\ A_{ij}(X_i - S_{i(j+1)}) \left(S_{ij} < X_i < S_{i(j+1)}; A_{ij} = \frac{1}{S_{ij} - S_{i(j+1)}} \right) \\ 0(X_i \geq S_{i(j+1)}) \end{cases} \tag{4}$$

(2) $j=2, \dots, m-1$, the function being expressed as Eq. (5):

$$r_{ij} = \begin{cases} 1(X_i = S_{ij}) \\ A_{ij}(X_i - S_{i(j-1)}) \left(S_{i(j-1)} < X_i < S_{ij}; A_{ij} = \frac{1}{S_{ij} - S_{i(j-1)}} \right) \\ A_{ij}(X_i - S_{i(j+1)}) \left(S_{ij} < X_i < S_{i(j+1)}; A_{ij} = \frac{1}{S_{ij} - S_{i(j+1)}} \right) \\ 0, \text{ otherwise} \end{cases} \tag{5}$$

(3) $j=m$, the function being expressed as Eq. (6):

$$r_{ij} = \begin{cases} 1(X_i \geq S_{ij}) \\ A_{ij}(X_i - S_{i(j-1)}) \left(S_{i(j-1)} < X_i < S_{ij}; A_{ij} = \frac{1}{S_{ij} - S_{i(j-1)}} \right) \\ 0(X_i \leq S_{i(j-1)}) \end{cases} \tag{6}$$

where: X is the observed value; S_{ij} is the j^{th} water quality criteria of the i^{th} observed water quality parameter; if $S_{i1} = S_{i2}$, the real observed value is smaller than S_{i1} , then r_{ij} can be calculated by depicting 0.5.

Step 4: Determine fuzzy weight of the observed value. The weight values express the relative importance of each parameter in order to be more consistent with the corresponding usage mode. Commonly, methods for calculating the weights include the national environmental quality standards method (Wang, 2002) and analytic hierarchy method (Li et al., 2005; Yang et al., 2005) as well as other methods according to the knowledge and experience of experts (Hu and Liu, 1999). In this study, the weight w_i is defined in Eq. (7). It expresses the pollution of one of all water quality parameters in a river section based on water quality criteria categories. The significance of w_i is that the more serious pollution, the greater value of w_i , and vice versa. The value of w_i in Eq. (7) is subject to the requirements in Eq. (8). Equation 8 is the process of normalization, i.e. the total pollution of all pollutants in river is seen as “1”, so the pollution degree of each pollutant is w_i .

$$w_i = \frac{X_i / \left(\frac{1}{m} \sum_{j=1}^m S_{ij} \right)}{\sum_{i=1}^n \left[X_i / \left(\frac{1}{m} \sum_{j=1}^m S_{ij} \right) \right]} \quad (7)$$

where, $\frac{1}{m} \sum_{j=1}^m S_{ij}$ is arithmetic mean of m evaluation criteria categories of the i^{th} water quality parameter.

$$\sum_{i=1}^n w_i = 1 \quad (8)$$

Step 5: Use the fuzzy algorithm to establish FSE vector B. This can be done by firstly choosing a fuzzy algorithm. It is the critical factor, which would affect the final evaluation results and determine the fuzzy algorithm of B. At present, two fuzzy composite operators (algorithm) are widely used in various resource and environmental evaluation systems, as follows:

(1) Model $M(\wedge, \vee)$

(2) Model $M(\bullet, +)$

The physical meaning of $M(\wedge, \vee)$ is to modify the original membership degree r_{ij} to $\min(w_i, r_{ij})$. The r_{ij} was adjusted with the w_i , the largest value of the r_{ij} was taken as the b_j in the end, i.e. the Eq. (9). Here, “ \vee ” and “ \wedge ” denote the supremum and the infimum operators. $M(\wedge, \vee)$ is known as the main factor decision. A fuzzy model using the $M(\wedge, \vee)$ operator will lose more information. Therefore, the overall membership degree is to consider only the grade with the most important factors while ignoring the influences of the others.

$$b_j = \vee(w_i \wedge r_{ij}) \quad (9)$$

The $M(\bullet, +)$ operator that uses a weight average to all the factors. Each factor u_i was considered in the model, which was defined as Eq. (10):

$$b_j = \sum_{i=1}^n (w_i \cdot r_{ij}) \quad (10)$$

Step 6: Calculate Fuzzy Composite Index (FSI). In this study, a new method of Fuzzy composite index was introduced, i.e. $FSI = B \cdot S$. Where, S was a vector of water quality criteria categories, as indicated in Eq. (11). It should be pointed out that the FSI calculation adopted here is more reasonable and applicable compared with the traditional FSI approach based on Expert Rating. In Expert Rating, S is obtained by expert scoring without fixed standard. The different results can be obtained depending on different experts recommended.

$$S = (1, 2, 3, 4, 5) \quad (11)$$

3. Description of the study river (Weihe River)

Baoji is the second largest city in Shaanxi province, China. It is located in the western Guanzhong plain. Its east is close to Xianyang, south meets Hanzhong while west and north approach Gansu Province. Baoji comprises 12 counties with 181.6 km from east to west and 160.0 km from south to north. The total area of Baoji is 18,196.44 km². Weihe River is the main river flowing through the Baoji from west to east. It is one of the first-level tributaries of the Yellow River. The total length of Weihe in Baoji area is 200 km, which represents about a quarter of the entire length of the Weihe River. The Weihe River is located in western Valley Basin in Baoji. It is a watershed linked mountain river and plain river. Greater change was frequently generated in river flow during the year. The runoff flow is 2.4×10⁹ m³ per year, which is 45.4% in flood season and 9.4% in winter (Li et al., 2006).

At present, increased cases and serious water pollution occur in China with the economic development. Wastewater was discharged with total volume of 1.1×10⁸ t in the urban area in 2004 (Xu et al., 2006). Because of insufficient stream flow, uneven rainfall, seasonal run-off and pollution from residential and factories, the water supply for domestic, agricultural and industrial purpose is facing a severe challenge. The development of analytical tools to assess the present and future ecological condition of water, as required in the Chinese Water Framework Directive, is highly desirable. In 2008, a two-year project to assess the Weihe River and its tributaries water quality was conducted under the financial support of local environmental protection agency. Twelve sampling locations (SL) of Weihe River and its tributaries in Baoji area were determined, which are indicated in Fig. 1.

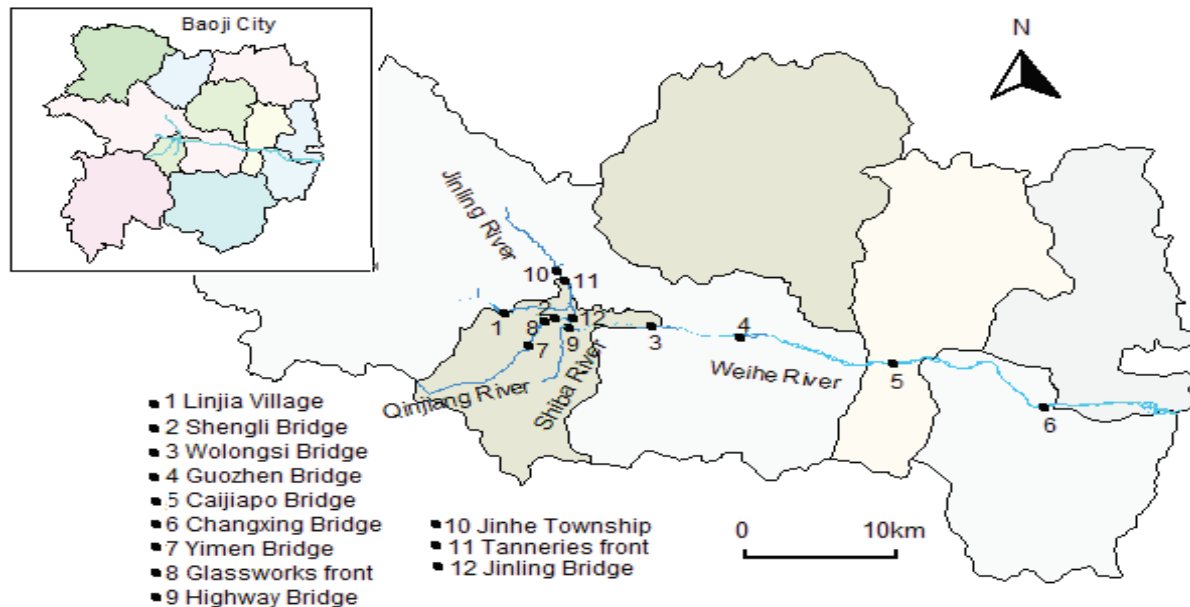


Fig. 1. Sampling locations of Weihe River and its tributaries in Baoji area

Water samples were taken once a month during the study period and seven water quality parameters of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), fluoride, ammonia, total phosphorus (TP), total nitrogen (TN) and permanganate index were monitored according to the Chinese national standard procedure (Wei et al. 2002). Selection of these seven parameters lies in the previous study, showing that these parameters represented the most serious river water quality parameters in Northwest China, a large semi-arid region. A water sample was divided into two parallel samples to determine in the laboratory. Finally, the average of two parallel samples was calculated.

4. Results and discussions

Fig. 2 and Fig. 3 present the results of Weihe River and its tributaries water quality monitoring in 2008 and 2009, respectively. Each result represents the average value of the samples of the year. It shows that one of the major parameters of BOD_5 , COD, TN and TP are high in some section while fluoride is always the lowest compared with the national standard (GB3838, 2002). Fig. 4 and Fig. 5 present the weight value of the water parameters in each section in 2008 and 2009, respectively. The weight values were obtained by Eq. (7). It clearly shows that the higher weight values are COD, TN and TP, which indicate the major pollutants of organics, TN and TP. By inspecting Fig. 4 and Fig. 5, it is clear that most of the nitrogen in Weihe River is derived from the Shiba River and the Jinling River. Relatively, the organic pollution is more serious in the Qingjiang River. It is noted in Fig. 4 and Fig. 5 that considerable change of weight values between 2008 and 2009 was observed. Weight values of BOD_5 , Fluoride and TN are greater in 2009 than in 2008 in almost all the river sections. It

indicated that these pollutants were getting worse. Weight values COD and Permanganate index are smaller in 2009 than in 2008, indicating that those pollutants were getting better. The average FSI values (expressed in one decimal place) of the 12 indices for the period 2008–2009 in each monitoring location are shown in Table 2. Water quality classification is clearly demonstrated via rounding numerical outcomes of FSE. The result is more intuitive and the water quality-dependent classification can be indicated directly (Table 2). It reflects the clear advantage of the approach in this study compared with those of comprehensive evaluation methods. Modified FSE calculation is more convenient than traditional methods of expert scoring (in FSE calculation) as a number of uncertainties can be avoided (Yi, 2010).

In order to validate the results of the modified FSE adopted in this study, comparison was made among the modified FSE and the comprehensive water quality identification index (WQII) (Xu, 2005b; Zhang and Geng, 2010) as well as the official reports (OR) transcribed from the annual reports of Baoji environmental protection agency. The results are illustrated in Fig. 6. It shows an overall profile of the water quality classification of each river sections studied. The classification is an integrated and comparative indication on water quality.

Comparative analysis based on the outputs in Yimen Bridge clearly indicates that OR presents the worst water quality situation while FSE suggests a relatively optimistic condition. Similar situations occur in most cases in Fig. 6.

OR is more strict and FSE is more tolerant, implying that outputs from FSE exhibit a mild optimistic trend compared with OR and WQII. The results generated by FSE have demonstrated an identical trend in comparison to those obtained using WQII and OR.

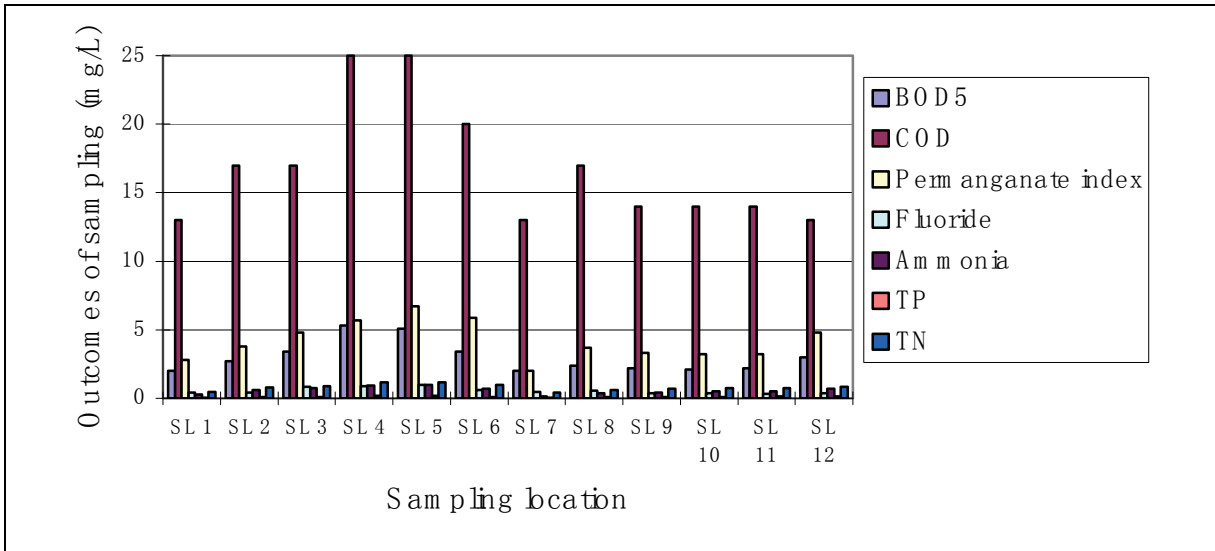


Fig. 2. The outcomes of sampling in the Weihe River and its tributaries in 2008

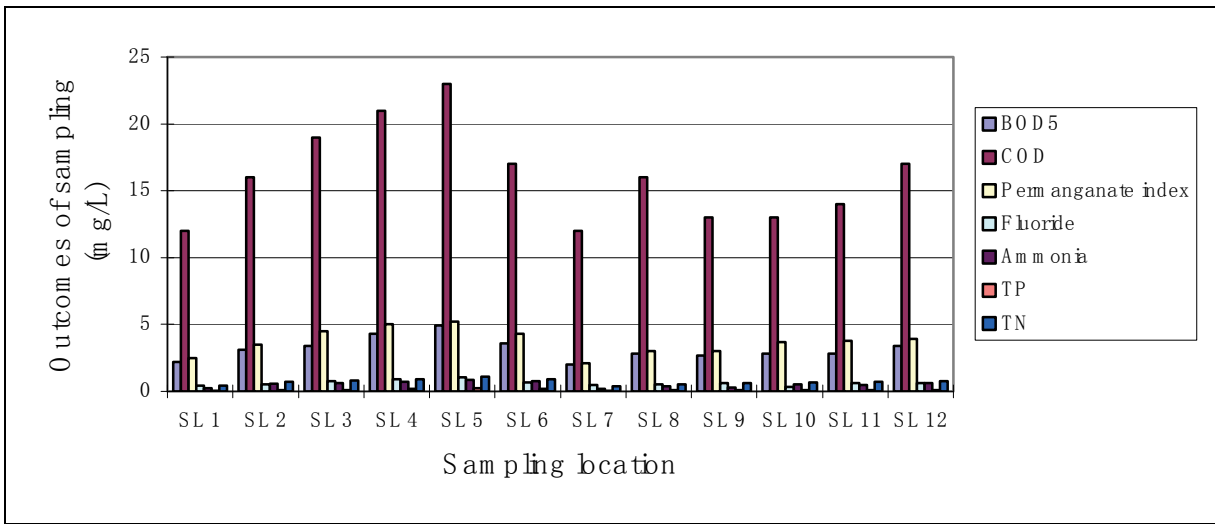


Fig. 3. The outcomes of sampling in the Weihe River and its tributaries in 2009

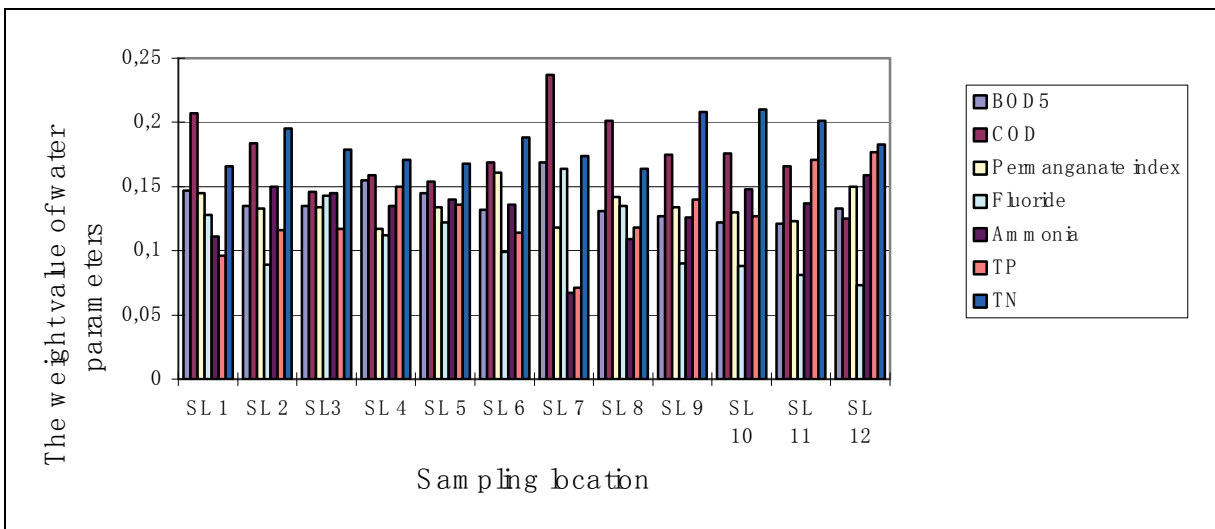


Fig. 4. The weight value of water parameters in each section of Weihe River and its tributaries in 2008

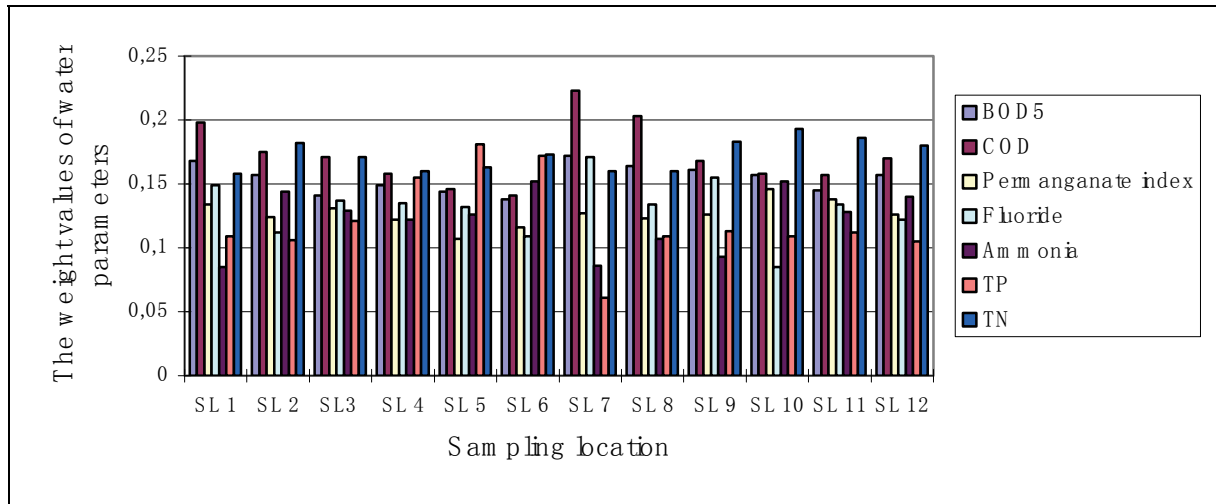


Fig. 5. The weight value of water parameters in each section of Weihe River and its tributaries in 2009

Table 2. The outcomes of water quality evaluation in each river section

Sampling location	Weihe River						Qingjiang River		Shiba River	Jinling River		
	SL 1	SL 2	SL 3	SL 4	SL 5	SL 6	SL 7	SL 8	SL 9	SL 10	SL 11	SL 12
FSI values	1.5	2.1	2.3	2.8	3.1	2.5	1.4	1.9	1.8	1.8	1.9	2.2
Water Quality Class	II	II	II	III	III	III	I	II	II	II	II	II

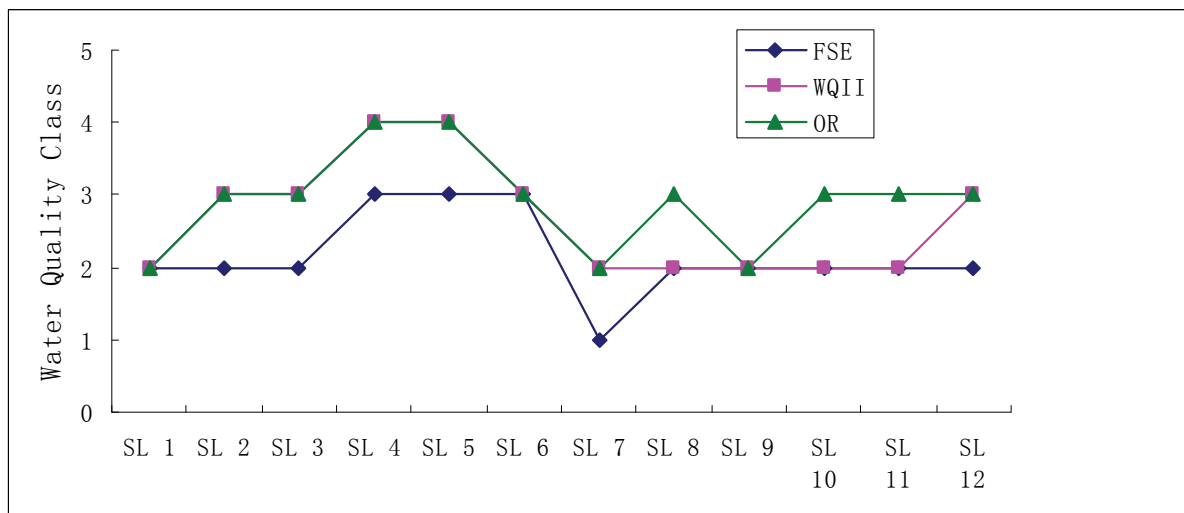


Fig. 6. Comparative outputs of water quality classification on FSE, WQII and OR

River water quality is getting worse from upstream to downstream in Baoji area. Water quality is improved due to the confluence with many small tributaries and reduction of pollution sources in Changxing Bridge as the last section.

5. Conclusions

In this study, a modified fuzzy synthetic evaluation method is applied to assess water quality in Weihe River and its tributaries. The output is more optimistic due to the effect of the consideration of each water quality parameter in the calculation process of weight values w_i . The method is more convenient to adopt than other traditional methods

that were mainly based on Expert Rating. By using the modified FSE, the water quality-depended classification can be indicated directly via the rounding numerical outcomes. The results of the water quality of Weihe River in Baoji area showed that the water quality is mainly Class II and III. The water quality is getting worse from upstream to downstream. The methodology derived from this study can be an alternative tool to be used in developing effective water management plan and assessing water quality status. It should be pointed out that due to the project funding and time limitation, large scale river trial and more extensive sampling with extended coverage of water quality parameters (such heavy metals etc) should be conducted to

further validate and improve the proposed methodology.

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References

- Astel A., (2007), Chemometrics based on fuzzy logic principles in environmental studies, *Talanta*, **72**, 1-12.
- Busscher W., Krueger E., Novak J., Kurtener D., (2007), Comparison of soil amendments to decrease high strength in SE USA coastal plain soils using fuzzy decision-making analysis, *International Agrophys*, **21**, 225-231.
- Benchea R.E., Cretescu I., Macoveanu M., (2011), Monitoring of water quality indicators for improving water resources management of Bahlui river, *Environmental Engineering and Management Journal*, **10**, 327-332.
- Chang N.B., Chen H.W., Ning S.K., (2001), Identification of river water quality using the Fuzzy Synthetic Evaluation approach, *Journal of Environmental Management*, **63**, 293-305.
- Chen S.Y., Li Y.W., (2005), Water quality evaluation based on fuzzy artificial neural network, *Advances in Water Science*, **16**, 88-91.
- Cheng C.T., Ou C.P., Chau K.W., (2002), Combining a fuzzy optimal model with a genetic algorithm to solve multi-objective rainfall-runoff model calibration, *Journal of Hydrology*, **268**, 72-86.
- Dahiya S., Singh B., Gaur S., Garg V.K., Kushwaha H.S., (2007), Analysis of groundwater quality using fuzzy synthetic evaluation, *Journal of Hazardous Materials*, **147**, 938-946.
- Debels P., Figueroa R., Urrutia R., Barra R., Niell X., (2005), Evaluation of water quality in the Chillán River (Central Chile) using physicochemical parameters and a modified Water Quality Index, *Environmental Monitoring and Assessment*, **110**, 301-322.
- Fisher B., (2003), Fuzzy environmental decision-making: applications to air pollution, *Atmospheric Environment*, **37**, 1865-1877.
- GB3838, (2002), Environmental quality standards for surface water, the State Environmental Protection Administration of China and General Administration of Quality Supervision, Inspection and Quarantine.
- Graca M.A.S., Rodrigus-Capítulo A., Ocón C., Gómez N., (2002), In situ tests for water quality assessment: a case study in Pampean rivers, *Water Research*, **36**, 4033-4040.
- Hu J.M., Liu X.T., (1999), Evaluation and analysis on soil quality changes in the Sanjiang Plain, *Scientia Geographica Sinica*, **19**, 417-421.
- Istrate M., Grigoras G., (2010), Energy consumption estimation in water distribution systems using fuzzy techniques, *Environmental Engineering and Management Journal*, **9**, 249-256.
- Lekkas T., Kolokythas G., Nikolaou A., Kostopoulou M., Kotrikla A., Gatidou G., (2004), Evaluation of the pollution of the surface waters of Greece from the priority compounds of list II, 76/464/EEC directive, and other toxic compounds, *Environment International*, **30**, 995-1007.
- Lermontov A., Yokoyama L., Lermontov M., Machado M.A.S., (2009), River quality analysis using fuzzy water quality index: Ribeira do Iguape river watershed, Brazil, *Ecological Indicators*, **9**, 1188-1197.
- Li J.Y., Shi C.W., Xu X.B., (2006), Synthesizing evaluation of Weihe River's ecologic control engineering at Baoji Section, *Bulletin of Soil and Water Conservation*, **25**, 44-47.
- Li X.M., Min M., Tan C.F., (2005), The functional assessment of agricultural ecosystems in Hubei Province, China, *Ecological Modeling*, **187**, 352-360.
- Liu L., Zhou J.Z., An X.L., Zhang Y.C., Yang L., (2010), Using fuzzy theory and information entropy for water quality assessment in Three Gorges region, China, *Expert Systems with Applications*, **37**, 2517-2521.
- Liou S.M., Lo S.L., Hu C.Y., (2003), Application of two-stage fuzzy set theory to river quality evaluation in Taiwan, *Water Research*, **37**, 1406-1416.
- Lu R.S., Lo S.L., Hu J.Y., (1999), Analysis of reservoir water quality using fuzzy synthetic evaluation, *Stochastic Environmental Research and Risk Assessment*, **13**, 327-336.
- Lumb A., Halliwell D., Shama T., (2006), Application of CCME Water Quality Index to monitor water quality. A case study of the Mackenzie River basin, Canada, *Environmental Monitoring and Assessment*, **113**, 411-429.
- Luo D.G., Wang X.J., Hou L.S., (2003), Fuzzy Synthetic Evaluation—application of Cluster Analysis Composite Model in the ground water quality assessment and Zoning, *Geography and Geo-Information Science*, **19**, 77-79.
- Mujumdar P.P., Sabhikar K., (2002), A fuzzy risk approach for seasonal water quality management of river water, *Advanced in Water Resources*, **38**, 1-9.
- Merdun H., Çinar Ö., (2010), Utilization of two artificial neural network methods in surface water quality modeling, *Environmental Engineering and Management Journal*, **9**, 413-421.
- Nasiri F., Huang G., Fuller N., (2007), Prioritizing groundwater remediation policies: a fuzzy compatibility analysis decision aid, *Journal Environmental Management*, **82**, 13-23.
- Ongley E., (1998), Modernization of water quality programs in developing countries: issues of relevancy and cost efficiency, *Water Quality International*, **Sep/Oct**, 37-42.
- Pesce S.F., Wunderlin D.A., (2000), Use of water quality indices to verify the impact of Cordoba City (Argentina) on Suqu a River, *Water Research*, **34**, 2915-2926.
- Pislaru M., Trandabat A., Avasilcai S., (2011), Neuro-fuzzy model for environmental impact assessment, *Environmental Engineering and Management Journal*, **10**, 381-386.
- Tzionas P., Ioannidou I.A., Paraskevopoulos S., (2004), A hierarchical fuzzy decision support system for the environmental rehabilitation of Lake Koronia, *Environmental Management*, **34**, 245-260.
- Ungureanu F., Lupu R.G., Stan A., Craciun I., Teodosiu C., (2010), Towards real time monitoring of water quality in river basins, *Environmental Engineering and Management Journal*, **9**, 1267-1274.
- Wang H.Y., (2002), Assessment and prediction of overall environmental quality of Zhuzhou City, Hunan Province, China, *Journal of Environmental Management*, **66**, 329-340.
- Wang W.C., Chau K.W., Cheng C.T., Qiu L., (2009), A comparison of performance of several artificial

- intelligence methods for forecasting monthly discharge time series, *Journal of Hydrology*, **374**, 294-306.
- Wei F.S., Qi W.Q., Bi T., Sun Z.G., Huang Y.R., Shen Y.W., (2002), Water and wastewater monitoring and analysis methods, 4th Edition, updated edition, *China Environmental Science Press, Beijing, China*.
- William O.D., Nria F.H., Jos L.D., Marta S., (2006), Assessing water quality in rivers with fuzzy inference systems: A case study, *Environment International*, **32**, 733-742.
- Wotawa F., Rodriguez-Roda I., Comas J., (2010), Environmental decision support systems based on models and model-based reasoning, *Environmental Engineering and Management Journal*, **9**, 189-195.
- Xu C.D., Guo J.L., Song J.L., (2006), Problem of urban water resources and its sustainable use in Baoji City, *Journal of Water Resources & Water Engineering*, **17**, 77-83.
- Xu Z.X., (2005a), Comprehensive water quality identification index for environmental quality assessment of surface water, *Journal of Tongji University (Natural science)*, **33**, 482-488.
- Xu Z.X., (2005b), Single factor water quality identification index for environmental quality assessment of surface water, *Journal of Tongji University (Natural science)*, **33**, 321-325.
- Yang S., Chu, Y., Yang X.K., Lou B.J., (2005), Application of analytic hierarchy process (AHP) in the evaluation of the geo-environmental quality in the Sanjiang Plain, *Geological Bulletin of China*, **24**, 485-490.
- Yi W., (2010), Water quality analysis and assessment of the Qianhe river in Baoji, *Henan science*, **28**, 1327-1330.
- Yilmaz I., (2007), Fuzzy evaluation of water quality classification, *Ecological Indicators*, **7**, 710-718.
- Zadeh L.A., (1965), Fuzzy sets, *Information and Control*, **1**, 338-353.
- Zhang J., Geng Y.N., (2010), Assessment for water environmental quality of main rivers in Baoji, *Journal of Water Resources & Water Engineering*, **21**, 142-144.
- Zou Z.H., Sun J.N., Ren G.P., (2005), Study and application on the entropy method for determination of weight of evaluating indicators in fuzzy synthetic evaluation for water quality assessment, *Acta Scientiae Circumstantiae*, **25**, 552-556.