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AI-BASED WATER QUALITY MONITORING OF THE RIVER GANGA USING FUZZY

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ABSTRACT

The optimum use of water requires an effective water supply management system that is smart enough to measure the flow rate, estimate consumption, estimate stored water, detect defects in the pipeline, automate actuators, measure water quality and produce details for the end user. Real-time implementation of such a water supply system requires a range of sensors with low power consumption and longer life with accuracy. Recent emerging sensors for water quality (WQ) and flow rate have been discussed in detail. The real-time adaptability of these sensors in water supply management systems has been discussed. Based on these sensor technologies, possible advancements have been proposed for the future. The emerging capability to improve sensor performance by image processing and computer vision-based methods has been discussed. Integration of computer vision with sensors can improve sensor capability. The IoT is an emerging technology capable of connecting end users to the access quality of water resources, monitoring flow and daily consumption. A futuristic model has been proposed based on computer vision technology integrated with IoT.

Keywords: Water quality, IoT, Water Supply Management, Sensor, Computer Vision

INTRODUCTION

Artificial intelligence and fuzzy logic use the same kind of approach. In a neural network, different weights are assigned to a variety of inputs so that complex situations can be analyzed. Similar to neural networks, fuzzy networks also analyze different inputs with a variety of logical conditions and empower the analysis of complex relationships with a definite set of rules. The capability of fuzzy to use a range of distribution and logic methods enables any model to be automatically integrated with intelligence capabilities.

Water quality parameters can be analyzed based on fuzzy techniques, and various researchers have contributions regarding this. In Abbasi et al. (2011), Brown et al. (1970), and BU et al. (2014), river management related to ambiguity in pollution under partial ignorance and goals of discharges dependent on various hydrological variables have been studied using fuzzy techniques. In Chau (2006), Protection of Environment (2022), and National Primary Drinking Water Standards (2007), various numerical modeling methods (SWAT, MIKE11, QUAL2K, etc.) are used to improve water quality in rivers and control pollution with large errors. The Fuzzy Technique can be used with a range of parameter variation, which results in less error in the WQ measurement (Environment Protection, Amendment Rules, 2000).

Fuzzy logic has been used to study various water qualities in river basins. The water quality index was defined in a few steps (CPCB Annual Report 2020-21, 2022). These steps are i) Choose Water Quality Parameter ii) Select Sub Index value iii) Assign weightage iv) Establish Water Quality Index Value. The national sanitation foundation water quality index (NSFWQI) was proposed, and this index is widely accepted in Indian subcontinents (CPCB: Pollution Assessment: River Ganga, 2013). The NSFWQI did not show good efficiency because of increasing pollution in Indian rivers and high BOD content in surface water (Gharibi, 2012). The Godavari River water quality index was assessed by using a fuzzy technique (LI, 2016). Studies have focused on sensitivity analyses of water quality parameters and the use of river water for drinking and bathing purposes. The limitations of WQI analysis have been assessed, and an approach to overcome these limitations has been proposed using the fuzzy technique. The Vedprakash Water Quality Index (VWQI-1970) was used, which considers only three water quality parameters: DO, BOD and pH (Mohd et al., 2013). This index has been widely used to predict the water quality of the river Ganga and finds locations along the stretch of the River Ganga, with a high difference between the actual and required water quality index. A fuzzy-based water pollution index was developed for determining water quality by providing rank (Nayak-Jyotiprakash et al., 2017). Reasons for the predominance of fuzzy techniques were developed. The reasons are as follows: nonlinear relationships among different variables are addressed, a local simple model can be developed, and individual expertise and experience can contribute to the model and are easy to understand (Rehana et al., 2009).

The River Ganga is widely spread over 860,000 sq km, including 11 states, and approximately 600 million Indians contribute almost 40% of the Indian GDP. More than its spiritual significance, 90% of surface water is used for irrigation. The Ganga Basin is divided into three reaches: Upper Ganga Reach, Middle Ganga Reach, and Lower Ganga Reach. The upper Ganga reach starts from Gomukh and ends at Haridwar. This reach has a narrow bed and flows on hilly rocks. This reach includes many hydropower projects and has immense potential for power generation. The middle Ganga reach starts from Haridwar and ends at Varansi. The middle Ganga Reach is mainly responsible for irrigation. The reason for the lower Ganga starts from Varansi and extends to the Bay of Bengal. In this reach, large rivers contribute to river Ganga, and the flow is lower in this reach.

Water quality measurement is a continuous requirement for proper planning and assessment. The Central Pollution Control Board of India has established 57 water quality monitoring stations on the river Ganga in 5 states. Table 1 shows different water quality criteria provided by the Environment Protection Act, 1986 and declared by the Central Pollution Control Board, India. The selected water quality parameter ranges required for bathing water and drinking water are shown in detail. If pH will become out of range, then it may cause skin-related problems. The dissolved oxygen minimum limit ensures the required oxygen for aquatic life plants and animals. Biochemical oxygen demand is dependent on dissolved oxygen change caused by aerobic biological organisms over a period of time at a fixed temperature.

Table 1: Water quality parameters and allowed limits

Water Designated Use in India	Water Quality Parameter	Minimum and Maximum Range
Bathing Water Quality	pH	6.5-8.5
	Dissolved Oxygen	5 mg/l or more
	Biochemical Oxygen	3 mg/l or less
Drinking Water Quality without conventional treatment	pH	6.5-8.5
	Dissolved Oxygen	6 mg/l or more
	Biochemical Oxygen	2 mg/l or less
Drinking Water Quality after conventional treatment	pH	6.0-9.0
	Dissolved Oxygen	4 mg/l or more
	Biochemical Oxygen	3 mg/l or less

In the proposed study, the water quality of the river Ganga was studied in three different basins at the end point location. In Upper Ganga Reach Rishikesh, Middle Ganga Reach Assi Ghat Varansi, and Lower Ganga Reach Diomand Harbor, 24 Pargana were selected for water quality measurement. Water quality data for three selected parameters over a period of five years from 2015-2020. Water quality assessment includes the fuzzy logic technique based on crisp input in terms of the water quality parameter, defining the fuzzy rule set on input parameters, defining the membership function, establishing the fuzzy inference engine and defuzzification in terms of crisp output. This paper has been divided into 5 sections. Section 1 is Introduction, Section 2 includes Methodology and Water Quality data, Section 3 includes Implementation of Fuzzy Logic, Section 4 includes Accessing water quality by Fuzzy Result and Section 5 includes Conclusion.

Methodology and Water Quality Data

In this paper, the methodology presented in Fig. 1 is adopted for AI-based water quality estimation using fuzzy methods. In the process of implementing water quality analysis using fuzzy first out of many rivers, river Ganga is selected due to its social and economic effect on India. After the selection of rivers, various water quality parameters were studied, and among these parameters, some of the major water quality parameters were selected as DO, pH and BOD. Along with it, the overall course of river Ganga is selected. The River Ganga is divided into three basins: the upper basin, middle basin and lower basin. In three basins, one location is selected in each. In the upper basin of river ganga Rishikesh, in the middle basin of river ganga Assi Ghat Varansi and in the lower basin of river ganga Diamond Harbor, 24 Pargana have been selected. All these locations have been selected in view that all these points lie in the lower region of individual basins. The rightmost corner of Fig. 1 over all courses of the river Ganga has been shown, and it also includes important locations in different basins of the river Ganga.

For data on different parameters of river Ganga from the 2020-21 Annual Report 2020-21, the Central Pollution Control Board (2022) has been consulted. The minimum and maximum values of the three selected water quality parameters were obtained for 2015-20. Fig. 2 shows the minimum and maximum values of pH for six consecutive years (2015-2020) for the three selected locations. In Fig. 2, the minimum and maximum values of pH for six consecutive years (2015-2020) for three selected locations are shown graphically. Fig. 3 shows the minimum and maximum values of BOD for six consecutive years (2015-2020) for the three selected locations. In Fig. 4, minimum and maximum values of DO for six consecutive years (2015-2020) for three selected locations are shown graphically. Based on these data, fuzzification was performed. We have knowledge about the range of these parameters, and based on that knowledge, each parameter will be assigned a certain weight, and an inference rule will be designed. Defuzzification will be performed, and the water quality index will be determined. A 3D map explaining water quality will be obtained at three different locations.

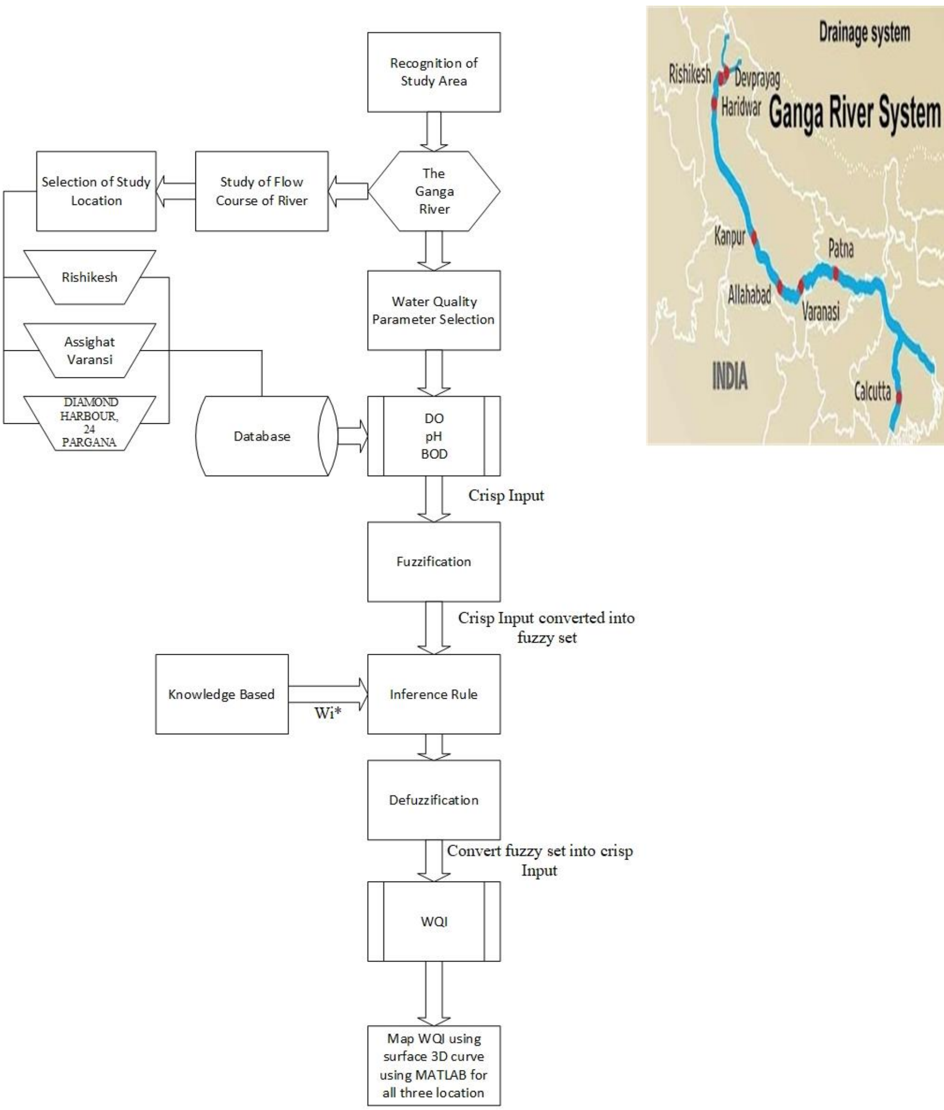

Figure 1: Flow chart of the proposed fuzzy-based water quality assessment for the Ganga River

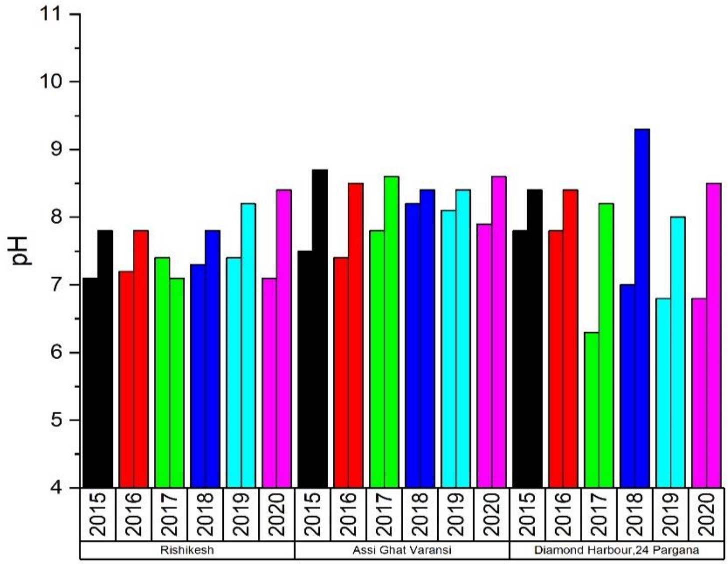

Figure 2: Maximum and minimum pH values at three different locations.

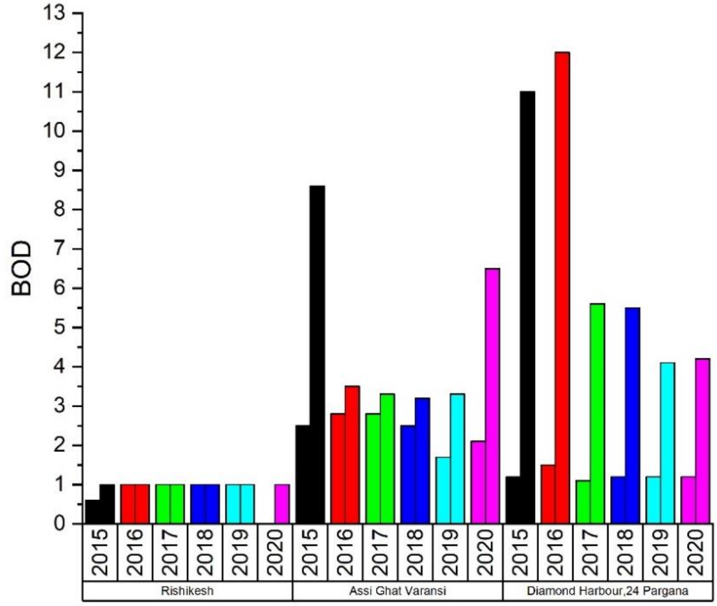

Figure 3: Maximum and minimum BOD values at three different locations.

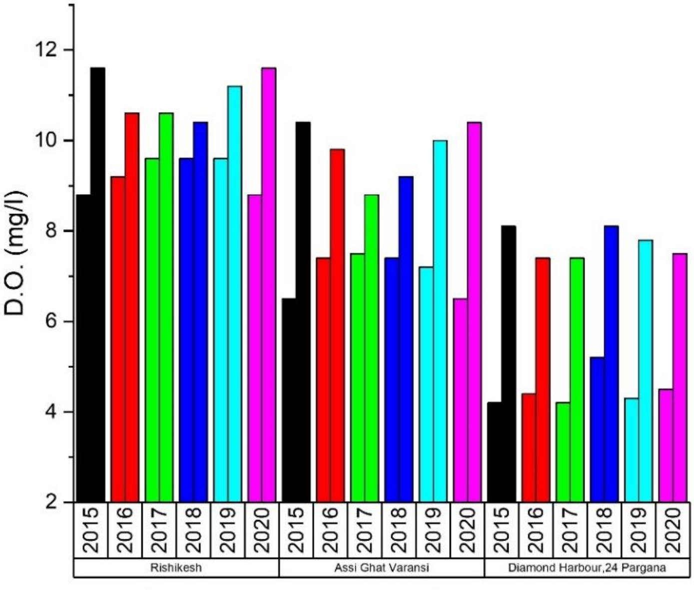

Figure 4: Maximum and minimum DO values at three different locations.

The fuzzy Logic Toolbox based on AI techniques is used to calculate the water quality index by using three parameters, DO, pH and BOD, of three different places from the upper part of the Ganga River span to the lower part of the Ganga River span, such as Rishikesh, Assi Ghat Varanasi and Diamond Harbor, 24 Pargana. These three input parameters, DO, pH and BOD, are transformed into fuzzy sets defined as:

$A= \{(d, \mu_A(d))\}$ d € DO

$B= \{(p, \mu_B(p))\}$ p € pH

$C= \{(b, \mu_C(b))\}$ b € BOD

where DO is a universe of disclosure for dissolved oxygen, pH is a universe of disclosure for pH level, and BOD is a universe of disclosure for biological oxygen demand.

We apply the fuzzy logic toolbox in MATLAB for the membership function we used trimf(). The syntax of the triangular membership function is given below:

y = trimf(x, params)

This returns fuzzy membership values computed using the following triangular membership function.

$$f(x, a, b, c) = \begin{cases} 0, & x \leq a \\ (x - a)/(b - a), & a \leq x \leq b \\ (c - x)/(c - b), & b \leq x \leq c \\ 0, & c \leq x \end{cases}$$

The membership function for dissolved oxygen, pH level and biological oxygen demand are defined below:

$$\mu_A(d) = \begin{cases} 0, & \text{if } d < 4.2 \\ (d - 4.2)/3.8, & \text{if } 4.2 \leq d < 8 \\ (10 - d)/2 & \text{if } 8 \leq d \leq 10 \\ 1, & \text{if } d > 10 \end{cases}$$

$$\mu_B(p) = \begin{cases} 0, & \text{if } p < 6 \\ (p - 6)/2.5, & \text{if } 6 \leq p \leq 8.5 \\ (10 - p)/0.8 & \text{if } 8.5 < p \leq 9.3 \\ 0, & \text{if } p > 9.3 \end{cases}$$

$$\mu_C(b) = \begin{cases} 1, & \text{if } b < 2 \\ (b - 2)/3, & \text{if } 2 \leq b \leq 5 \\ (5 - b)/5, & \text{if } 5 < b \leq 10 \\ 0 & \text{if } b > 10 \end{cases}$$

A fuzzy relation is a relation between elements of D and RE described by a membership function μ_{d*p*b} and is defined as:

μ_{d*p*b} (d,p,b): d € DO, p € pH, b € BOD

The fuzzy operator AND(^) is used to find the best fuzzy conjunction relation, and the equation is written below:

$$\mu_A(d) \wedge \mu_B(p) \wedge \mu_C(b) = \min(\mu_A(d), \mu_B(p), \mu_C(b))$$

Rule evaluation regarding the proposed fuzzy-based water quality is discussed and proposed below. The proposed fuzzy logic-based protocol is used for the calculation of the water quality index in three places, such as Rishikesh, Assi ghat Varanasi and Diamond Harbor, 24 and Pargana, for the comparison of the water quality index in these three places. We used three input parameters, such as dissolved oxygen, pH level and biological oxygen dissolved, which are important parameters in water that determine whether water is useful for aquatic life as well as for human beings. The input functions use three membership functions to show the degree of input variables shown in Table 2, where we used all place minimum values and maximum values in all three parameters. The precedence of the input function is:

Dissolved oxygen > pH level > Biological oxygen dissolved

Table 2: Input function parameters

Input	Membership function		
Dissolved Oxygen	DO_R	DO_V	DO_H
pH level	pH_R	pH_V	pH_H
Biological Oxygen Demand	BOD_R	BOD_V	BOD_H

where

A. DO_R indicates that dissolved oxygen in Rishikesh starts from 8.8 mg/l to 11.6 mg/l, DO_V indicates that dissolved oxygen in Assi Ghat Varanasi starts from 6.5 mg/l to 10.4 mg/l, DO_H indicates dissolved oxygen in Diamond Harbor, and 24 Pargana starts from 4.2 mg/l to 8.1 mg/l.

B. pH_R indicates that the pH level in Rishikesh starts from 7 to 8.4, pH_V indicates that the pH level in Assi Ghat Varanasi starts from 7.4 to 8.6, pH_H indicates that the pH level in Diamond Harbor, 24 and Pargana starts from 6.3 to 9.3.

C. BOD_R indicates biological oxygen demand in Rishikesh from 0 mg/l to 1 mg/l, BOD_V indicates biological oxygen demand in Assi Ghat Varanasi from 1.1 mg/l to 8.5 mg/l, BOD_H indicates biological oxygen demand in Diamond Harbor, and 24 Pargana from 1.1 mg/l to 12 mg/l.

The I/P function uses three membership functions to show the degree of the I/P variable and generate nine sets of O/P variables multiplied by weight factors that vary from 0 to 1 according to the input parameters, as shown in Table 3.

Table 3: Output Function

Output Variable	Membership Function
Water Quality Index	LOW_H_WQI, FAIR_H_WQI, GOOD_H_WQI, LOW_V_WQI, FAIR_V_WQI, GOOD_V_WQI, LOW_R_WQI, FAIR_R_WQI, GOOD_R_WQI

LOW_H_WQI < LOW_V_WQI < FAIR_H_WQI < GOOD_H_WQI < LOW_R_WQI < FAIR_V_WQI < GOOD_V_WQI < FAIR_R_WQI < GOOD_R_WQI

where LOW_H_WQI is Low Diamond Harbor, 24 Pargana Water Quality Index, LOW_V_WQI is Low Assi Ghat Varanasi Water Quality Index, FAIR_H_WQI is Fair Diamond Harbor, 24 Pargana Water Quality Index, GOOD_H_WQI is Good Diamond Harbor, 24 Pargana Water Quality Index, LOW_R_WQI is Low Rishikesh Water Quality Index, FAIR_V_WQI is Fair Assi Ghat Varanasi Water Quality Index, GOOD_V_WQI is Good Assi Ghat Varanasi Water Quality Index, FAIR_R_WQI is Fair Rishikesh Water Quality Index and GOOD_R_WQI is Good Rishikesh Water Quality Index.

The fuzzy relationships are defined in Table 4. Selecting an optimal CH follows rule sets based on three input parameters, i.e., dissolved oxygen, pH level and biological oxygen demand I/P parameters multiplied by the weighing factor, which varied from 0 to 1.

Table 4: Logical Rule Sets

Dissolved Oxygen	pH level	Biological Oxygen Demand	Water Quality Index	Weight factor
DO_H	pH_H	BOD_H	LOW_H_WQI	0.1
DO_V	pH_V	BOD_H	LOW_V_WQI	0.2
DO_H	pH_H	BOD_R	FAIR_H_WQI	0.3
DO_H	pH_V	BOD_R	GOOD_H_WQI	0.4
DO_R	pH_R	BOD_V	LOW_R_WQI	0.5
DO_V	pH_V	BOD_V	FAIR_V_WQI	0.6
DO_V	pH_R	BOD_R	GOOD_V_WQI	0.7
DO_R	pH_R	BOD_V	FAIR_R_WQI	0.8
DO_R	pH_R	BOD_R	GOOD_R_WQI	1

The Fuzzy Logic Tool Box Model for Measuring the Water Quality Index is shown in Fig. 5. In the fuzzy inference system model, the input parameters are dissolved oxygen (DO), pH level (pH) and biological oxygen demand (BOD). The output is calculated using the water quality index (WQI), and we used the Mamdani tool box to generate logical output by using input.

The input parameter for dissolved oxygen (DO) is shown in Fig. 6, where we used the trimf() function for the membership function. The input parameter for the pH level (pH) is shown in Fig. 4 using the trimf() function for defining the membership function, and the input parameter of biological dissolved oxygen (BOD) is shown in Fig. 5 using trimf(). In Fig. 6, we show the water quality index (WQI) using trimf().

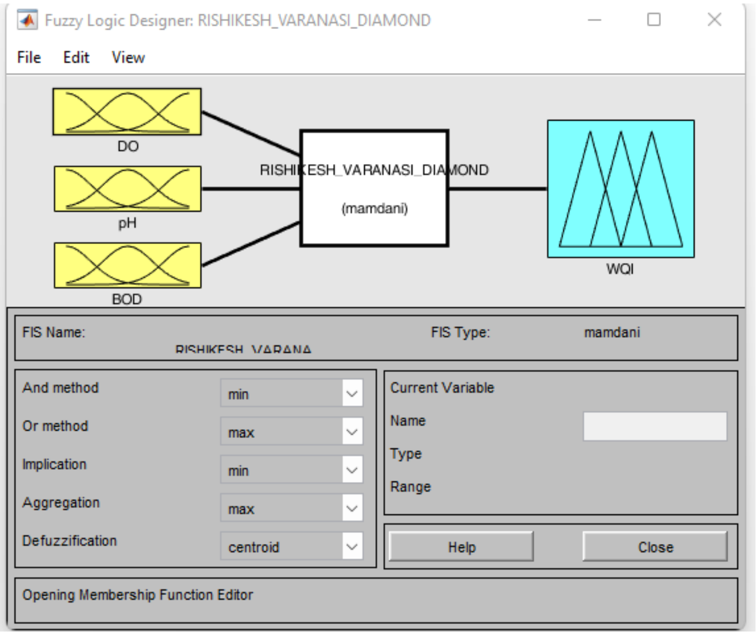

Figure 5: Fuzzy Inference System

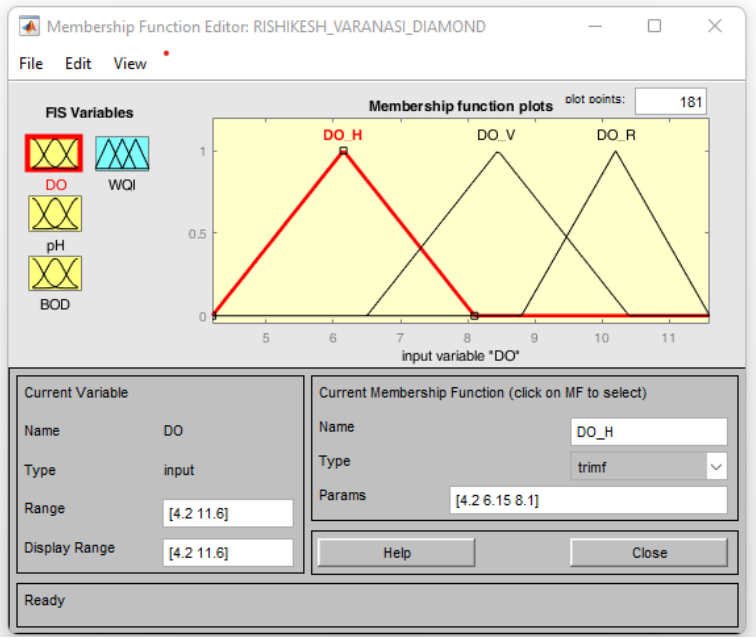

Figure 6: Membership function defined for dissolved oxygen (DO)

In Fig. 6, we used three membership functions using trimf(), which range for DO from 0 to 11.6 mg/l, where 0 to 8 mg/l indicates dissolved oxygen at Good Diamond Harbor, 24 Pargana, from 6.5 to 10.5 mg/l indicates dissolved oxygen at Assi Ghat, Varanasi and from 8.8 to 11.6 mg/l indicates dissolved oxygen at Rishikesh.

In Fig. 7, we used three membership functions and used trimf(), which ranges from pH 6.3 to 9.3, where 6.3 to 9.3 indicates the pH level at Good Diamond Harbor, 24 Pargana, 7.4 to 8.6 indicates the pH level at Assi Ghat, Varanasi and 6.5 to 8.5 indicates the pH level at Rishikesh.

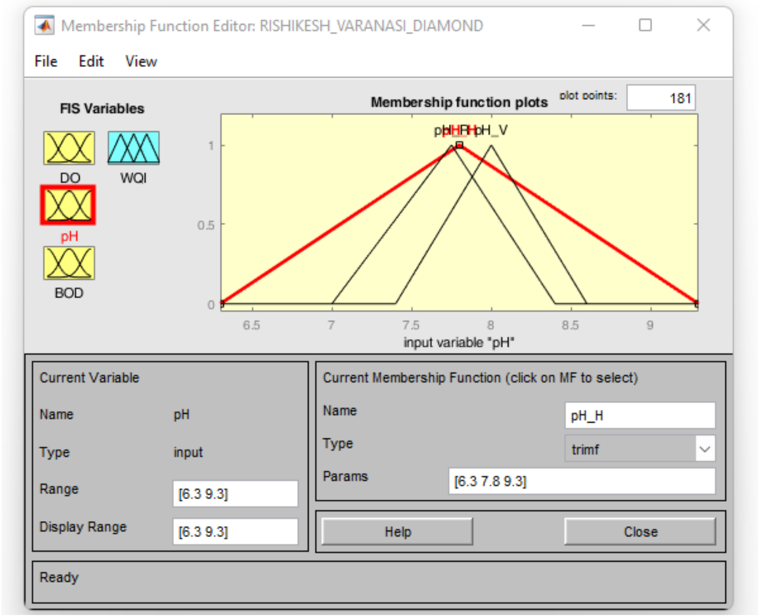

Figure 7: Membership function for pH level

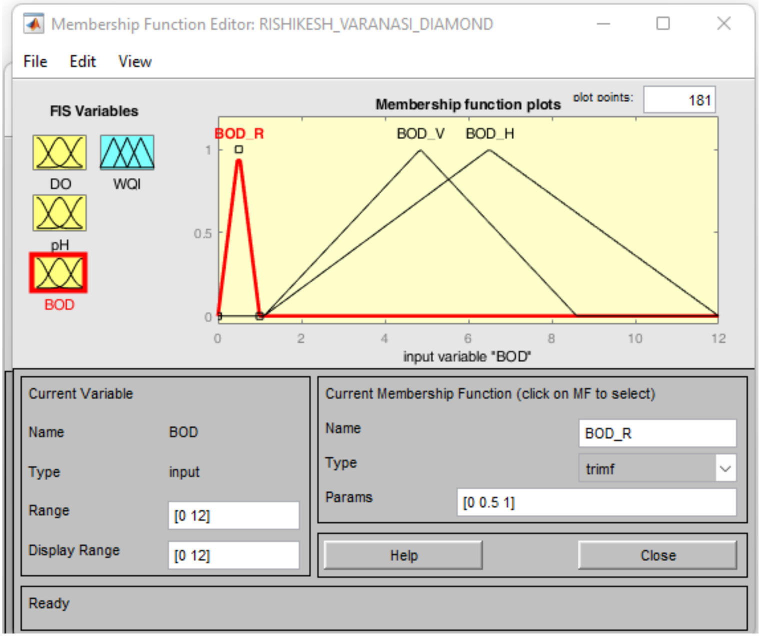

Figure 8: Membership function for biological oxygen demand

In Fig. 8, we used three membership functions for defining BOD uses, trimf(), which range for BOD from 0 to 12 mg/l, where from 1.1 to 12 mg/l indicates BOD at Good Diamond Harbor, 24 Pargana, from 1.1 to 8.6 mg/l indicates BOD at Assi Ghat, Varanasi and from 0 to 1 mg/l indicates BOD at Rishikesh.

Fig. 8 indicates the WQI for all three places, which uses the nine membership functions described above. Fuzzy logic gives results on the basis of the min-max function (min function was used) and multiples with some weighing factors, which improves its decision-making process for all three places of river Ganga. The membership function for the water quality index is shown in Fig. 9(a). The rule set for this model is shown in Fig. 9(b).

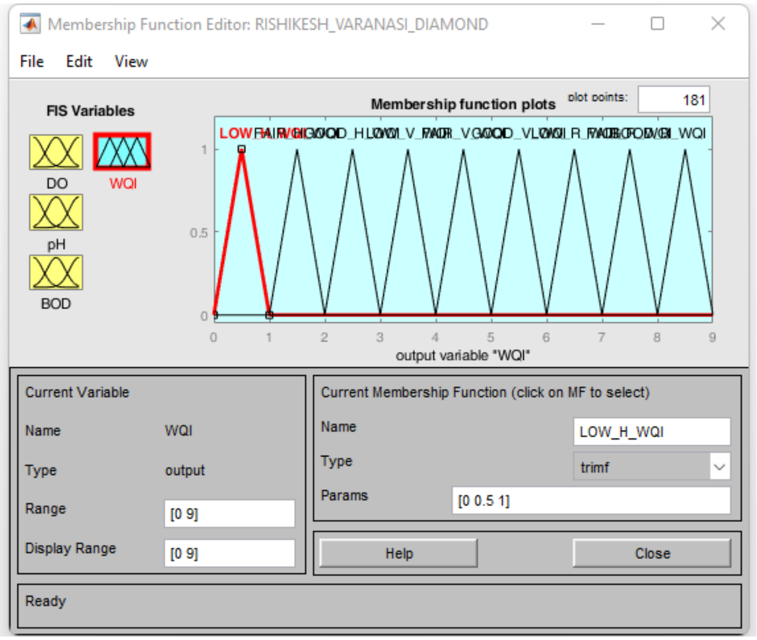

Figure 9 (a): Membership function for the water quality index (WQI)

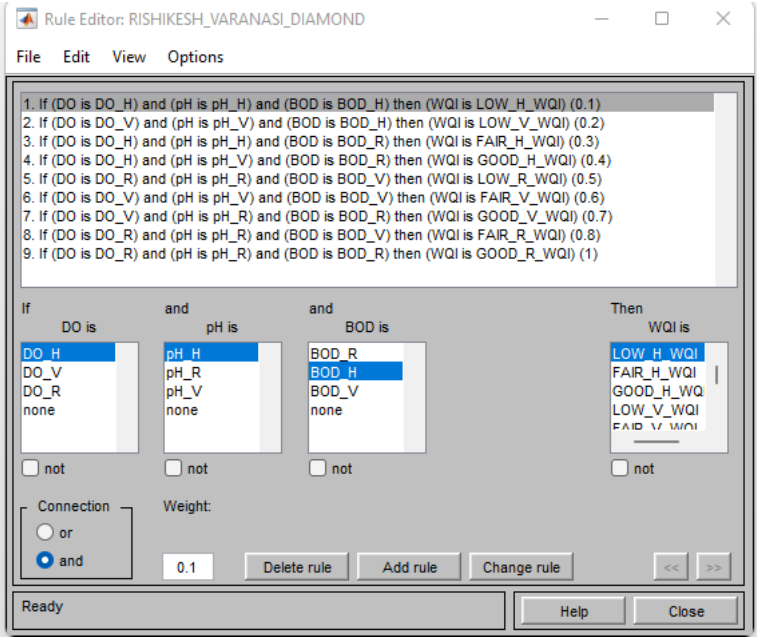

Figure 9 (b): Rule set of our proposed model

RESULTS AND DISCUSSION

As we defined the rule set in the Fuzzy tool box, we also draw three different surface viewer graphs in 3-D. Fig. 10 shows the relationship between WQI, DO and pH; Fig. 11 shows the relationship between WQI, BOD and DO; and Fig. 12 shows the relationship between WQI, BOD and pH. Fig. 10 shows that when the pH level is between 7 and 8 and dissolved oxygen is greater than 8.5 mg/l, the surface is high, and the color yellow, which is generally found in Rishikesh, also indicates that the WQI is good. In the Assi ghat Varanasi region, the pH level is the same, but DO becomes less than 8 mg/l. The three regions with blue color have high pH levels or low pH levels with low DO in the Ganga River, which generally we find at Diamond Harbor. The 24 Pargana region also indicates poor WQI. Fig. 11 shows that when the BOD value is from 2 to 10 mg/l and DO is less than 5 mg/l, it shows a dark blue color, where the WQI is also poor, which is found in Good Diamond Harbor, 24 Pargana. As the DO value increases slowly and the BOD is below 8 mg/l, the light green graph indicates that the quality of the WQI is average, which is found in the Assi Ghat Varanasi region. The DO high and BOD less than 2 mg/l than WQI is excellent, which shows the sea green color found at Rishikesh. Fig. 12 shows that as the BOD is in the range of less than 5 mg/l and the pH level varies between 7 and 8.5, the WQI is good, with good dissolved oxygen, which is good for river quality.

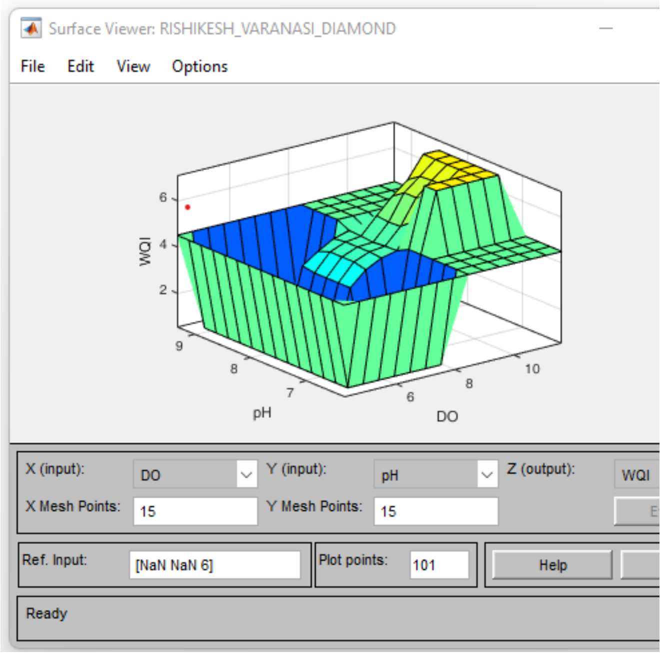

Figure 10: 3D graph of WQI, pH and DO

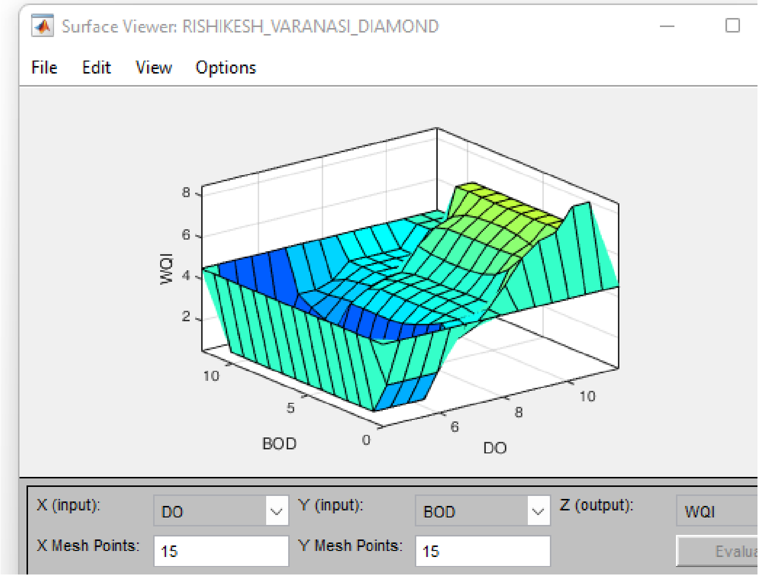

Figure 11: 3D graph of the WQI, BOD and DO

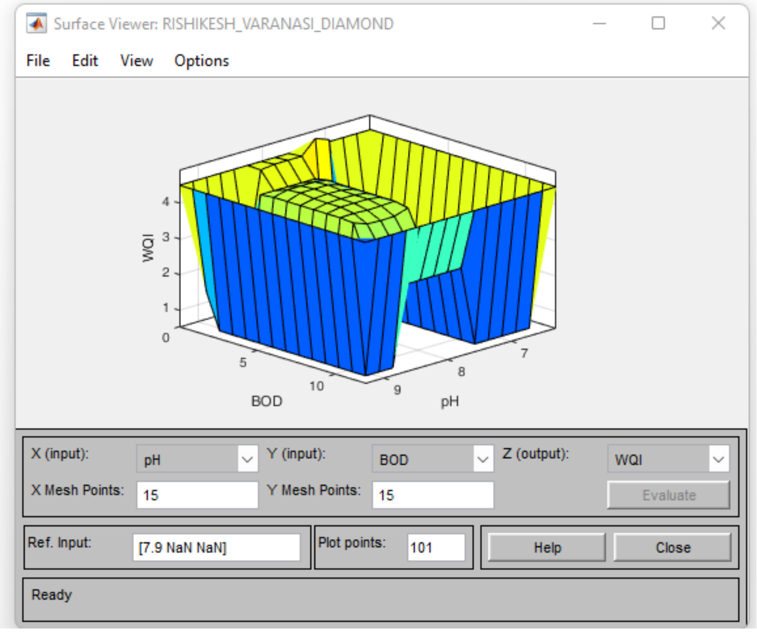

Figure 12: 3D graph of WQI, pH and BOD

CONCLUSION

As in this paper, to measure the water quality index of river Ganga, we used the Fuzzy Logic Toolbox in MATLAB, which provides accuracy in deciding the quality of water. We considered three parameters for calculating the water quality index: dissolved oxygen, pH level and biological oxygen demand. The values of these parameters are determined on the basis of three different places from the upper area reach to the lower area reach, such as Rishikesh (upper area), Assi ghat Varnasi (middle area) and Good Diamond Harbor, 24 Pargana (lower area). In this paper, we done comparison with Vedprakash water quality index(VWQI), where we found the accuracy of fuzzy has been higher than VWQI because in VWQI we uses only mathematical values but in fuzzy we can able to use range for defining membership function of each parameters. Fuzzy Logic used membership functions trimf() for defining the range, which are shown in Figures 5, 6 and 7. To decide the rule set, we used the weight factor mathematical value from 0 to 1 and multiplied by each rule set, which provides better results with more accuracy if there is a slight change in the parameter values, which reflects a large impact on the quality index of water in the surface graph. After simulating the proposed model in the Fuzzy Logic Toolbox, we find that in Rishikesh, the WQI is excellent, and as we go down at Assi Ghat, Varanasi, the WQI is good because the pH level and BOD are within the range and DO is good because it lies in the middle reach of the river. However, at Good Diamond Harbor, 24 Pargana, the pH value varied on a large scale, as shown in Fig. 6, and BOD was also high in the lower reach from the river at the end point; therefore, the WQI was acceptable but not good. To ensure a better quality of water, we will need sensors of various types (Pandey et al., 2021) and a fuzzy logic toolbox for determining the WQI of river Ganga use for human beings and aquatic life survival purposes.

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