IJST, Transactions of Civil and Environmental Engineering, Vol. 35, No. C1, pp 131-136
Printed in The Islamic Republic of Iran, 2011
© Shiraz University

"Research Note"

A FUZZY INDUSTRIAL WATER QUALITY INDEX: CASE STUDY OF ZAYANDEHRUD RIVER SYSTEM*

F. SOROUSH[1], S. F. MOUSAVI[1**] AND A. GHARECHAHI[2]

[1]College of Agriculture, Isfahan University of Technology, Isfahan 84156-83111, I. R. of Iran
Email: mousavi@cc.iut.ac.ir
[2]Central Laboratory, Water & Wastewater Co., Isfahan, I. R. of Iran

Abstract– Fuzzy logic provides an effective tool for classifying water quality in a river system based on limited observations. In this study, a fuzzy index (range of 0-100) is proposed for evaluation of water quality for industrial uses. Fuzzy inference system makes it possible to combine the certainty levels for the acceptability of water based on a prescribed limit of various regulatory bodies' quality classes and expert opinions. Application of the proposed fuzzy index is demonstrated with a case study for the Zayandehrud River, located in Isfahan province, Iran. A data set on nine sampling stations along this river was used. Water quality was evaluated for industrial purposes by means of six parameters (pH, TH, TA, SO_4^{2-}, Cl^- and TDS). The results showed that during the study period, the water quality of the river was suitable for some industrial purposes except in Varzaneh. In this station, Zayandehrud receives wastewater of some small industries and agricultural lands. The water quality degraded from Pole Kalleh (index value of 90) to Varzaneh (index value of 15) in the winter months. In the summer months, the index was variable for these two stations. The proposed approach exhibits a convenient tool for continuous monitoring of river water for industrial purposes.

Keywords– Water quality index, fuzzy logic, water quality classification

Archive of SID

1. INTRODUCTION

Availability of fresh and clean water for human consumption is one of todays most important issues. Classification of water resources to satisfy water quality standards is an important issue in this respect. Environmental protection agencies have defined comprehensive sets of indicators to monitor water quality. In Iran, the Ministry of Energy has defined "Guidelines for quality classification" and has classified waters in four groups for industrial uses. However, water resources with the first and second group quality are scarce. Thus, standards have been defined for the third and fourth groups of industrial uses [1].

Traditional reports on water quality tend to present data on individual substances, without providing a whole picture of water quality. To resolve this gap, various indices have been developed to integrate water quality variables [2]. The first Water Quality Index (WQI) was developed in the United States by Horton [3] and has been applied in Europe since the 1970s [4]. This methodology was developed by USEPA [5].

However, discrepancies on WQI frequently arise from lack of clear distinctions between each water utilization mode, uncertainty in the quality criteria employed, and the vagueness or fuzziness embedded in the decision-making output values [6]. In classification schemes, fuzziness makes the use of sharp boundaries hard to justify. A small increase/decrease in pollutant data, near its boundary value, will change its class.

*Received by the editors October 26, 2008; Accepted June 8, 2010.
**Corresponding author

www.SID.ir

The fuzzy set theory was introduced by Zadeh [7]. In a few recent studies, imprecision in water quality management problems has also been modeled using fuzzy sets. Tung and Hathhorn [8] considered the waste load allocation for water quality management of a river system as a fuzzy optimization problem. Chang *et al.* [6] assessed water quality conditions using three fuzzy synthetic evaluation techniques. The findings indicated that these techniques may successfully harmonize inherent discrepancies and interpret complex conditions. Ocampo-Duque *et al.* [9] proposed a water quality index for the Ebro River, Spain, based on fuzzy inference systems (FIS). Tabesh and Dini [10] used fuzzy models for short-term water demand forecasting for Tehran.

In the present study, fuzzy logic was used to assess water quality by developing a water quality index. Keeping the importance of uncertainty in industrial water quality assessment and versatility of the fuzzy set theory, an attempt is made to classify the water quality of the Zayandehrud River for industrial uses.

2. MATERIALS AND METHODS

Water samples were collected and analyzed by Isfahan Water Authority in several stations located along the Zayandehrud River, Isfahan, Iran. The results were taken for the fuzzy interference system (FIS) model to assess the water quality using 6 parameters, viz., pH, total dissolved solids (TDS), total alkalinity (TA), total hardness (TH), chloride (Cl^-) and sulphate (SO_4^{2-}). Though there are other parameters in industrial water quality guidelines, we have limited the assessment to these six parameters.

Ranges for fuzzy sets were based on the guidelines of the Ministry of Energy [1]. This guideline has been defined for the third and fourth groups of industrial uses. The ranges are shown in Table 1. Column (A) of this table shows the permitted limits for industrial processes that need high quality water. Column (B) illustrates standards for processes not very sensitive to water quality. Column (C) presents waters that have low quality for industrial uses [1].

Table 1. Selected water quality variables for industrial uses and their limits [1]

Parameter	A Group	B Group	C Group
pH	6-9	6-9	6-9
TH (mg L^{-1})	< 250	< 500	> 500
TA (mg L^{-1})	< 150	< 500	> 500
SO_4^{2-} (mg L^{-1})	< 250	< 500	> 500
TDS (mg L^{-1})	< 500	< 1000	> 1000
Cl^- (mg L^{-1})	< 200	< 500	> 500

a) Fuzzy set theory

Fuzzy set theory has been designed to supplement the interpretation of linguistic or measured uncertainties for real-world random phenomena. Fuzzy set theory may be regarded as a generalization of classical set theory. In classical set theory the membership function of a set is 1 within the boundaries of the set and is 0 outside. A fuzzy set is defined in terms of a membership function which maps the domain of interest onto the interval (0,1) [11]. Symbol μ has been used to represent fuzzy memberships. If x represents the value of an environmental variable, then $\mu(x)$ is the corresponding membership. Fuzzy method utilizes the max-min operator to perform the FIS [7]. The standard fuzzy set operations are: union (OR), intersection (AND) and additive complement (NOT).

These steps are explained with the following example, in which the aim is to assign a water quality score using just two variables: chloride (Cl) and total dissolved solids (TDS) managed within a FIS. A few sample rules are designed to recognize what is happening in a FIS. In this example, we have chosen "good", "average", and "bad" fuzzy sets for inputs, and "bad", "average", and "good" fuzzy sets for the output. Trapezoidal membership functions define these fuzzy sets (Fig. 1). In fuzzy language, it could be expressed as follows:

Archive of SID
www.SID.ir

Rule 1: If (Cl is good) and (TDS is bad) Then (quality is average)
Rule 2: If (Cl is average) and (TDS is average) Then (quality is average)
Rule 3: If (Cl is bad) and (TDS is good) Then (quality is average)

The process of formulating the mapping from a given input to an output was implemented with Mamdani's fuzzy inference method. Since decisions are based on testing all the rules in a FIS, the rules must be combined in some manner. Aggregation is the process by which the fuzzy sets are combined into a single fuzzy set.

The final step is defuzzification. The input for the defuzzification process is the aggregate output fuzzy set and the output is a single number for each variable. However, the aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified [12]. In this study, we used 'centroid method' to defuzzify outputs.

b) Fuzzy industrial water quality index (FIWQI)

A water sample may have hundreds of constituents. One needs to choose a set of parameters which, together, reflect the overall water quality. Six parameters were used from the industrial water quality table and these 6 parameters were divided into three categories in the FIS approach, on the basis of experts' opinion as follows:
First group: pH; Second group: Total hardness (TH), Total alkalinity (TA) and sulphates (SO_4^{2-}), and third group: Total dissolved solid (TDS) and Chloride (Cl^-).

Archive of SID

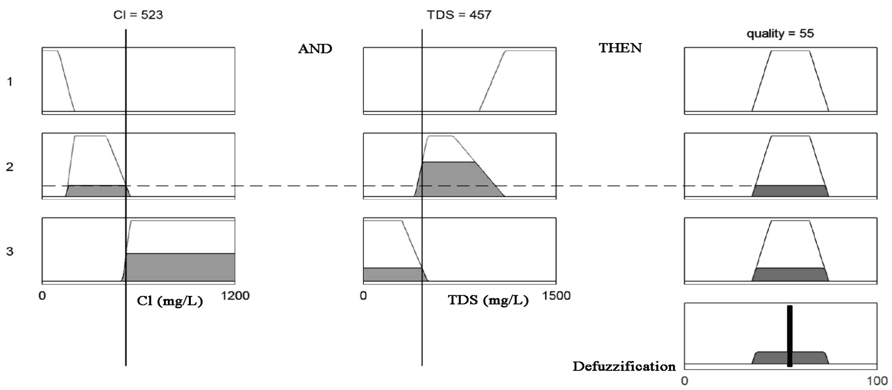

Fig. 1. Schematic of fuzzy inference for the water quality

All membership functions were defined in trapezoidal shape on the basis of an expert's perception. The fuzzy sets of 'bad', 'average' and 'good' were chosen for the inputs (Table 2) and 'bad', 'average', 'good' and 'excellent' fuzzy sets for the output (Fig. 2). The membership function of pH was different and it is shown in Fig. 3. The prescribed limits for the fuzzy model to classify the industrial water quality are shown in Table 2. A total of 73 rules based on the industrial water quality expert perception were designed.

Table 2. The limits of membership functions

Class	Parameter	Good			Average				Bad			Range
		a=b	c	d	a	b	c	d	a	b	c=d	
Second	TH (mg L^{-1})	0	150	200	150	200	400	500	450	550	2000	0-2000
	TA (mg L^{-1})	0	100	150	100	150	400	550	450	550	1500	0-1500
	SO_4 (mg L^{-1})	0	100	250	200	250	400	550	450	550	1500	0-1500
Third	TDS (mg L^{-1})	0	300	500	400	500	700	1100	900	1100	20000	0-20000
	Cl (mg L^{-1})	0	100	200	150	200	400	550	500	550	1200	0-1200

www.SID.ir

The fuzzy industrial water quality index ranges from zero to 100. Water quality changes this index. Figure 2 shows how the quality of water changes with this index value.

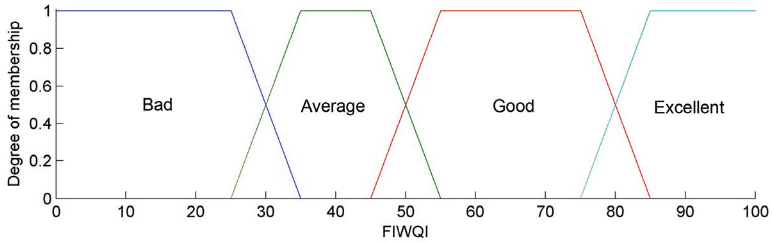

Fig. 2. Membership functions for FIWQI

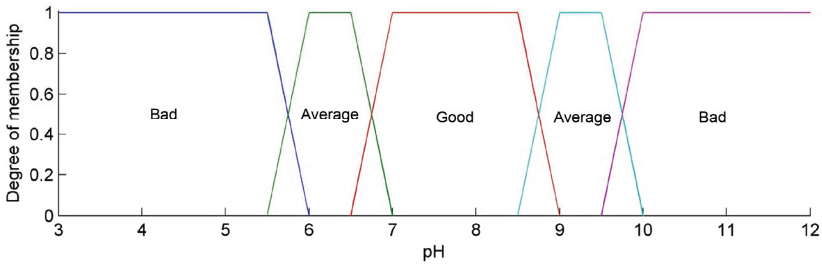

Fig. 3. Membership functions for pH

c) Case study

The Zayandehrud basin is located in the central part of Iran, with geographical coordinates of 50º 24' to 53º 24' east longitude and 31º 11' to 33º 42' north latitude, an area of 41,500 km^2 and altitude of 1466 to 3974 m. The Zayandehrud River starts in the Zagros mountains and travels about 400 km eastward before ending in the Gavkhouni swamp, southeast of Isfahan city. Pollution of the Zayandehrud River due to increasing water withdrawals from and wastewater discharges into this river has decreased its water quality for many purposes. There are some big chemical industries in the riparian zone and their water demands are provided from the Zayandehrud River [13]. Figure 4 illustrates the location of the water sampling stations in the study area. The fuzzy index was applied to assess the industrial water quality of the Zayandehrud River during different months of the year 2006. The water quality of nine stations (1- Ghaleh Shahrokh, 2- Sadde Tanzimi, 3- Pole Zamankhan, 4- Pole Kalleh, 5- Dizicheh, 6- Lenj, 7- Moosian, 8- Pole Choom, 9- Varzaneh) was evaluated.

Archive of S

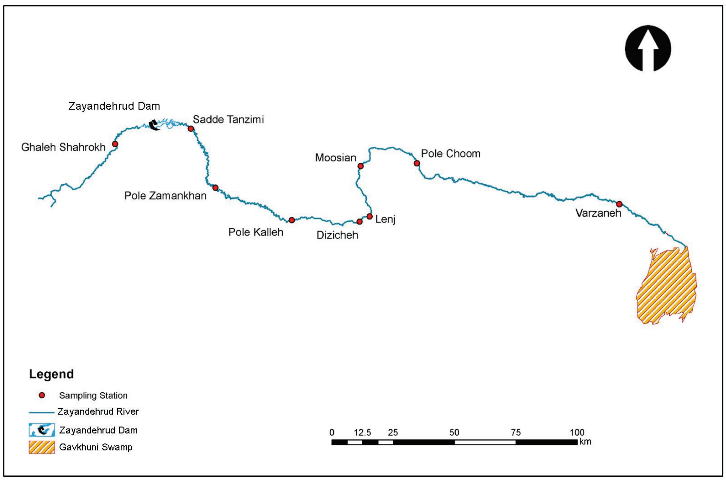

Fig. 4. Map of the sampling site locations

www.SID.ir

3. RESULTS AND DISCUSSION

The results for the FIWQI calculated according to the FIS are shown in Figs. 5 and 6. Figure 5 presents changes in the water quality of the Zayandehrud River from October to March. According to FIWQI values, water quality along the river did not change from Ghaleh Shahrokh to Pole Kalleh during the period from October to January. Varzaneh has a low FIWQI and it seems that river water is suitable for the processes that were mentioned in column C of Table 1. In November, FIWQI has an abrupt decrease in Dizicheh, an increase in Lenj and Mossian and then the index decreased. The index value in December was the same as in October and it was the same in all stations except in Varzaneh. In January, February and March, FWQI reduced after Pole Kalleh as the water quality of the river was suitable for processes that were mentioned for column B of Table 1. In this region, a major part of the applied agricultural water is returned to the river by drainage and return flows. Also, Zarinshahr drainage and Isfahan's abattoir discharge into the river. The river flow rates decline in these months of the year and so the assimilative capacity of the river decreases [14].

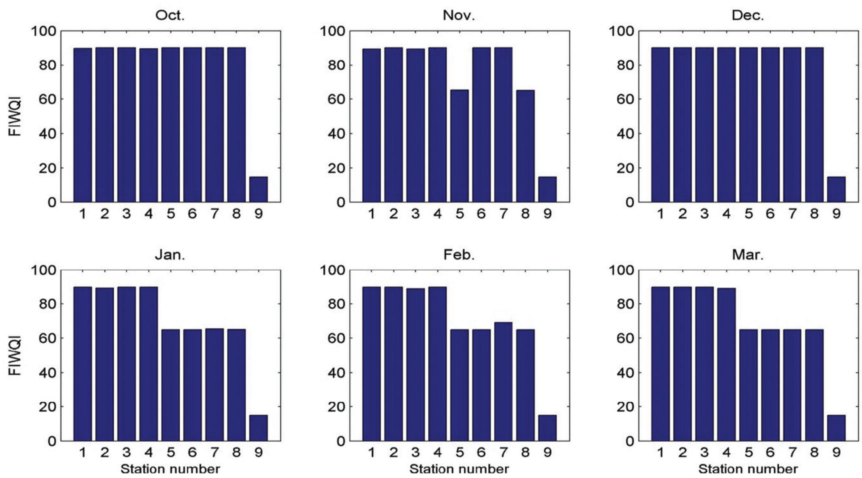

Fig. 5. Fuzzy industrial water quality index in October until March for nine sampling points (1- Ghaleh Shahrokh, 2- Sadde Tanzimi, 3- Pole Zamankhan, 4- Pole Kalleh, 5- Dizicheh, 6- Lenj, 7- Moosian, 8- Pole Choom, 9- Varzaneh) along the Zayandehrud River.

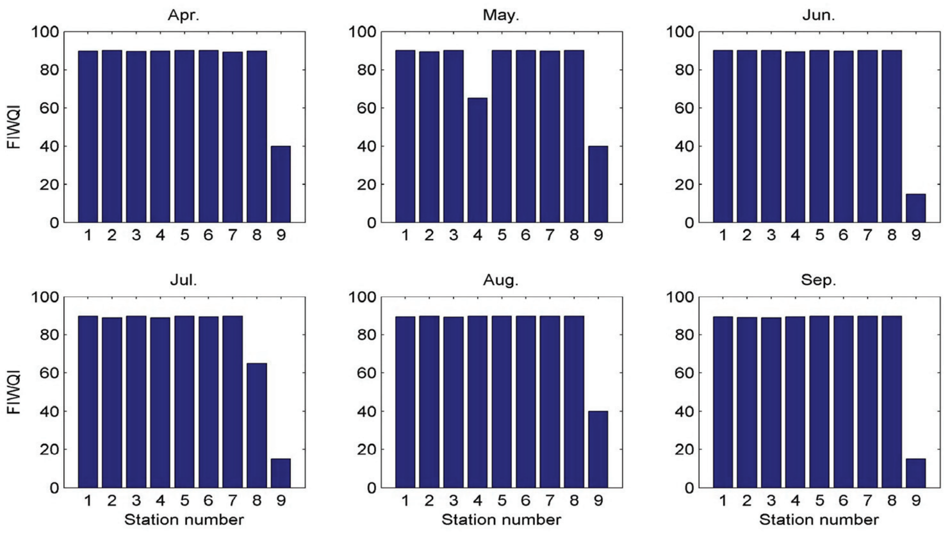

Fig. 6. Fuzzy industrial water quality index in April until September for nine sampling stations. Station numbers are similar to Fig. 5

www.SID.ir

In April, June, August and September, FIWQI was the same in all sampling sites except in Varzaneh (Fig. 6). This index was in the range of 80-100 and it was appropriate for some industries. In May, FIWQI decreased in Pole Kalleh and in July it decreased in Pole Choom.

4. CONCLUSION

A fuzzy index is proposed for the evaluation of water quality for industrial uses. Water quality changes this index. Application of this index is demonstrated for the Zayandehrud River. A data set on nine sampling stations along this river was used. Water quality was evaluated by means of six parameters (pH, TH, TA, SO_4^{2-}, Cl^- and TDS). The results showed that during the study period, the water quality of the river was suitable for some industrial purposes, except in the Varzaneh station. In this paper, a classification model was presented with a simple fuzzy framework that can be applied to resolve uncertainty problems (such as incompatible judgments) in standards for water quality issues.

REFERENCES

1. Office of Standards and Technical Criteria of Iran. (2007). Guidelines for quality classification of raw water, effluent, and reused water for industrial and recreational uses. Available at: www.wrm.ir/standard/Publications/v-estview.asp?ID=337.
2. Silvert, W. (2000). Fuzzy indices of environmental conditions. *Ecological Modelling,* Vol. 130, pp. 111–119.
3. Horton, R. K. (1965). An index number system for rating water quality. *Journal of Water Pollution Control Fed.* Vol. 37, pp. 300-305.
4. Bordalo, A. A., Nilsumranchit, W. & Chalermwat, K. (2001). Water quality and uses of Bangpakong River (eastern Thailand). *Water Res.*, Vol. 35, No. 15, pp. 3635–3642.
5. Ott, W. R. (1978). Water quality indices: A survey of indices used in the United States. EPA-600/4-78-005, US Environmental Protection Agency, Washington, DC, 128 p.
6. Chang, N. B., Chen, H. W. & Ning, S. K. (2001). Identification of river water quality using the fuzzy synthetic evaluation approach. *Journal of Environ. Manage.,* Vol. 63, pp. 293–305.
7. Zadeh, L. A. (1965). Fuzzy sets. *Inform. Control*, Vol. 8, pp. 338–353.
8. Tung, Y. K. & Hathhorn, W. E. (1989). Multi-objective waste load allocation. *Water Resour. Manage.,* Vol. 3, pp. 129–140.
9. Ocampo-Duque, W., Ferré-Huguet, N., Schuhmacher, M. & Domingo, J. L. (2006). Assessing water quality in rivers with fuzzy inference systems: A case study. *Environment International,* Vol. 32, pp. 732–742.
10. Tabesh, M. & Dini, M. (2009). Fuzzy and neuro-fuzzy models for short-term water demand forecasting in Tehran. *Iranian Journal of Science & Technology, Transaction B: Engineeing*, Vol. 33, No. B1, pp. 61-77.
11. 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,* Vol. 147, No. 3, pp. 938–946.
12. Fuzzy Logic Toolbox User's Guide. Copyright 1995–2008, The MathWorks, Inc. Available at: www.mathworks.com/access/helpdesk/help/pdf_doc/fuzzy/fuzzy.pdf.
13. Zayandehrud River. Available at: http://en.wikipedia.org/wiki/Zayandeh_River.
14. Healthy Life. (2006). Zayandehrud will be monitored. *Sociomedical Journal*, December. http://www.zendegisalem.ir/Journal/Show_Items_Desc.aspx.

Archive of SID

www.SID.ir