ORIGINAL PAPER

THE EFFECT OF MICROBIOLOGICAL FACTOR ON THE EVALUATION OF WATER QUALITY USING FUZZY LOGIC

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Abstract. *In this study, it was aimed to reveal the importance of microbiological factors in water quality determination studies based on fuzzy logic and to determine the usability of management in water quality. Six critical parameters for water quality detection are included. In the study of Avsar [1], only bacteriological data were emphasized, and no information was obtained about quantitative data on water quality. It was found that fecal coliform was more effective on the changes in water quality compared to fecal coliform and temperature based fuzzy quality indexes. When the fuzzy quality values were determined, the effect of seasonal changes did not appear to be high, but the change in pH and coliform values affected the quality. This showed that water quality assessment would not be accurate without microbiological data. As a result, the proposed data can be considered accurate and reliable, so we recommend that microbiological data should be included in the evaluation of water quality determination studies. In addition, we can say that fuzzy logic technique will be a comprehensive and reliable technique in the assessment of the quality of the streams that are used in irrigation, fishing and recreational areas.*

Keywords: *Fuzzy logic; water quality; fecal coliform; microbiology.*

1. INTRODUCTION

Rivers provide a wide range of functions, particularly the conservation of biodiversity and the regulation of climate, in particular the recycling of materials. Unfortunately, human activities have a bad impact on the river ecosystem. In particular, industry, land irrigation, and recreational activities have affected both water quality and biodiversity and deepened the bad course [2]. Recreational use of inland and marine waters is increasing in many countries. Marine and freshwater reservoirs are contaminated with human and animal feces as a consequence of local and foreign tourists spending time at the waterside, beach or coastal recreational resorts [3, 4]. Fecal material is transported from the watershed surface into stream, rivers and lakes, and subsequently to the coastal environment. The transport of microorganisms is controlled by the flow of water, and the presence of fecal derived opportunistic pathogen and/or pathogenic microorganisms in this water is the causative agent of several infectious diseases [5]. *E. coli* have traditionally been used to monitor water quality. Total coliforms and fecal coliforms can also be used as an alternative test in many circumstances. *E. coli* is present in large numbers in the normal intestinal flora, where it generally causes no harm; however, in other parts of body, *E. coli* can cause serious disease in

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human and other warm blooded animals [6]. The Karasu stream originates from Gündüzlü forests of Küre Mountains. The Karasu stream flows into the Black Sea 8 km west of the city of Sinop, and it finds the length of 80 km. Sinop is our main research area, heavily used for recreational activities, swimming, fishing and mussels harvesting during all seasons. The population density in coastal areas of the region is very high. Sewage is often discharged directly or indirectly into the sea from various point or non-point sources along the coast [7]. Physical, chemical and microbiological indicators are used to detect and prevent diseases caused by water. However, each indicator has different upper or lower evaluation criteria for water quality determination.

When viewed from these aspects, Fuzzy Logic is one of the most widely used for measuring water quality involving biological parameters. Fuzzy Logic was introduced by Zadeh [8] and it is one of the important branches of mathematics that has the ability to reflect human thoughts and expertise.

In this study, fuzzy technique will be used to determine water quality by applying Mamdani Fuzzy Logic model with Matlab programming [9]. In addition, the importance of microbiological criteria against physical and chemical properties of water will be compared.

2. MATERIALS AND METHODS

In this chapter water quality index (WQI) model has been made using Fuzzy Inference System (FIS) by help of Matlab Fuzzy logic toolbox editors. The parameters in defining WQI are pH, Dissolved Oxygen (DO), Conductivity (Cn), Fecal Coliform (FC) and Temperature (T). Here two cases are considered such that WQI with DO, Cn, ORP, FC, pH parameters and WQI with DO, Cn, ORP, T, pH parameters. For these cases the fuzzy logic water quality model can be shown in the Figs. 1-2.

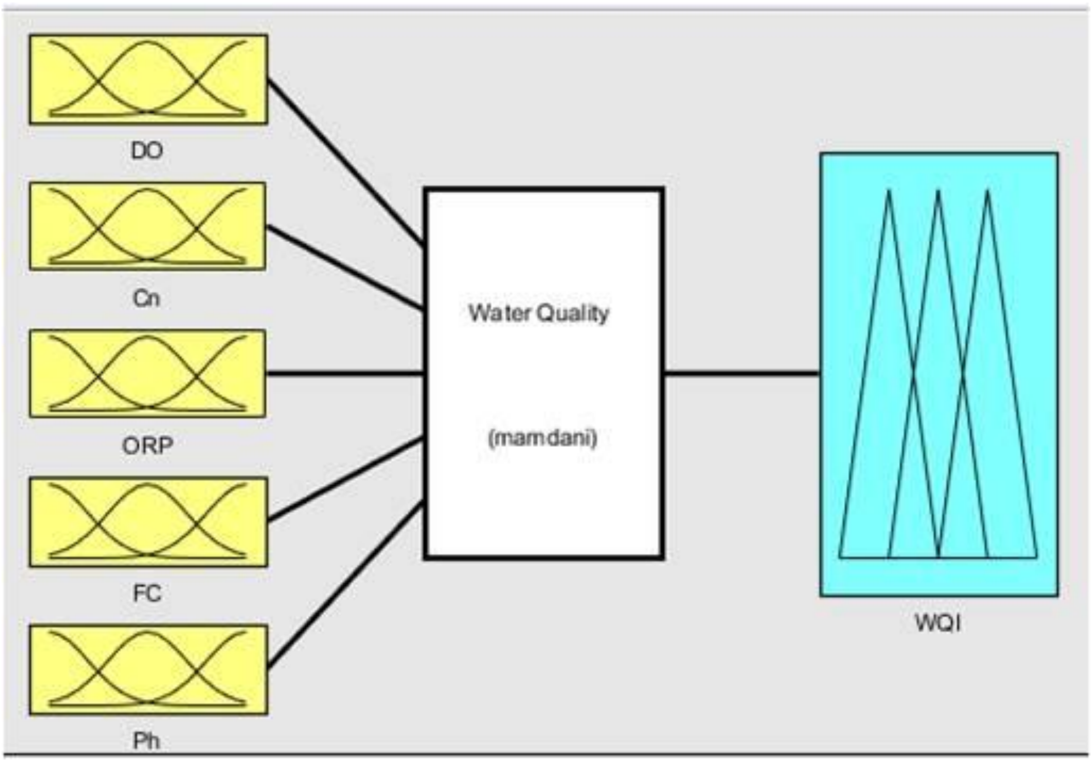

Figure 1. Fuzzy System of Water Quality Index.

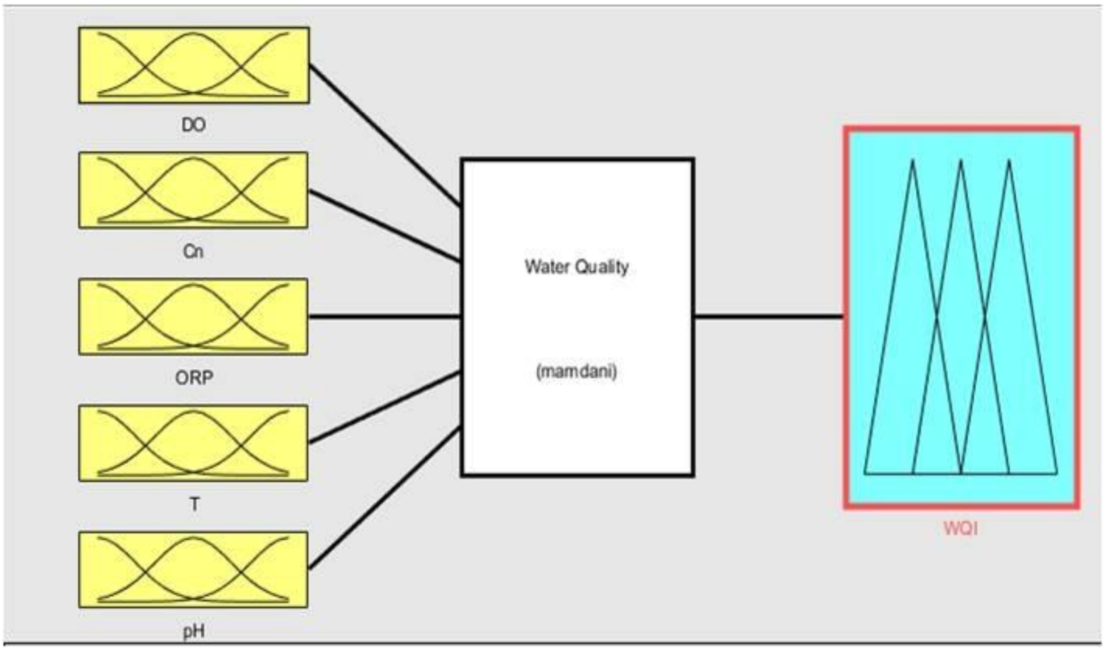

Figure 2. Fuzzy System of Water Quality Index.

2.1. MEMBERSHIP VALUES

Membership values are defined by referencing the standards by World Health Organization (WHO) and USEPA (United States environmental protection agency), as shown in Table 1.

Table 1. Linguistic terms for input parameters

Parameters	Parameter Classes		
pH	Low 0-6.5	Medium 6-9	High 8.5-11
T	Good 0-25	Medium 20-33	Bad 32-40
DO	Low 2-4	Medium 3-7	High 6-11
Cn	Good 100-450	Medium 400-900	Bad 800-1000
ORP	Bad 0-250	Medium 200-600	Good 400-800
FC	Good 0-50	Medium 30-5000	High 450-20000

2.2. DETERMINATION OF MEMBERSHIP FUNCTIONS

A membership function (MF) for a fuzzy set A on the universe of discourse X is defined as μ_A: X → [0,1], where each element of X is mapped to a value between 0 and 1. This value, called membership value or degree of membership, quantifies the grade of membership of the element in X to the fuzzy set A.

Membership functions allow us to graphically represent a fuzzy set. The x axis represents the universe of discourse, whereas the y axis represents the degrees of membership in the [0,1] interval. The shape of a membership function depends on the application and can be trapezoidal, triangular, or Gaussian, etc. The most commonly used is the linear type, trapezoidal and triangular. A trapezoidal MF is specified by four parameters a_1, a_2, a_3, a_4 with $a_1 < a_2 \leq a_3 < a_4$ and a triangular MF is specified by three parameters a_1, a_2, a_3 with $a_1 < a_2 < a_3$ in Fig. 3 [10].

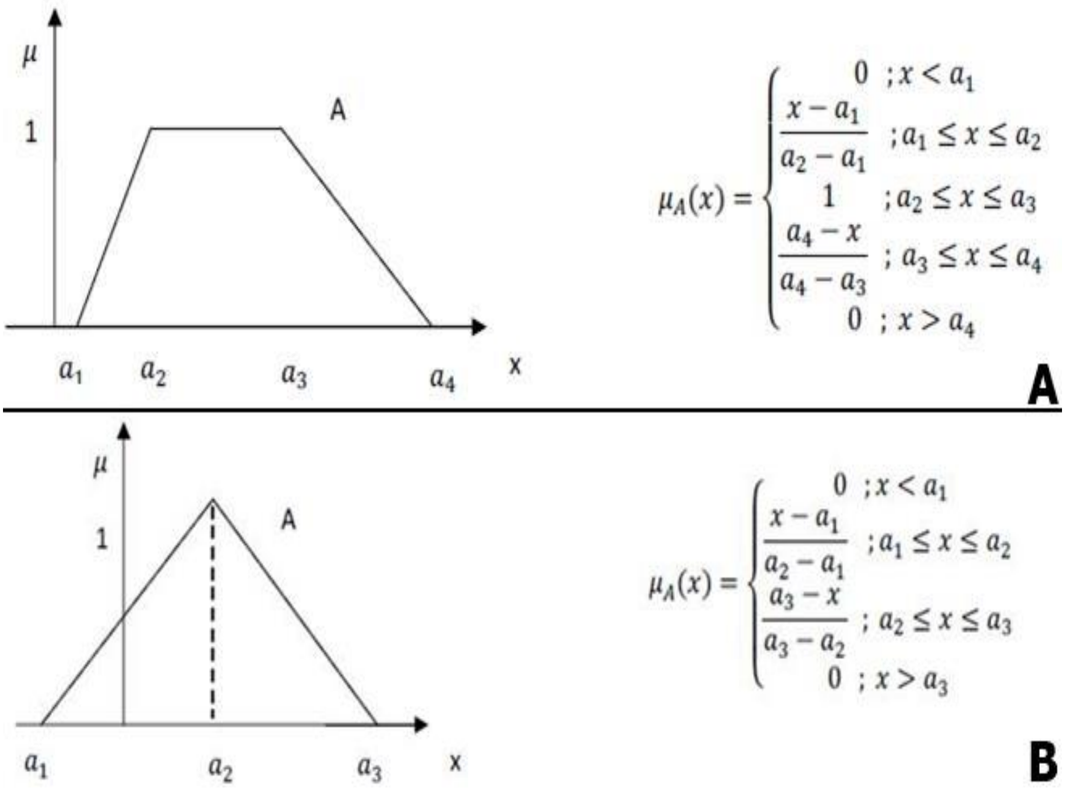

Figure 3. Trapezoidal and Triangular Membership Functions.

The input and output data which were obtained from Avsar [1] are taken in the form of linguistic format. For example, the input variables are pH={low, medium, high}, DO={low, medium, high}, Cn={Good, Medium, Bad}, FC= {Good, Medium, Bad}, ORP= {Bad, Medium, Good}, T={Good, Medium, Bad }. The output variable is similarly divided into WQI={VeryPoor, Poor, Medium, Good, Excellent}. Based on Table 1, membership functions assigned to input variables and output variable respectively in Fig. 4.

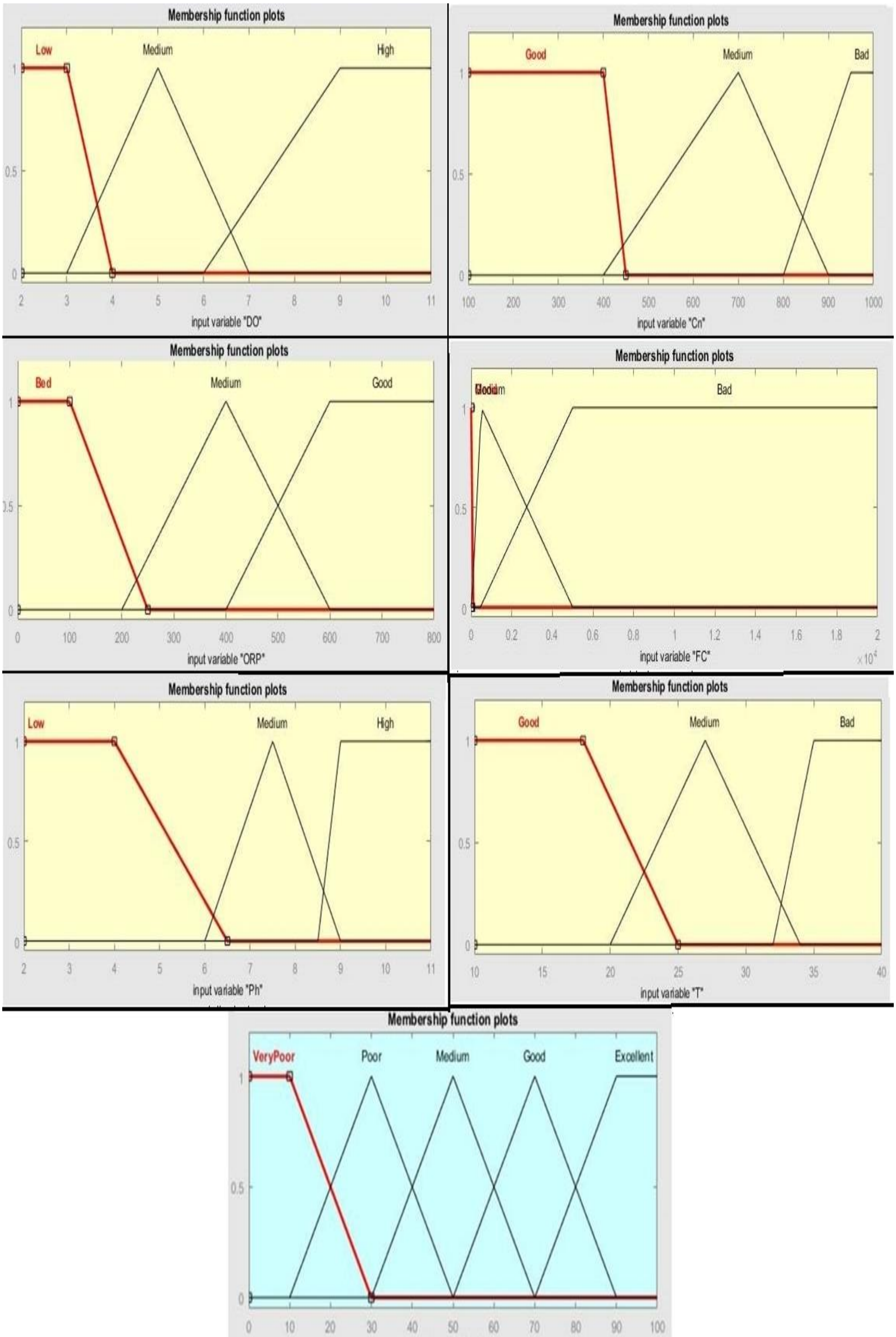

Figure 4. Membership Functions for DO, Cn, ORP, T, FC, pH, and FWQI.

2.3. DETERMINATION OF FUZZY RULES

Fuzzy rule systems are one of the most important areas of application of fuzzy sets and fuzzy logic. These systems have been successfully applied to a wide range of problems in different domains for which uncertainty and vagueness emerge in multiple ways. A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion. In this system, the input variables pH, Cn, FC, T, DO, ORP have three membership functions and the output variable WQI has five membership functions. So the fuzzy system has 243 rules (3x3x3x3x3). The rule editor for water qualities with Ph, Cn, T, DO and ORP input variables and for water qualities with pH, Cn, FC, DO and ORP input variables are shown respectively in the Figs. 5-6.

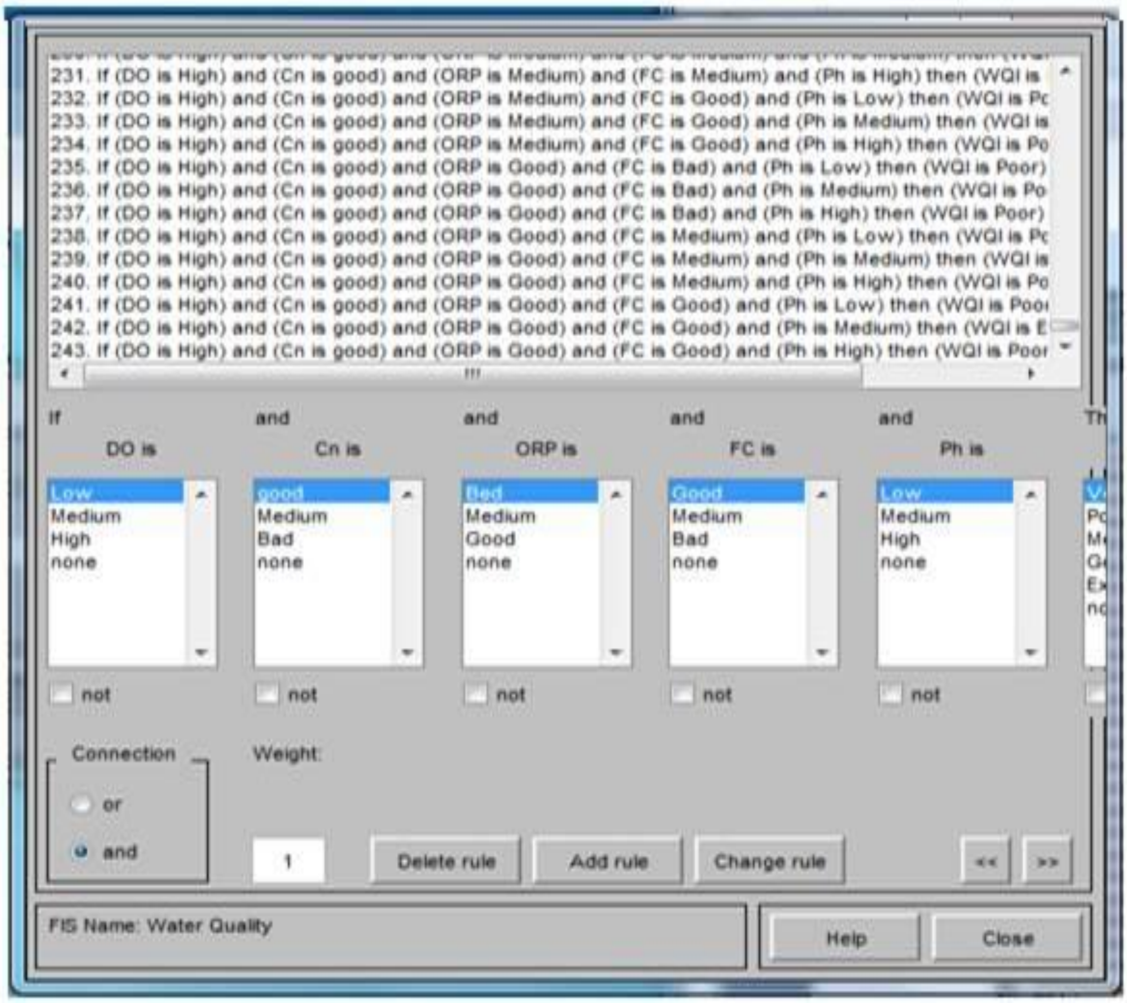

Figure 5. Some Rules of Input and Output Variables.

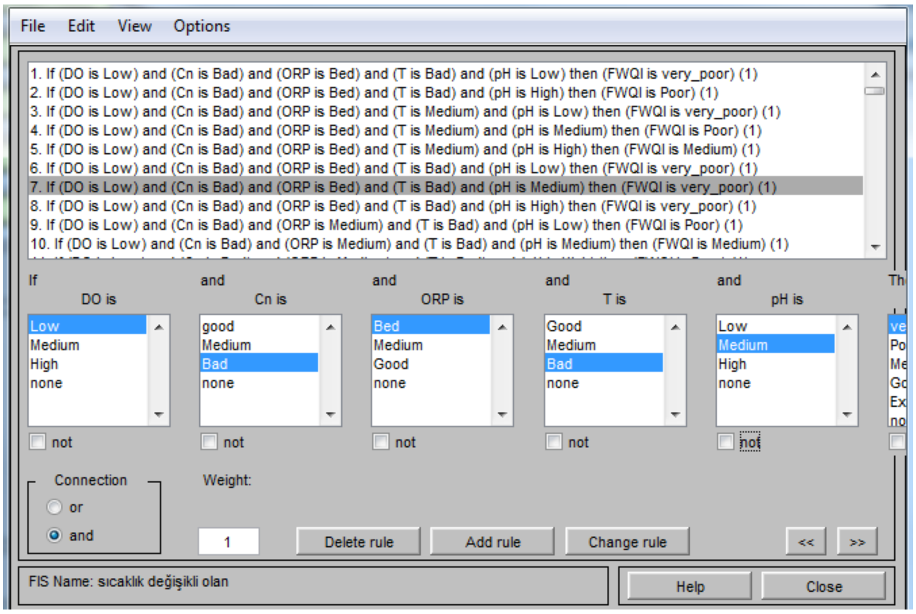

Figure 6. Some Rules of Input and Output Variables.

2.4. SURFACE VIEWERS AND SIMULATIONS

After completing the fuzzy decision process with defuzzifying the outputs, the rule viewer shows a crisp output. The defuzzification method was carried out by using the centroid method which is the most accurate and widely used amongst the other methods. When the input values are entered into the system such as [6.5; 550; 400; 1200; 6.5] for different parameters in the Table 2, then from the system, simulated result is shown for this values in Fig. 7.

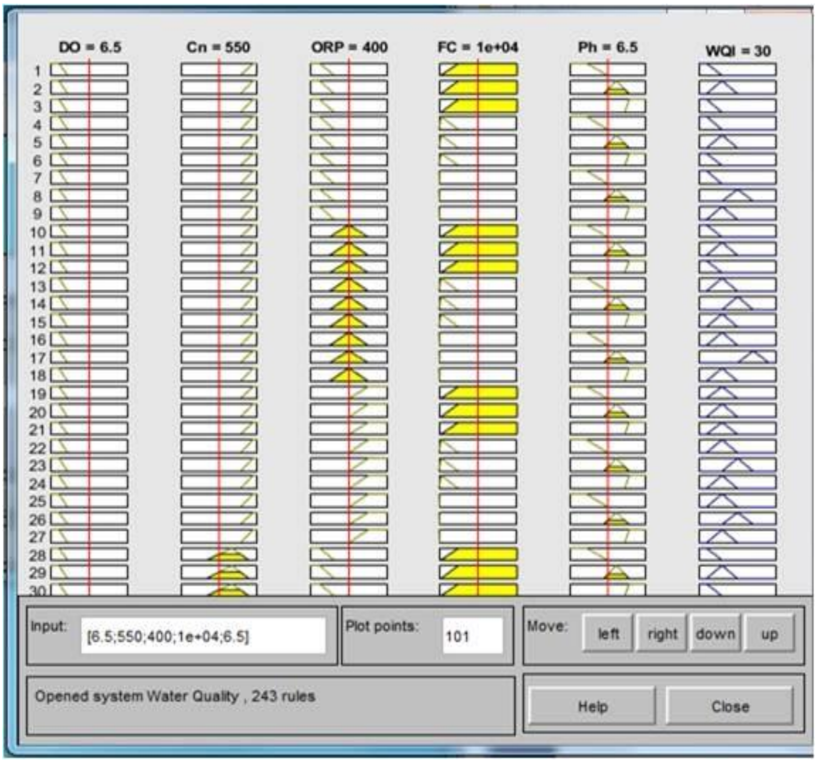

Figure 7. Rule Viewer of Input and Output Variables

Similarly, different simulated results can be obtained by entering other parameter values. Finally, surface viewer is also used to show the output behavior corresponding to the inputs. It works basically that any two inputs can be selected as x and y axis and the output water quality can be mapped accordingly. For Water Quality, some surface viewers are shown with pH, Cn, FC, DO, ORP in the Fig. 8A-B, and with pH, Cn, T, DO, ORP in the Fig. 8C-D.

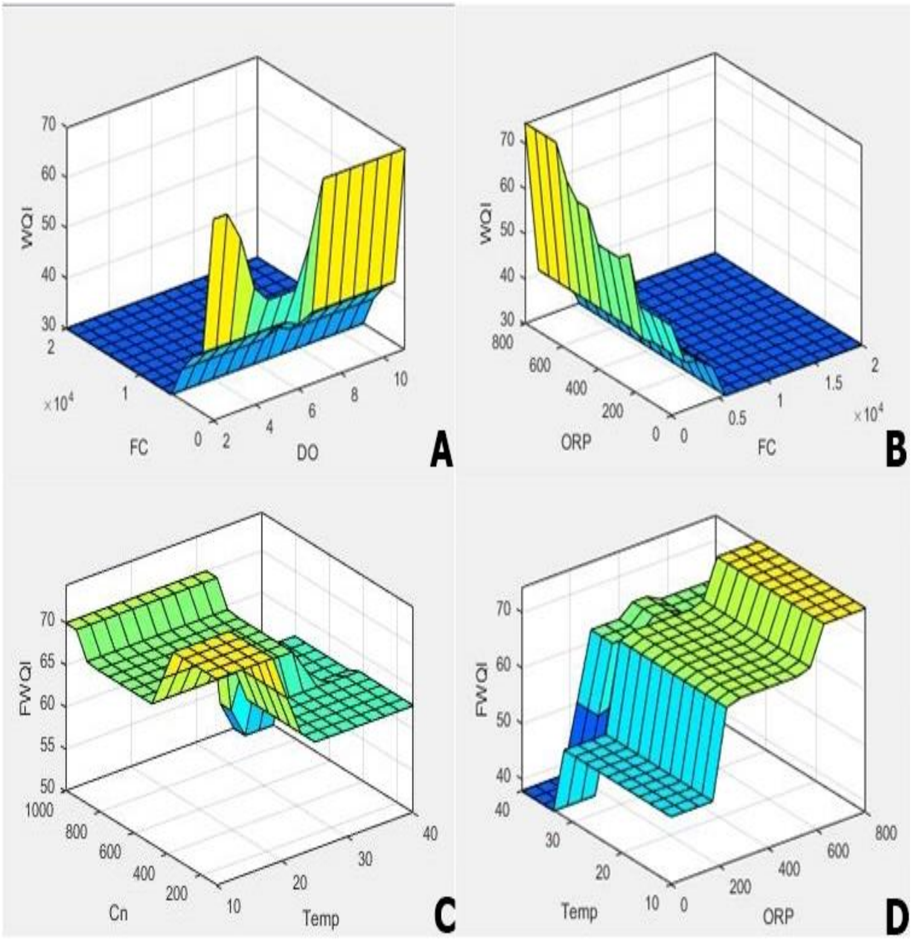

Figure 8. Surface Viewers of Relationship Between Input and Output Variables.

Table 2. Physical properties of sampling stations

Stations	**June**						**July**					
	pH	T	DO	Cn	ORP	FC	pH	T	DO	Cn	ORP	FC
1	8.11	23.70	8.70	334.00	125.70	23.00	8.19	27.90	7.96	296.00	135.70	94.00
2	8.00	23.60	8.69	400.00	155.30	240.00	8.18	27.60	7.71	305.00	136.80	220.00
3	7.68	26.20	6.98	454.00	167.00	79.00	7.66	26.20	7.20	500.00	158.00	140.00
4	7.61	22.70	6.98	520.00	143.40	79.00	7.57	29.90	5.35	524.00	153.80	170.00
Stations	**August**						**September**					
	pH	T	DO	Cn	ORP	FC	pH	T	DO	Cn	ORP	FC
1	7.90	27.40	8.11	334.00	122.90	180.00	6.88	19.30	9.35	331.00	128.80	280.00
2	7.96	25.20	7.95	362.00	147.80	350.00	7.66	20.10	9.60	377.00	135.90	540.00
3	7.40	27.70	6.58	552.00	161.50	920.00	6.79	19.60	8.37	476.00	181.30	2400.00
4	7.74	27.00	7.48	894.00	165.60	79.00	7.32	21.10	7.77	458.00	159.30	920.00

Stations	October						November					
	pH	T	DO	Cn	ORP	FC	pH	T	DO	Cn	ORP	FC
1	6.80	16.40	9.86	359.00	150.50	180.00	7.47	14.50	9.21	361.00	111.50	180.00
2	6.99	18.80	9.52	411.00	155.60	280.00	7.33	12.10	10.42	448.00	165.60	180.00
3	6.65	16.50	8.77	487.00	207.00	540.00	7.07	13.70	8.83	539.00	300.80	280.00
4	6.36	15.30	8.80	492.00	174.30	70.00	6.80	17.70	7.86	570.00	163.60	280.00

The stations: *1 - Erfelek (waste water), 2 - Bektaşağa (waste water, and it is used for irrigation and watering livestock), 3 - Cemal Bridge (waste water and it is used for irrigation), 4 - Martı Camping (waste water and it is used for irrigation, fishing and watering livestock).* ***Parameters:*** *T - temperature (°C); DO - Dissolved oxygen (mg/L); Cn - Conductivity (μS/cm); ORP - Oxidation Reduction Potential (mV).*

3. RESULTS AND DISCUSSION

According to the results obtained based on fuzzy logic, water quality of Karasu River was determined at average values (Table 3). When Table 3 was examined, both fecal coliform and temperature-dependent quality index tests showed the same results at all stations in June and July. However, it was determined that the quality due to fecal coliform decreased at the third and fourth stations where the water was poured into the sea and the agricultural areas were irrigated.

Table 3. Fuzzy based water quality index

Stations	June		July		August	
	With FC	With Temperature	With FC	With Temperature	With FC	With Temperature
1	50.0	50.0	50.0	50.0	50.0	50.0
2	50.0	50.0	50.0	50.0	50.0	50.0
3	50.0	50.0	50.0	50.0	43.8	50.0
4	50.0	50.0	50.0	50.0	31.3	33.9
Stations	**September**		**October**		**November**	
	With FC	With Temperature	With FC	With Temperature	With FC	With Temperature
1	50.0	50.0	50.0	50.0	50.0	50.0
2	49.4	50.0	50.0	50.0	50.0	50.0
3	40.0	50.0	48.9	53.4	50.0	67.1
4	43.4	50.0	42.5	48.6	50.0	50.0

T - temperature (°C).

In addition, it was observed that the quality based on fecal coliform continued to decrease in September and October and the average quality again in November. Tayal and Prema [11] used fuzzy technique in drinking water quality determination studies and reported that the technique yielded good results. Chang et al. [12] reported that fuzzy technique was successful in river water quality determination studies. Gharibi et al. [13] reported that the fuzzy technique produced accurate and reliable results in their water quality study and therefore could be used as a comprehensive tool for water quality assessment, especially for the analysis of human drinking water. Nasr et al. [14] used fuzzy model for quality analysis with 60 groundwater physical and chemical data and reported that this technique was successful. However, they did not include microbiological data in their studies. Mourhir et al.

[15] compared six physicochemical with the traditional physicochemical water quality index currently in use in Morocco to determine river water quality. The results showed that the fuzzy index provides classifications at different rates compared to the traditional index. He reported that these exceptions were due to large inequalities between the different quality thresholds of fecal coliform and total phosphorus. This study supports our conclusion for fecal coliform. Bai et al. [16] reported that in most countries only physico-chemical parameters have been made because of the great efforts required to measure biological parameters when determining water quality. However, in their study to determine river water quality, researchers reported that the fuzzy model provides a good way to include pathogens in water quality criteria. These findings were found to be parallel to our study.

4. CONCLUSION

Fuzzy Logic allows more detailed interpretation of the results by expressing numerical data in linguistic terms and evaluating multiple parameters simultaneously. In present work, the estimation of water quality was investigated in two cases, with and without parameters including microbiological factor and the results were discussed. Estimates of water quality obtained with different groups provide a different perspective to the studies to be performed in this field.

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