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## Various inference systems for classification of water quality status: A case study.

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### ABSTRACT

Water quality is considered one of the main factors controlling health and the disease state of humans and animals. Four assessment methods (two pollution indexes and two fuzzy mathematical models) were used to understand the water quality parameter levels and characteristic accurately. Several physico-chemical parameters such as dissolved oxygen, nitrate, nitrite, phosphate, chlor, sulphure and total organic carbon were measured in Karasu River, Turkey. Water quality was assessed as class IV (heavy polluted) in A, B, C and D stations and class III (polluted) in station E with single-factor index method. It was also identified as class III (polluted) for waters in A, B, C and D stations and class II (slightly polluted) for water in station E with the comprehensive index model. Using the two fuzzy mathematical methods (single-factor deciding and weighted average models), the water quality was determined as II, II, III, III and II classes for waters in A, B, C, D and E stations, respectively. In conclusion, it can be proposed that fuzzy logic assessment methods may also be used as an alternative tool for decision-making in environmental management.

### Introduction

Karasu River is one of the most important rivers of Eastern Anatolia Region. After a certain section it is widely polluted by urban runoff and sewage water, wastes of meat enterprises, oil, sugar and cement factories (Sönmez, 2011). Therefore, its environmental monitoring and reasonable assessment should be made to help to make the right judgment and to take active measures for achieving the goal of ecological remediation of the river.

Many pollution index methods are used in evaluating water quality. Traditional water quality evaluation methods that involve upper and lower limits have two uncertainties, one of which is the use of a discontinuous form. This classification technique could cause an approach that is rough and has no certainty about the data since evaluation of concentration is equally important when the parameter is near to or far away from the limits. Additionally, each quality parameter might belong to one of the four categories. In other words, all of the parameters cannot be in a single category. The presence of various quality classes created in a single sampling area might lead to uncertainty in the quality definition of the aforementioned sampling area (Icaga, 2007). Because of this uncertainty some environmental researchers had to turn to work on fuzzy- based advanced evaluation methods. Fuzzy methods comprehensively evaluate the contributions of various pollutants according to predetermined weights, and decrease the fuzziness using membership functions (Ludwig and Tulbure, 1996; Liou et al., 2003; Liou and Lo, 2005). Fuzzy comprehensive assessment has been proved to be effective in solving

problems of fuzzy boundaries and controlling the effect of monitoring errors on assessment results (Sadiq and Husain, 2005; Shen et al., 2005; Wang and Zhou, 2008).

In this study, the monitoring and assessment work on water quality in Karasu River has been carried out. Water samples were collected from 5 different point of Karasu River and physico-chemical parameters such as dissolved oxygen (DO), nitrate ( $\text{NO}_3^-$ ), nitrite ( $\text{NO}_2^-$ ), phosphate ( $\text{PO}_4^{3-}$ ), chlor ( $\text{Cl}_2$ ), sulphure ( $\text{S}^{2-}$ ) and total organic carbon concentrations were measured for 24 months in 2010-2011. After that water quality was assessed with the index methods of Single Factor Pollution and Nemeru Comprehensive Pollution, and with the fuzzy mathematical methods of Single Factor Deciding Model and Weighted Average Model. Their advantages and disadvantages were also compared and analyzed.

### Material and methods

#### Collection and analysis of water samples

Five stations were chosen according to Water Pollution and Control Regulation from Karasu River to be used as sampling region. Stations cover a total area of 70 km starting from the region that is close to the water resource to the point where the river leaves Erzurum Plain. The regions where various industrial wastes and sewage water mixed up with the water were considered in determining stations in order to sample all regions (Figure 1).

Between January 2010 and December 2011, monthly duplicate samples from each stations were collected from the region which exemplifies the whole station using a Nansen bottle. Samples were put into polyethylene bottles after filtrating through 0.45  $\mu\text{m}$  membrane filters. Both Nansen bottle and polyethylene bottles were shaken three times with ambient water (Alam et al., 2001).

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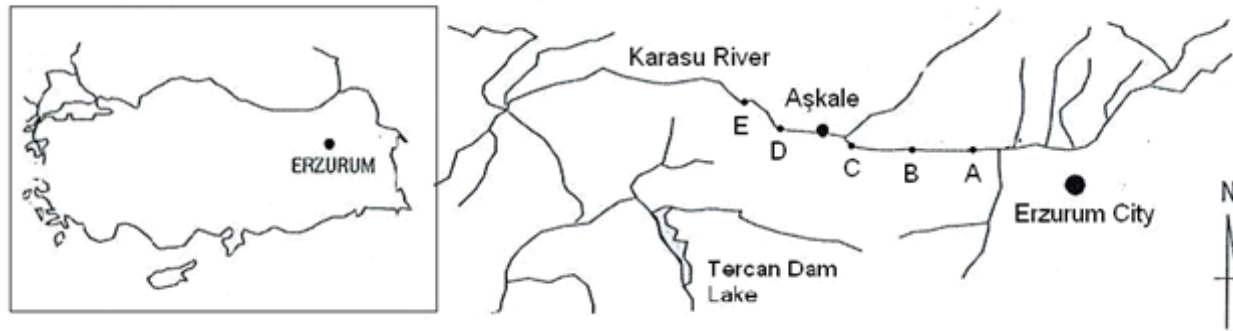


Figure 1. Sampling sites in the studied area.

Procedures for analysis of the parameters of water quality were carried out according to guidelines of Standard Methods for the Examination of Water and Wastewater (APHA, 1998). Briefly,  $\text{NO}_3^-$  and  $\text{NO}_2^-$  were analyzed by brucine and diazotization methods, respectively.  $\text{PO}_4^{3-}$  was measured by molybdate ascorbic acid method, TOC was analyzed by high temperature combustion method,  $\text{S}^{2-}$  was determined spectrophotometrically by barium sulfate turbidity method. The dissolved oxygen of each water sample were measured at the sampling points by a Oxygen meter.

**Assessment Methods**

The concentrations of the physico-chemical parameters in rivers and the variation in these concentrations according to water quality classification are presented in Table 1. Water quality is classified into four groups by taking into consideration of the evaluation criteria: Class I: clean, Class II: slightly polluted, Class III: polluted, Class IV: heavily polluted (WPCR, 2004).

Table 1. Allowable upper limit values of some physico-chemical parameters according to water quality classes

Parameters (mg/l)	Water Quality Class			
	I	II	III	IV
Dissolved oxygen	8	6	3	<3
Phosphate	0.02	0.16	0.65	>0.65
Sulphure	2	2	10	>10
Total organic carbon	5	8	12	>12
Chlor	10	10	50	>50
Nitrate	5	10	20	>20
Nitrite	0.002	0.01	0.05	>0.05
Nemero Comprehensive index (P)	$P \leq 0.7$	$0.7 < P \leq 1.3$	$1.3 < P \leq 2.0$	$P > 2.0$

**Index methods of Single factor pollution and Nemero comprehensive pollution**

The calculation of the single factor pollution index method can be expressed as:

$$P_i = C_i / S_i \tag{1}$$

and the mathematical formula for determining Nemero comprehensive pollution index is as follows:

$$P = \sqrt{\frac{\left(\frac{1}{n} \sum_{i=1}^n P_i\right)^2 + [\max(P_i)]^2}{2}} \tag{2}$$

Where,  
 $P_i$  is the pollution index of parameters,  $C_i$  is the observed real

values of parameters,  $S_i$  is the value of the river that is measured in the past (observed in 2010) and  $P$  is the Nemero multi factor pollution index.

While water pollution degree in Single factor pollution index method was accepted as the worst pollution class determined, in Nemero comprehensive pollution index it was calculated through the mathematical formula and then determined by the appropriate method (Wei-Xin et al., 2008).

**Fuzzy mathematical methods of Single Factor Deciding and Weighted Average Model**

Fuzzy evaluation method transfers the measured values to the quality values by membership functions which represent the degrees to which the specified concentration belongs to the fuzzy set. For this purpose, a membership matrix can be established by the relations of the measured data and each grade in national water quality standards.

Degree of membership of physico-chemical parameters at all levels might be expressed qualitatively by a formula series of membership functions as follows:

$$U_{i,m} = \begin{cases} 1 - U_{m-1}(C_i) & e_{m-1} \leq C_i \leq e_m \\ (e_{m+1} - C_i) / (e_{m+1} - e_m) & e_m \leq C_i \leq e_{m+1} \\ 0 & C_i \geq e_{m+1} \end{cases} \tag{3}$$

Where,  
 $U_{i,m}$  is the membership degree of parameters  $i$  at class  $m$ ,  $C_i$  is the measured value of parameters  $i$  in  $\text{mg L}^{-1}$  and  $e_m$  is the criteria value at class  $m$  in  $\text{mg L}^{-1}$ .

After the monitored data of each water quality parameter at each water station and the assessment criteria were substituted into the membership function, the fuzzy matrix was obtained for each assessed water station. For example, the fuzzy matrix of station A was expressed as:

Station A =

0.95	0.05	0	0
0	0	0	1
0	0.84	0.16	0
0	0.76	0.24	0
0	0.55	0.45	0
0.60	0.40	0	0
0	0	0	1

In this station, the calculated values were complied with class IV water quality by 100% in terms of phosphate concentration whereas

95% class I and 5% class II water quality for dissolved oxygen concentration.

The contribution to integrated environmental quality varies greatly among different water quality parameters. Therefore it is important to choose the appropriate weight for each factor. The weight of each water quality parameters at each station is allocated according to:

$$W_{ik} = \frac{C_{i,k} / A_i}{\sum_{i=1}^n C_{i,k} / A_i} \quad (4)$$

Where,

$W_{i,k}$  indicates the weight of water quality parameter  $i$  at station  $k$ ,  $C_{i,k}$  is the monitoring concentration of water quality parameter  $i$  at station  $z$  in  $mg L^{-1}$  and  $A_i$  is the average assessment criteria of water quality parameter  $i$  in  $mg L^{-1}$

Water quality of five stations were evaluated by two different fuzzy logic mathematical methods (Wei-Xin et al., 2008).

- 1-Single factor deciding model,
- 2-Weighted average model,

In order to get the evaluation set which shows the membership grade of water quality, one can multiply the weight factor by membership matrix. Calculations of single factor deciding and weighted average model are formulated as follows:

$$b_m = \max_{i=1}^n W_i \cdot u_{i,m} \quad (5)$$

$$b_m = \sum_{i=1}^n W_i \cdot u_{i,m} \quad (6)$$

Where,

$b_m$  is the membership degree of the last evaluation result at class  $m$ ,  $W_i$  indicates the weight of water quality parameter  $i$  at the assessed water,  $U_{i,m}$  is the membership degree of the water quality parameter  $i$  at class  $m$ .

## Results and Discussion

The water quality parameters data which were collected from five stations and the assessment results utilizing the index methods of pollution were shown in Table 2.

As seen in Table 2, all the stations except E were evaluated as class IV according to single factor index method. The results of this method indicate excessive protection, because only the maximum contributing factors are introduced into the single factor index method, and other factors are neglected in the assessment. Thereby, in practical assessment work, it is usually found that the factors have a fateful influence on the final assessment results obtained by the single-factor method (Chen et al., 2005).

Nemero comprehensive index method showed that only the last station's water quality was slightly polluted, the other station's water quality was polluted. Although the dominant parameter and the average contribution of all factors were both taken into account for the comprehensive index method used in the present research, a better environmental quality was not achieved as the assessment result.

The weights of the seven physico-chemical parameters in the five assessed waters in this study were achieved according to both water quality evaluation criteria and measured actual values and given in Table 3.

Prior to the application of the results to assess the water quality for the five water stations, the assessment vectors of single factor deciding model were normalized. The latest evaluation results of the two fuzzy logic mathematical methods are given in Table 4.

The two fuzzy mathematical methods shared a common environmental evaluation result for water quality parameters, assessed as classes II, II, III, III and II, respectively. However, difference of the membership degree to each pollution class still existed between the two methods (Table 4). In the single factor deciding model, the dominant factor is given more attention, and the effects of the other factors are weakened. On the other hand, in the weighted average model, the contribution of each factor is well taken into account, and the weights are allocated for the factors according to the contribution degree; therefore, the assessment results of the weighted average model are dependent on the integrated effects of all factors to a great extent (Geldermann et al., 2000).

According to the results in Tables 2 and 4, it was observed that fuzzy mathematical models were better at evaluating the results of water quality than the pollution index methods. This may result from the fact that traditional water quality regulations involve quality categories defined by sharp clusters and boundaries between different categories have an internal ambiguity (Silvert, 2000). For example, in station A, the concentration of dissolved oxygen was 7.88

Table 2. Water quality evaluation results for five water stations using single factor and Nemero comprehensive index methods.

Stations	Index	Water Parameters							Water Quality	
		DO	NO <sub>3</sub> <sup>-</sup>	NO <sub>2</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>	S <sup>2-</sup>	TOC	Cl <sub>2</sub>	Single Factor Index	Comprehensive Index
A	C <sub>i</sub> mean	7.88	7.02	0.16	1.49	3.73	8.48	18.84	IV	(P=1.48)
	C <sub>i</sub> -Std	0.53	2.2	0.33	1.5	1.35	3.89	11.88		
	P <sub>i</sub>	0.87	1.71	1.29	1.08	1.79	1.77	0.83		
	Class	II	II	IV	IV	III	III	III		
B	C <sub>i</sub> mean	6.58	11	0.2	1.73	4.62	10.05	25.96	IV	(P=1.54)
	C <sub>i</sub> -Std	0.29	2.37	0.35	0.45	1.94	4.8	11.04		
	P <sub>i</sub>	0.88	0.82	0.31	1.51	1.58	1.93	1.12		
	Class	II	III	IV	IV	III	III	III		
C	C <sub>i</sub> mean	4.1	18.28	0.34	1.66	4.98	11.21	29.96	IV	(P=1.33)
	C <sub>i</sub> -Std	0.29	5.84	0.34	1.02	2.11	5.89	12.79		
	P <sub>i</sub>	0.78	0.9	0.53	0.8	1.31	1.63	1.03		
	Class	III	III	IV	IV	III	III	III		
D	C <sub>i</sub> mean	3.68	20.44	0.24	2.7	4.95	12.58	35.04	IV	(P=1.46)
	C <sub>i</sub> -Std	0.1	6.02	0.36	2.43	2.62	6.83	15.69		
	P <sub>i</sub>	0.84	0.93	0.35	0.78	1.19	1.83	1.02		
	Class	III	IV	IV	IV	III	IV	III		
E	C <sub>i</sub> mean	8.76	5.7	0.002	0.63	2.18	4.18	11.98	III	(P=1.28)
	C <sub>i</sub> -Std	0.31	1.61	0.002	0.16	0.58	1.56	3.73		
	P <sub>i</sub>	0.93	1.35	0.01	1.03	1.12	1.55	0.8		
	Class	I	II	I	III	III	I	III		

\*P<sub>i</sub> is the pollution index of physico-chemical parameters  $i$ ; C<sub>i</sub> mean represents the average value of physico-chemical parameter  $i$  concentration in  $mg L^{-1}$ ; C<sub>i</sub>-Std indicates the standard deviation of physico-chemical parameter  $i$  concentration in  $mg L^{-1}$ .

Table 3. Weights of physico-chemical parameters in the assessed waters

Stations	DO	NO <sub>3</sub> <sup>-</sup>	NO <sub>2</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>	S <sup>2-</sup>	TOC	Cl <sub>2</sub>
A	0.1	0.09	0.17	0.21	0.15	0.16	0.14
B	0.1	0.13	0.16	0.2	0.13	0.15	0.13
C	0.14	0.12	0.17	0.17	0.13	0.14	0.13
D	0.12	0.15	0.17	0.17	0.15	0.16	0.12
E	0.08	0.14	0.07	0.2	0.22	0.08	0.21

Table 4. The latest membership degree of fuzzy logic mathematical models for five water stations.

Class	Single-factor deciding model					Weighted average model				
	Stations					Stations				
	A	B	C	D	E	A	B	C	D	E
I	0.04	0.01	0	0	0.33	0.09	0.03	0	0	0.32
II	0.45	0.48	0.24	0.12	0.46	0.41	0.45	0.26	0.15	0.43
III	0.1	0.13	0.42	0.54	0.21	0.12	0.16	0.4	0.5	0.25
IV	0.41	0.38	0.34	0.34	0	0.38	0.36	0.34	0.35	0
Water quality	II	II	III	III	II	II	II	III	III	II

mg L<sup>-1</sup>, and the two closest environmental criteria values were 8 (class I) and 6 mg L<sup>-1</sup> (class II). It is self-evident that the number 7.88 is closer to 8 than to 6, but using the pollution index method, the environmental quality of station A was determined as class II in terms of dissolved oxygen. In fuzzy methods, fuzziness logic makes it difficult to justify the use of criteria's sharp boundaries. Membership functions were employed to describe the limit between different pollution degrees. The membership degree of 7.88 to 8 is 0.95, and to 6 is 0.05, which demonstrates that class I, not class II is more reasonable to be assigned to the level of environmental risk according to dissolved oxygen level at station A. From this point of view, more constructive results were obtained by the use of the mathematical models depending on fuzzy logic in classification of the water quality. Hence, previous studies support the results of this study (Icaga, 2007; Duque et al., 2006; Lermontov et al., 2009; Rahana and Mujumdar, 2009).

## Conclusion

The pollution index methods define the exact limits that show the amount and the different degrees of water pollution. However there is an uncertainty in quality assessments due to the instability of each pollutant. Presence of definite boundaries in uncertainty classification diagrams complicates the use of these diagrams. In the fuzzy mathematical methods, the measured values are transferred to the quality values by membership functions which describe the limit between different pollution degrees, and different weights were allocated for the factors according to their pollution contribution. Therefore, compared with the present methods, fuzzy mathematical models were more reasonable for water quality assessment owing to the introduction of membership degree and weight of each factor to the models.

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