Research Article
Open Access

Fuzzy Logic Inference Index to Assess the Water Quality of Tigris River within Baghdad City

Salam Hussein Ewaid[1*], Turki Diwan Hussein[1], Faiza Kadhim Emran[2]
[1]*Technical Institute of Shatra, Southern Technical University, Iraq*
[2]*Dept. of Biology, College of Science, University of Baghdad, Iraq*
**Correspondent author email: salamalhelali@stu.edu.iq*

ArticleInfo

Received
03/10/2018

Accepted
16/10/2018

Published
10/03/2019

Abstract
This study aimed to develop a new water quality index for routine assessment of the river water quality for drinking purpose based on fuzzy logic artificial intelligence method. Four water quality parameters were involved in light of their significance to Iraqi waters, these parameters are biological oxygen demand, and total dissolved solids, total hardness, and fecal coliform. Fuzzy logic inference system with specific rules was developed by Matlab software using Mamdani fuzzy logic Max–Min inference system method. To evaluate the performance of this new fuzzy water quality index (FWQI), tests were conducted using the Iraqi standards for drinking water quality and the 2017 data set of Tigris River within Baghdad. Results revealed the FWQI ability to assess the water quality of Tigris River during the period of the study and that the method of fuzzy inference system was a simple, valuable and applied water quality evaluation tool for human drinking water of Iraqi rivers.

Keywords: Water quality index, Iraqi Rivers, Fuzzy logic.

الخلاصة
هدفت هذه الدراسة إلى تطوير مؤشر جديد لجودة المياه من أجل التقييم الروتيني لجودة مياه الأنهار لأغراض الشرب على أساس طريقة الذكاء الاصطناعي المنطقي. أستعملت أربعة من متغيرات جودة المياه في ضوء أهميتها للمياه العراقية ، وهذه المتغيرات هي الطلب البيولوجي للأوكسجين ، المواد الصلبة الذائبة الكلية ، العسرة الكلية ، والبكتريا القولونية البرازية. تم تطوير قواعد خاصة لنظام أستدلال المنطق الضبابي بواسطة برنامج ماتلاب وبطريقة نظام الاستدلال المنطقي ممداني للحد الأقصى- الأدنى. ولغرض تقييم أداء هذا الدليل الجديد لجودة المياه ، أجريت أختبارات باستخدام المعايير العراقية لجودة مياه الشرب ومجموعة بيانات جودة المياه لعام ٢٠١٧ لنهر دجلة داخل بغداد. وكشفت النتائج عن قدرة الدليل المقترح على تقييم جودة مياه نهر دجلة خلال فترة الدراسة ، وأن طريقة نظام أستدلال المنطق الضبابي كانت أداة عملية وبسيطة يمكن الاعتماد عليها لتقييم نوعية المياه لغرض الشرب في الأنهار العراقية.

Introduction

The quantity, accessibility, and quality of the potable water are a standout among the essential ecological, political and social concerns at the worldwide level. Qualitative decision-making about water quality based on the available statistics during monitoring is a test for hydrologists and ecologists as each progression from the sampling phase to laboratory examination has vulnerabilities and doubts [1].

Rivers are confined stream systems passing on a basic stack of particulate and dissolved matter from both anthropogenic and natural sources. The quality, accessibility, and measure of potable water are a champion among the greatest basic, natural, political and social subjects at a general level. Increased lack of water and drought in developing nations has influenced river water quality assessment an important subject starting late [2, 3].

Generally, the water quality reports masterminded from the study data with a highlight on individual parameters is sensible only for specialists and not for decision makers. Another basic issue in the examination of the nature of drinking water is the number of parameters deciding the quality [4]. As a rule, water specialists convey water quality grade by contrasting the individual variable with the recommended standards, but that would be excessively specialized and would not give an entire picture on drinking water quality [5]. To monitor the quality of water and to settle on qualitative and quantitative choices in view of genuine information is now a test for ecological specialists over all phases of the practice, from information gathering, storing and processing up to investigate and translation of the outcomes with instabilities aggregate along this chain [6].

To resolve this problem, much research has been done to derive models or indices of water quality, Horton, in 1965 [7] developed a spearheading endeavor to depict the first water quality index which then was further enhanced by many other researchers [5].

Water quality index is a mathematical scientific tool to incorporate the intricate water quality information into a mathematical result that depicts the general water quality status [8]. The complexities and limitations of the assessment models, and in addition the approximations required in the conventional techniques accustomed develop the indices of water quality, persuaded the improvement of a more propelled assessment technique, equipped for coordinating and representing the incorrect, dubious, subjective and fuzzy data that frequently encompasses water quality. Conclusion, there is a clear necessity for more propelled methods to evaluate the significance of water quality factors and to incorporate the distinct parameters included [9].

The uses of artificial intelligence methods like fuzzy logic and artificial neural networks have been utilized to change over human experience by computers into a type of defensible and this intelligence has to turn into a tool for modeling water quality [10].

Fuzzy logic gives an intense and helpful form for categorizing ecological situations and for depicting both anthropogenic and natural fluctuations. While conventional indices are constructed both in light of crisp sets with intermittent limits among them and on constant factors whose scores are just important to specialists, fuzzy logic sets make it conceivable to consolidate these methodologies, can be utilized to characterize, evaluate environmental impacts of a particular sort and it even gives formalism for managing lost information [11].

There are many studies used fuzzy logic inference system (FLIS) tool to predict the water quality of rivers [12, 13, 14, 15, 16, and 17]. It is recommended that fuzzy methods ought to be applied to take care of with the doubts in the policymaking on the drinking water quality, the current research is an attempt to classify the water of Tigris River within Baghdad for drinking purposes by developing a new water quality fuzzy logic index and to be used for the rest of the rivers in Iraq.

Materials and Methodologies

Tigris River is 1850 km long; stems in the mountains of eastern Turkey then go south and enter the land of Iraq from the north to the south to be the main source of water dividing the urban zone of Baghdad, the Iraqi capital into two sides for about 50 km [18].

Baghdad Water Authority conducts periodic surveys as a part of the continuous monitoring program of the Tigris River water, where raw water samples are collected near the purification plants and examined in their laboratories. In this study, the data of the 4 parameters included were obtained from the Baghdad Water Authority for the year 2017.

The fuzzy logic inference system (FLIS) is a rule-based system where fuzzy logic is utilized as a tool to represent the various types of knowledge about the issue and modeling compound structures in the imprecise uncertain situation [11] (Figure 1).

The FLIS is the way toward figuring the mapping from the input to the output utilizing fuzzy logic to give a base for decisions made. The FLIS procedure includes 3 critical ideas: inference rules, fuzzy set operations and membership functions (Figure 2).

The membership function is a curve that characterizes how every point in the space of input is mapped to a membership rate in the vicinity of 0 and 1. The space of the input is known as the universe of discourse and the membership rate is the output-axis [10].

Fuzzyfication unit processes the membership values estimations of each input to an understanding with the fuzzy values characterized in the database. FLIS translates the rules joined in the rule base. Finally, defuzzification changes the fuzzy output to cripes value [9].

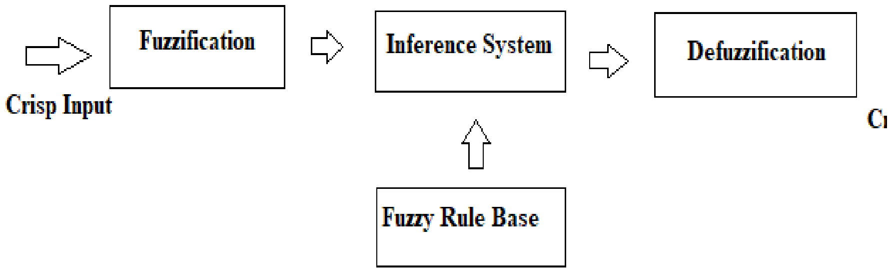


Figure 1: The components of the FLIS

The system in this study comprises of 81 rules, 4 inputs, 1 output, and is utilized for designing a fuzzy water quality index (FWQI) for Tigris and other Iraqi rivers, the output gives the drinking water quality which has 3 sorts and described by the membership functions planning the linguistic variables.

Five linguistic variables are defined, out of them, four are input variables namely biological oxygen demand (BOD), total hardness (TH), total dissolved solids (TDS), fecal coliform (FC) and the output variable is the Fuzzy Water Quality Index (FWQI)which has the ranges between 0 and 100 and without units (Figure 2).

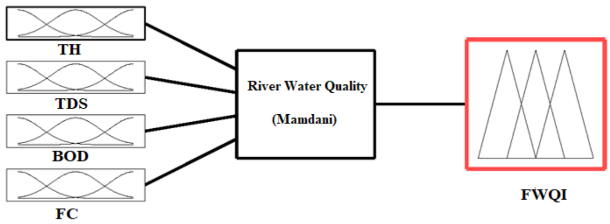


Figure 2. Membership functions of the FWQI.

Water quality can be assessed by its physicochemical and bacteriological features. In this study, the four water parameters mentioned above are used to design an easy to understand index for assessing drinking water quality and the membership functions derived from the parameters within the FLIS are shown in Figure 3.

The strength of the FLIS index depends on the type of water quality variables and a number of rules used, but increasing the number of parameters and rules make the model difficult to design [19].

Some parameters such as temperature, pH, nitrate concentration and some others are often used to design models (9, 20), but in this study, four parameters were chosen according to their importance in the Iraqi rivers [21, 22, 23]:

1- Total hardness (TH) is the measure of divalent cations (calcium, magnesium, and manganese) in water which react with the sodium soap to accelerate an insoluble deposit; it is measured as milligrams per liter of calcium carbonate. The hardness expansion can be ascribed to the decline in water volume because of evaporation at high temperature, organic substances, chlorides, detergents and other pollutants [24].
2- The total dissolved solids (TDS) consist of dissolved materials and inorganic salts, both come from anthropogenic and natural sources. Salts are comprised of cations such as Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+}, anions such as chlorides, carbonates, nitrates, and sulfates [25, 26].
3- The parameter BOD represents the amount of oxygen spent by the microbes during the breakdown of organic compounds in water. High BOD is a symptom of low water quality and high BOD is often joined by a low level of dissolved oxygen [24].
4- Fecal coliform bacteria (FC) by colony-forming unit (CFU) are an indicator organism, the presence of these bacteria is confirmed that the water has been contaminated with human or other warm-blooded creatures' feces [27, 28].

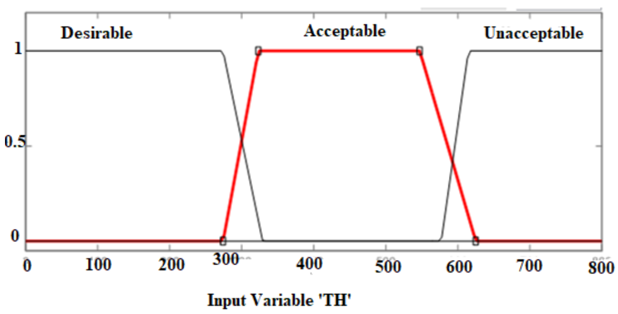
In this study, the [29] method was used to develop the FWQI model. This method is known for its simplicity and Max–Min inference. The method used is the "min" while the aggregation method is "max". The center of gravity is the defuzzification method applied to express the output. The fuzzy logic toolbox package, Matlab R2013b, [30] is the tool used for simulating the system.
The desired, acceptable and unacceptable values for the four parameters of water quality were based on the Iraqi standards [31], each parameter has 3 membership functions and the output variable (FWQI) shows the water quality by 3 classes with the range 0-100. Table 1.

Table 1. The parameters fuzzy membership grade for the three classes.

Parameter	Desirable	Acceptable	Unacceptable
TH by mg/l	≤ 325	275-625	≥ 575
TDS by mg/l	≤ 600	500-2100	≥ 1900
$BOD_5$by mg/l	≤ 4	3-6	≥ 5
FC by CFU/100 ml	≤ 500	400-600	≥ 500
FWQI without units (Output)	0-50	40-80	70-100

Results and Discussion

In the current study, every one of the four input parameters has been classified into 3 classes and defined by a trapezoidal membership function to show how points in each input variable are charted to a membership value between 0-1, the membership functions were designed as displayed in Figure 3.



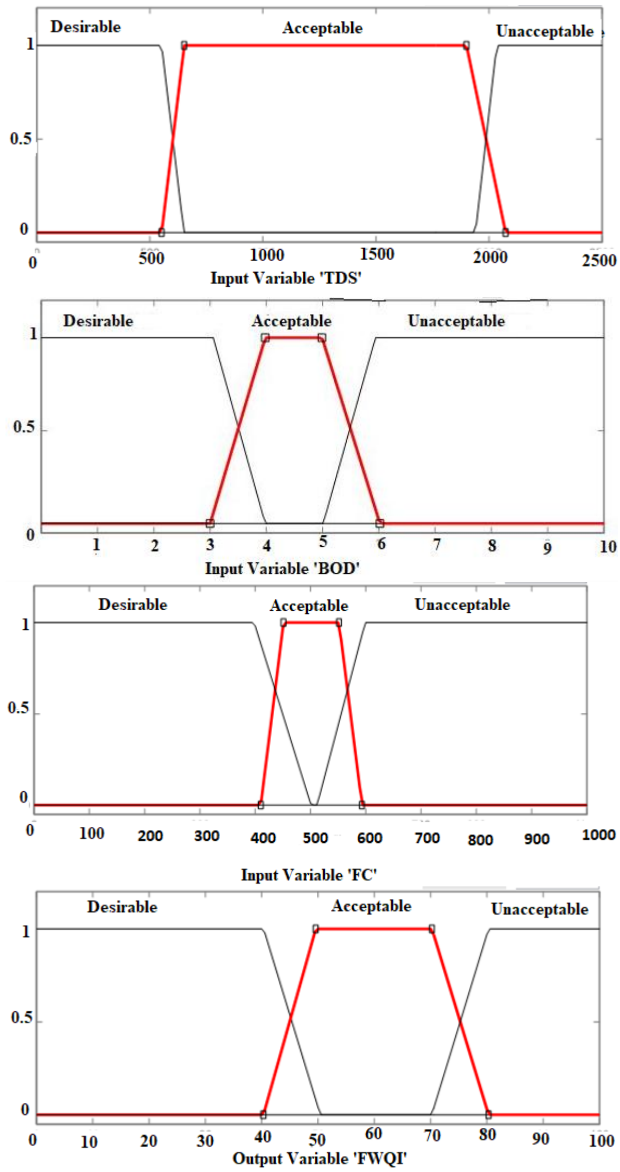


Figure3. The membership functions for the 4 input and the FWQI output.

There are three stages of utilizing FLIS to develop the FWQI: Fuzzyfication, generating the inference rules, and defuzzification the output results. The if-then is the origin of the inference rule generator, has one or more antecedents, and joined by the linguistic operator "and", with this form:

Ri: if A is xi and B is yi then C is zi

Where the input variables are *A* and *B*, the output variable is *C*. *xi*, *yi* and *zi* are linguistic values for the variables *A*, *B*, and *C* respectively. The if-part of a rule is called the antecedent, the then part of a rule is the consequent and both can have multiple parts.

Fuzzification is the process to define inputs, outputs and their membership functions that convert the mathematical value of the parameter to a membership score of the fuzzy set.

The implication method used to generate the 81 rules is the "min" and the aggregation method is "max". For example, Rule 1: If TH is desirable and TDS is acceptable, and BOD is desirable and fecal coliform is acceptable then FWQI is acceptable. Same way, other rules had been generated.

Figure 4 shows the Matlab rule viewer used in FLIS and the following figure shows the surface graph of the interaction between FC and BOD variables with the score of the water quality as an example.

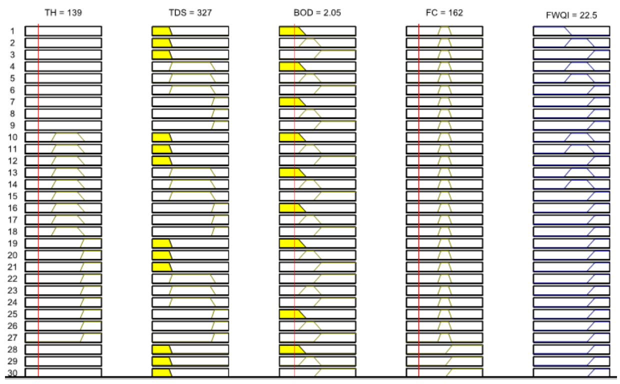


Figure4.Matlab Rule viewer showing the inputs and the output used in FLIS

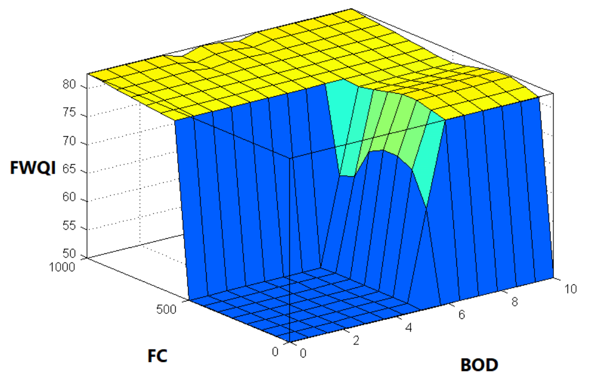


Figure 5: The surface graph of the interaction between FC and BOD and the score of the water quality.

When the rules viewer in the Matlab fuzzy logic toolbox used to enter different input values, the system gave the correct output according to the standards. For example, when the inputs were the Iraqi standards values for drinking water of the parameters TH, TDS, BOD, and FC (500, 1000, 5, 500) respectively, the FWQI was 60 indicating an acceptable value for drinking because the four parameters are within the allowed range. When the inputs were the mean of the seasonal values (winter, spring, summer, and autumn respectively) of the four parameters recorded in Tigris river water during 2017, the FWQI was 37.2, 40.7, 87.7, and 60.1 respectively indicating the desired class of water for drinking for winter and spring, the unacceptable class for summer and the accepted class for autumn. The FWQI was 87.7 during summer indicating the unacceptable class of water for drinking because the four parameters values were out of the allowed range, Table 2.

It is worth mentioning that the water of the river, which is acceptable according to the FWQI needs to be treated before using it for drinking since there are different components that influence the quality such as turbidity, taste, and smell.

Table 2. The FWQI values for Tigris River water.

Parameter	Winter	Spring	Summer	Autumn	Standard
TH (mg/l)	380	303	276	304	500
TDS (mg/l)	520	396	431	553	1000
BOD_5 (mg/l)	2.8	3.5	6	4.8	5
FC (CFU/100 ml)	260	350	620	450	500
FWQI unit less	37.2	40.7	87.7	60.1	60

Acknowledgment

The authors acknowledge the engineer Mrs. Jullanar Al-Sharqi the director of laboratories in the Baghdad Water Authority for support by giving the water data.

Conclusions

This research is an attempt to develop a new index named the Fuzzy Logic Water Quality Index that offers an easy illustration of the wide and compound parameters (physicochemical and biological) that rule the general quality of river water, which is planned for drinking.

On the base of their importance, four water quality parameters involving TH, TDS, BOD, and FC were assumed as the important indicator parameters to evaluate the quality of river water. The use of this index was verified by entering different input values to rules viewer of the Matlab fuzzy logic toolbox from the 2017 data set of Tigris River within Baghdad.

The FWQI is supposed to help decision makers in recording the status of water quality and examination of spatial and temporal variations. The study showed that fuzzy logic designs if used practically could be an actual instrument for future determination of Iraqi rivers water quality.

References

[1] Ewaid, S. H., & Abed, S. A. (2017). Water quality index for Al-Gharraf River, southern Iraq. *The Egyptian Journal of Aquatic Research*, *43*(2), 117-122.

[2] Ewaid, S. H. (2017). Water quality evaluation of Al-Gharraf river by two water quality indices. *Applied Water Science*, *7*(7), 3759-3765.

[3] Al-Ansari, N. (2013). Management of water resources in Iraq: perspectives and prognoses. *Engineering*, *5*(6), 667-684.

[4] Chau, K. W. (2006). A review of the integration of artificial intelligence into water quality modeling. *Marine pollution bulletin*, *52*(7), 726-733

[5] Abbasi, T., & Abbasi, S. A. (2012). *Water quality indices*. 1st Edition, eBook. Elsevier.

[6] Perrin, J. L., Salles, C., Bancon-Montigny, C., Raïs, N., Chahinian, N., Dowse, L., ... & Tournoud, M. G. (2018). Comparison of index systems for rating water quality in intermittent rivers. *Environmental monitoring and assessment*, *190*(2), 70.

[7] Horton, R.K., 1965. "An index number system for rating water quality", *J. Water Poll. Cont. Fed.*, 37(3). 300-305.

[8] Ocampo-Duque, W., Osorio, C., Piamba, C., Schuhmacher, M., & Domingo, J. L. (2013). Water quality analysis in rivers with non-parametric probability distributions and fuzzy inference systems: application to the Cauca River, Colombia. *Environment international*, *52*, 17-28.

[9] Chapra, S. C. (2008). *Surface-water-quality modeling*. Waveland Press.

[10] Ross, T. J. (2010). *Fuzzy logic with engineering applications*. 3rd Edition. John Wiley & Sons.

[11] Hamad, S. H., Schauer, J. J., Shafer, M. M., Abed Al-Raheem, E., & Satar, H. (2012). The distribution between the dissolved and the particulate forms of 49 metals across the Tigris River, Baghdad, Iraq. *The Scientific World Journal*, *2012*.

[12] Jayawardena, A. W. (2014). *Environmental and hydrological systems modeling*. CRC Press.

[13] 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*(3), 293-305.

[14] Ocampo-Duque, W., Ferre-Huguet, N., Domingo, J. L., & Schuhmacher, M. (2006). Assessing water quality in rivers with fuzzy inference systems: a case study. *Enviro. International*, *32*(6), 733-742.

[15] Semiromi, F. B., Hassani, A. H., Torabian, A., Karbassi, A. R., & Lotfi, F. H. (2011). Water quality index development using fuzzy logic: A case study of the Karoon River of Iran. *African Journal of Biotechnology*, *10*(50), 10125-10133.

[16] Al-Badaii, F., Shuhaimi-Othman, M., & Gasim, M. B. (2013). Water quality assessment of the Semenyih River, Selangor, Malaysia. *Journal of Chemistry*, *2013*.

[17] Mourhir, A., Rachidi, T., & Karim, M. (2014). River water quality index for Morocco using a fuzzy inference system. *Environmental Systems Research*, *3*(1), 21

[18] Lindang, H. U., Tarmudi, Z. H., & Jawan, A. (2017). Assessing water quality index in river basin: Fuzzy inference system approach. Malaysian Journal Geosciences (MJG) 1(1) (2017) 27-31.

[19] Icaga, Y. (2007). Fuzzy evaluation of water quality classification. *Ecological Indicators*, *7*(3), 710-718.

[20] Gharibi, H., Mahvi, A. H., Nabizadeh, R., Arabalibeik, H., Yunesian, M., & Sowlat, M. H. (2012). A novel approach to water quality assessment based on fuzzy logic. *J. of Env. Manag.*, *112*, 87-95.

[21] Alobaidy, A. H. M. J., Abid, H. S., & Maulood, B. K. (2010). Application of water quality index for assessment of Dokan lake ecosystem, Kurdistan region, Iraq. *journal of water resource and protection*, *2* (09), 792.

[22] Rabee, A. M., Abdul-Kareem, B. M., & Al-Dhamin, A. S. (2011). Seasonal variations of some ecological parameters in Tigris River water at Baghdad Region, Iraq. *J. of Water Res. and Protect.*, *3*(04), 262.

[23] Ewaid, S. H., Abed, S. A., & Kadhum, S. A. (2018). Prediction of the Tigris River water quality within Baghdad, Iraq by using water quality index and regression analysis. *Environmental Technology & Innovation 11(2018) 390-398.*

[24] Tiwari, S. (2015). Water quality parameters–A review. *International Journal of Engineering Science Invention Research and Development*, *1*(9), 319-324.

[25] Ireland, E. P. A. (2001). Parameters of water quality–interpretation and standards. *Environmental Protection Agency, Wexford*.

[26] Ewaid, S. H. (2018). Irrigation water quality of Al-Gharraf Canal, south of Iraq. In *Journal of Physics: Conference Series* (Vol. 1003, No. 1, p. 012006). IOP Publishing.

[27] Al-Bayatti, K. K., Al-Arajy, K. H., & Al-Nuaemy, S. H. (2012). Bacteriological and physicochemical studies on the Tigris River near the water purification stations within Baghdad. *J. of Env. and Public health*.

[28] Ewaid, S. H., & Abed, S. A. (2017) Water Quality Assessment of Al-Gharraf River, South of Iraq Using Multivariate Statistical Techniques. J. of Al Nahrain Univ.-Science, *5*(6), 7.

[29] Mamdani, E. H. (1976). Application of fuzzy logic to approximate reasoning using linguistic synthesis. In *Proceedings of the sixth international symposium on Multiple-valued logic* (pp. 196-202). IEEE Computer Society Press.

[30] MathWorks, I. (2013). MATLAB and Statistics Toolbox Release. *Natick, MA: The MathWorks*.

[31] Central Agency for Standardization and Quality Control (CASQC) (2009). Iraqi guidelines for drinking water, IQS: 417 2nd update.