Dear Reviewer 1,

Thank you for your valuable comments on this work which helps us to improve our revised manuscript quality.

Reply to Comments

Referee Comment: In this paper a Raspberry Pi based Smart Sensing Platform is described, including Graphic User Interphase and a Fuzzy Inference System modelled in Python for drinking water quality monitoring. The topic is of importance since on-line water quality monitoring is emerging and dash-board like applications to inform operators and support them in decision making is becoming relevant. However the presented paper is rather superficial mainly describing the system and not the advantages in terms of operation. Especially because the application is about monitoring of groundwater quality that does not vary much in time and, therefore, is not the most indicated example to test such an on-line system. General comments: - Avoid starting abstract and introduction with very general statements on the "global water crisis"

Author Response: General Statements have been removed and the Abstract and Introduction is updated.

Referee Comment: It is not clear if the application is about groundwater quality (page 2, line 1) or drinking water quality (after treatment of groundwater, page 2 line 24).

Author Response: The application is about drinking water quality after treatment. The same has been corrected in the introduction. (Page 2 line 8)

Referee Comment: The choice of the sensors seems more practical than related to e.g. health issues. More explanation of this should be given.

Author Response: currently we have not focused on sensor selection. We are focusing on the parameter selection which are related to health issues.

Referee Comment: More explanation of the reasoning behind the "post-processing" should be given (as described on pg 4 and in figure 5). In principle drinking water is "good" when all parameters are in the specification or "unsatisfactory/bad" when at least one is out the specifications.

Author Response: If the water quality is monitored before post-processing, many of the parameters will be out of the permissible range and there is no significance of this work. In case if a parameter is on the lower and upper edge of the permissible range, this will have the same affect as the unsatisfactory/bad quality of the parameter. The same has been mentioned in the manuscript. (Page 3 line 3-5)

Referee Comment: Avoid copying figures and tables from others sources (such as figure 1-5,; table 1)

Author Response: The data in **table 1** is freely available in the CPCB website open for user and the same has been properly cited.

Figure 1 is also open source and properly cited.

Figure 2 has been removed.

Figure 3 the standard triangular membership function and is redrawn in Microsoft Visio. Also, all the parameters have been taken different.

Figure 4 has been corrected and updated.

Figure 5 is taken from the MATLAB fuzzy model which was used to validate the fuzzy model implemented in the python. The same has been updated in the section 4.3 validation and performance comparison. (Page 6 line 28-29)

Referee Comment: Check language including tenses: present tense when general, past tense when part of own research

Author Response: Checked and Corrected.

Referee Comment: Avoid repetition: explanation in materials and methods should not be repeated in results and discussion

Author Response: Checked and Corrected.

Referee Comment: Give more emphasis on the results and discussion: how do the results relate to other methods/literature, what is the advantage/disadvantage of the implemented system; what is missing and what is the way forward, etc.

Author Response: All these suggestions have been taken into correction and manuscript has been updated.

Referee Comment: Specific comments: - Pg1, line 7-9, delete sentence (not relevant here) – Pg 1, line 11, 12, 13, "is" = "was" (check rest of paper too) – Pg1, line 17-19, delete sentence (not relevant here) – Pg1, line 21-22, delete sentence (not relevant here) – Pg 1, line 25, "chlorine" = "chloride" – Pg 1, line 29, "Therefore: : :." Not clear what is meant, so rephrase. –

Author Response: Checked and Corrected in the complete paper.

Referee Comment: P2, line 6, explain the reasoning behind the guideline..-

Author Response: Explained in the section 2.1.

Referee Comment: Pg 2, line 15-17 check referencing (only last name first author, e.g.Jinturkar et al. (2010) and Icaga (2007) have: : : -

Author Response: References have been updated.

Referee Comment: Pg 2, line 15, check parentheses. –

Author Response: Corrected.

Referee Comment: Pg 2, line 25, this is a totally wrong statement! Not all water with e.g. high or low DO content contains e.g. nicotine: : : -

Author Response: Corrected and updated in the manuscript in the materials and methods section.

Referee Comment: Pg 3, line 7 "produce" = "produces". – Pg 4, line 6 "systam" = "system" – Pg 5, line 2 check parentheses. – Pg 5, line 24-30, repetition of materials and methods –

Author Response: Corrected and updated.

Referee Comment: Pg 6, line 8-11, this should be the major message of the paper. What can we conclude, how does this relate to other work, how we can use the system e.g. for error detection?

Author Response: The suggestions have been taken into consideration and updated in conclusion section.

Raspberry Pi based Smart Sensing Platform for Drinking Water Quality Monitoring System: A Python Framework Approach

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Abstract. ~~Drinking or potable water quality monitoring is essential for mankind as it affects the human health directly or indirectly. This work reports a smart sensing platform for potable water quality monitoring. Five water quality parameters (pH, Dissolved Oxygen, Oxidation Reduction Potential, Electrical Conductivity, and Temperature) have been selected to monitor the water quality.~~ This paper proposes the development of Raspberry Pi based hardware platform for water quality monitoring. The selection of water quality parameters was~~is~~ made based on guidelines of the Central Pollution and Control Board, New Delhi, India. A Graphical User Interface (GUI) was~~is~~ developed for providing~~to provide~~ an interactive Human Machine Interface to~~for~~ the end user for ease of operation. Python programming language was~~is~~ used for GUI development, data acquisition and for data analysis. Fuzzy computing technique was~~is~~ employed for decision making to categorize the water quality in different classes like bad, poor, satisfactory, good and excellent. The system has been tested for various water samples from five different locations~~resources~~ and results have been displayed. For authentication, the results were compared with benchmark instrument EXO-1.

1 Introduction

~~Drinking water quality monitoring is very essential before consumption in daily life as it affects directly or indirectly human health (Bhardwaj et al., 2018). The water crisis has become a global problem in recent years, it is not limited to a particular region or country. By the end of 2025, half of the world population will be living in water-stressed areas (World Health Organization (WHO), 1996).~~ Water quality monitoring is essential before consumption in daily life as it may effect human health directly or indirectly (Bhardwaj et al., 2018). According to world health organization, half of the world's population will be living in water-stressed areas till the end of 2025 (World Health Organization, n.d.). In developing countries, as much as 80% of illnesses are linked to poor quality water and sanitation conditions (Anan, 2003). ~~India is one of the most water-challenged countries, among developing countries in the world. Groundwater levels are decreasing day by day as farmers, city residents and industries are regularly draining wells and aquifers.~~ The available water is severely polluted, and the situation may become ~~it may create the~~ worst ~~situation~~ in the future. Drinking water with pollutant concentration exceeding BIS (Bureau of Indian Standard) limits, is considered unsafe. The ~~groundwater~~water quality was measured by different govt. agencies among 632 districts in India which can be ~~by~~ accessed on IWT (India Water Tool) visualization~~2.1~~ tool (World Resources

Institute, 2016) among 632 districts in India. Among 632 districts, 59 are above BIS limits. The yellow and red areas in figure 1 indicate places where chloridechlorine, fluoride, iron, arsenic, nitrate and/or electrical conductivity exceed national standards. This is one of the most critical reasons why drinking water quality monitoring is essential.

Traditionally, water quality measurement involves sample collection on sites and subsequent laboratory chemical based analysis, which is both the labor and cost intensive (Korostynska et al., 2013). Also, the measurement is not in real-time. Hence, to reduce the labor cost and time consumption,Therefore it is the there is a need of the hour to have real-time monitoring of water quality for drinking applications (Bhardwaj et al., 2015). The work presented in this paper aims to provide an efficient real-time monitoring of ground water quality in drinking applications and can address the issues related to drinking water quality for various species.

The proposed work consists of Multi-Sensor Array (MSA), hardware platform along with a software platform (i.e. python framework). In the first stage, MSA iswas designed that consists an array of commercially available individual sensors for water quality parameterspH, Dissolved Oxygen (DO), Oxygen Reduction Potential (ORP), Electrical Conductivity (EC) and temperature. The Total Dissolved Solids (TDS) is derived from Electrical Conductivity (EC). The selection of the parameters is based on the guidelines of the Central Pollution and Control Board (CPCB), New Delhi, India (Central Polution Control Board, 2007). In the second stage, the hardware platform was designed based on the Raspberry Pi board. An additional serial port expander wasis used since Raspberry has only one I2C channel and it iswas required to communicate with all the sensors simultaneously. In the third stage, a Graphical User Interface (GUI) was designed for Human Machine Interface (HMI) and fuzzy modeling in python. software platform is designed which consists of Graphical User Interface (GUI) for interactive Human Machine Interface (HMI) and fuzzy modeling. A python framework is utilized in software and GUI development. The water standard wasis defined based on calculated water quality parameters using Fuzzy Inference System (FIS) since FIS has the capability to imbibe vagueness related to observed parameters. The fuzzy approach reported in this work has been used and discussed widely in many environmental applications and helps in decision making in many real-life complex problems (Lermontov et al., 2009).

Many researchers such as(S. Ponsadailakshmi (Ponsadailakshmi et al., 2018), A. Tiri (Tiri et al., 2018), B. V Raman (Raman et al., 2009), A. M. Jinturkar (Jinturkar et al., 2010), and Y. Icaga (Icaga, 2007), etc.) have implemented the fuzzy modeling in MATLAB for water quality index calculation. That process of modeling is offline for e.g. researchers have collected the data and later done the modeling in MATLAB. Whereas in this paper, we are trying tohad implement the fuzzy in real-time calculation spontaneously after the data collection with the help of libraries in the Python framework.

2 Materials and methods

2.1 Water Quality Parameter Selection Criteria

Water quality parameter selection is a critical step as this will determine the overall water quality. The Central Pollution and Control Board (CPCB) have suggested the criteria of water quality parameters for different usage of the water which is shown in table 1. CPCB have decided five different categories for the use of water in different applications such as irrigation, drinking, bathing, etc. In this work, category 'C' parameters have been considered since we are targeting drinking water source after conventional treatment and disinfection. If the water quality is monitored before the treatment and disinfection, most of the parameters will be out of permissible range. In case if the parameter is on the lower or upper edge of the permissible range, this will have the same effect as the poor quality of the parameters. This is the reason behind the selection of category 'C'. Also, ~~E~~experimental work done by US Environmental Protection Agency (USEPA) has proven that ~~water quality parameters such as pH, EC, and DO~~ high or low level of DO and ORP are ~~indirect~~the indicators of contaminants such as nicotine, arsenic trioxide and Escherichia coli (Hall et al., 2007) (Power and Nagy, 1999). That's why for the detection of contamination, the same~~se~~ water quality parameters ~~have~~can be~~en~~ considered as promising criterion.

2.2 Defining Water Quality

The fuzzy inference system (FIS) has the ability to include vagueness in decision making and reasoning ~~mimics the way human thinks in his day to day life~~. Hence fuzzy logic based techniques proved to be very effective since it is less mathematically intensive as compared to neural networks and genetic algorithms etc. and supports approximate reasoning. In FIS, the knowledge is presented as linguistic rules. The inputs are converted from crisp value to linguistic variable by the process called fuzzification and these variables are fed to inference system. This inference system gives a new set of a linguistic variable which is then converted to crisp value with the help of defuzzification (MathWorks, n.d.). The basic process to design a fuzzy logic involves three (3) basic steps: 1) define membership function for each variable, 2) perform fuzzy inference based on the inference method, and 3) select defuzzification method to define water quality. ~~shown in figure 2.~~

The proposed fuzzy logic was implemented in python with the help of library known as scikit-fuzzy library (Anon, n.d.) to define the water quality from the groups of five linguistic variables defined as bad, poor, satisfactory, good and excellent. The fuzzy system uses Mamdani implication model, which takes five inputs pH, Electrical Conductivity (EC), Oxidation Reduction Potential (ORP), Dissolved Oxygen (DO) and temperature. The Mamdani Fuzzy Inference System produces~~produce~~ a more accurate response as compared to Takagi-Sugeno type model since it uses~~exerts~~ the centroid method of defuzzification. The defuzzified output of the model is water quality which corresponds to five inputs of the model. In this paper, Mamdani-type FIS model was~~is~~ implemented for~~in a~~ decision support system since it has~~possesses~~ spontaneous and interpretable nature of the rule base capability. To decide the water quality, five inputs and one output were~~are~~ selected, and modeling was~~is~~ performed based on these parameters. The selection of the membership function is done based on the complexity of the system considered for decision making. Triangular membership functions (MF) are~~is~~ most commonly used membership functions because of their~~its~~ linear nature and ease of implementation~~easy implementation ability~~ (Zhao and Bose, 2002) (Kosko, 1993), hence we have selected triangular MF to fuzzify the crisp variable into linguistic one. The triangular membership function as shown in figure 2~~3~~ depends on three parameters l, m and n and are given by equation 1.

$$f(x;l,m,n)=\begin{cases}0 & \text{for } x<l\\ \dfrac{x-l}{m-l} & \text{for } l\le x\le m\\ \dfrac{n-x}{n-m} & \text{for } m\le x\le n\\ 0 & \text{for } x>n\end{cases} \quad (1)$$

The logic operations used in the fuzzy logic are *min, max* and *compliment* and these are defined by the equation (2), (3) and (4) respectively. Let A and B are two subsets.

$$\mu_{A\cup B}(x)=\max\left[\mu_A(x),\mu_B(x)\right] \quad (2)$$

$$\mu_{A\cap B}(x)=\min\left[\mu_A(x),\mu_B(x)\right] \quad (3)$$

$$\mu_{\bar{A}}(x)=1-\mu_A(x) \quad (4)$$

After the logic operations, 'if-then' rule was~~is~~ applied. All the rules were ~~are~~ applied in parallel and the rule which does not a~~e~~ffect the output was~~is~~ ignored~~fired~~. The outputs of all rules were~~are~~ then aggregated and all fuzzy sets that affect the output, were~~are~~ combined into a single fuzzy set. Finally, the fuzzy set was~~is~~ converted into a crisp set by means of defuzzification in which a single number was~~is~~ generated. There are several methods for defuzzification such as centroid, maximum, mean of maxima, height and modified height. In this work, the centroid defuzzification method was~~is~~ used which is the most popular method. The output was~~is~~ calculated by averaging individual centroids, weighted by their heights as given by equation 5 (Zadeh, 1988).

$$U_o=\frac{\sum_{i=1}^{n}u_i\mu(u_i)}{\sum_{i=1}^{n}\mu(u_i)} \quad (5)$$

Where $\mu(u_i)$ is the min/max value of the membership degree of the input values (depends on min/max operator). The overall fuzzy inference system~~systam~~ used in this work is shown in figure 3~~4~~.

As per the acceptable range of water quality parameters, we have assigned two groups to each parameter which are desirable (DES) and undesirable (UNDES) as described in table 2. If the parameters are in the desirable range, then~~than~~ only fuzzy has been applied otherwise that~~e~~ sample has been rejected. After checking the desirable ~~acceptable~~ range, we have assigned individual membership functions to each parameter as shown in figure 4~~5~~. Also, we have defined the membership function for water quality on the scale of 0 to 100. After assigning the membership functions, "if-then" rule was~~is~~ applied and overall quality was~~is~~ defined ~~on the basis of~~based on adopted rule base formulation.

3 Hardware Platform Design

The hardware platform plays a vital role in any system development since data acquisition and data processing is done with the help of the hardware platform itself. The main task of the hardware platform design is MSA design and its interfacing with the raspberry pi board followed by python framework. The details of the design are given below.

3.1 Multi-Sensor Array (MSA) Design

For the proposed work, Multi-Sensor Array (MSA) is designed using the industrially manufactured sensors from Atlas Scientific, USA. The individual sensors are arranged in an array form to make the MSA. The sensors used are pH sensor, Electrical Conductivity (EC) sensor, Dissolved Oxygen (DO) sensor, Oxidation Reduction Potential (ORP) sensor and a temperature sensor. Total Dissolved Solids (TDS) parameter was derived from EC. The block diagram of MSA and its interfacing with hardware followed by software framework is shown in figure 5~~6~~.

3.2 Integration of MSA with Raspberry Pi board and interfacing with Python

Once the MSA is designed, it must be coupled to ~~integrated with~~ the Raspberry Pi for data acquisition and further data processing. Raspberry Pi is a single board credit card size micro-computer with ARM cortex A-53 processor (Raspberry Pi Foundation, 2014). It is an open hardware with many on-board running components like CPU, graphics, memory, USB controller etc. Nowadays, Raspberry Pi board is being used in many real-time applications (for e.g. real-time video surveillance system (MathWorks, n.d.), real-time paper currency recognition of new Indian notes after demonetization (Anilkumar and Srikanth, 2018), automatic traffic control system (Talukder et al., 2017), smart traffic system (Kumar et al., 2017), energy management system based on real-time electricity pricing model (Qureshi et al., 2017), self-driving system (Sumardi et al., 2018), 3D wavelet transform (Bernabé et al., 2018), and air quality monitoring system (Alkandari and Moein, 2018)).
Bhardwaj implemented the Cyber-Physical System (CPS) based water quality monitoring (Bhardwaj et al., 2018) using Arduino Uno board which has got some limitation with computational capabilities. Although Arduino is user-friendly, the reason for selecting the Raspberry Pi for this work is its computational capabilities that cannot be done in the Arduino platform. Apart from the computational capabilities, Raspberry Pi is bundled with inbuilt Bluetooth module, Wi-Fi module, HDMI interface, camera interface, display slot, SD card slot, USB slot, etc. which ~~has to~~must be interfaced externally in case of Arduino depending upon application.
For stand-alone applications, we can use a display panel and interface it with the python framework. We have used a 7″ touch screen and interfaced it with the python programming. Python is an open source programming platform and supports the data processing and computing. The only drawback that we are facing with raspberry Pi board is a limited number of I2C channel, so we have interfaced external serial port expender with the board to enhance the number of I2C channels. The experimental setup of MSA integrated with Raspberry Pi board is shown in figure 6~~7~~. It includes MSA connected to serial port expender and Raspberry board followed by python programming.

4 Results and Discussion

4.1 Experimental Procedure

The proposed system has been tested for water samples from five different locations. In order to get accurate readings, each sensor node has been calibrated before going for measurement. The calibration was performed with the reference solution given for each sensor. Initially, the measurement iteration was carried out for at least five minutes so that sensor reading gets stabilized because the original readings must be recorded only after the sensor attains stability in order to make any conclusive decision ~~illation~~ out of data. The system was tested for the total duration of 21 hours over seven days. The results obtained from MSA were accumulated through fuzzy inference system implemented in python framework. The average values of the experiment for all locations are shown in table 3.~~The data readings obtained from MSA were fed to the fuzzy decision support system implemented in python with the help of available libraries. The complete procedure of data acquiring, and fuzzy decision support system was implemented in python for real-time measurement.~~

4.2 Interactive User Interface

The graphical representation was ~~is being~~ provided for real-time data obtained from various sensors with the help of GUI platform for the interactive ~~user interface~~HMI. An interactive ~~Graphical User Interface (~~GUI~~)~~ has been designed in python framework with touch interface as ~~where the user can select the individual parameter to be measured as well as check overall water quality. A screenshot of GUI is~~ shown in figure 7~~8~~. The touch interface is provided for the ease of operation for operator. In the GUI, the operator can select the measurement from menu whether it is individual parameter or water quality with a single touch. The acquired data was kept for future use by means of saving in memory drive provided with Raspberry board. The live plotting of data is shown in figure 8~~9~~. The X-axis represents time and Y-axis represents the sensor node reading.

4.3 Validation and Performance Comparison

The validation of results acquired from the proposed system was done by comparing the results obtained from available benchmark equipment YSI EXO-1 sonde monitoring system and calculating the percentage relative error (PRE) (Lee, 2016). PRE expresses the error in percentage to determine the accuracy and is given by

$$\mathbf{PRE} = 100 * \left(\frac{\mathbf{actual} - \mathbf{observed}}{\mathbf{actual}} \right) \tag{6}$$

~~The system was tested for the total duration of 21 hours over seven days. The results obtained from MSA were accumulated through fuzzy implemented in python framework. The average values of the experiment are shown in table 3.~~ The calculated PRE plot is shown in figure 9~~10~~. Based on the results of the parameters obtained from MSA, water quality has been defined for all the locations using fuzzy libraries as shown in table 4. The input and output membership functions shown in figure 4 were implemented in MATLAB. The same has been used for the validation of the fuzzy model implemented in python.

The acquired results are from the distribution networks in real-time and hence, there is not much variation in sensor reading within the desirable range. To validate the system for water quality parameter deviation, parameters acquired from the benchmark equipment for different water sample has been used as input to the fuzzy model. The output of the fuzzy model has been observed and same has been shown in table 3 and 4.

5 Conclusion

Water quality monitoring is essential before consumption and its real-time monitoring will reduce the risk of illness in the human being. Traditional methods for water quality monitoring are being replaced by online water quality monitoring. The developed system has the facility for online water quality monitoring as compared to traditional methods. This reduces the labor-cost as well as time-consumption. The developed GUI has touch functionality which can help operators to operate the developed system easily and in decision making based on the results displayed on the screen. The system can be deployed in remote locations as it can run on a 12 V battery. In terms of the cost, the developed system is low cost as the benchmark which we are using costs approximate 11,000 USD and the proposed setup costs less than 1000 USD.

The developed system can be used for the fault detection of the sensors as well. We can scan the sensors if they are giving the right measurement value or not. The pH and ORP sensors need to dip into the reference solution, so these two sensors will give a fixed measurement value for the solution. The Do and EC sensors do not need any reference solution. They will have a certain amount of measurement value and can be observed. We can also scan the temperature sensor for the measurement. Based on the scanning of the sensors we can conclude that if the sensors are giving genuine sensor value or fake sensor value or not giving any value.

Internet of Things (IoT) can be implemented in the system as the Raspberry Pi has built-in Wi-Fi module which is missing in this work andThis paper reported a smart sensing platform for real-time water quality monitoring and to collect a large database. The designed platform is compatible with IoT networks as the Raspberry Pi used here has a built-in Wi-Fi module and will be implemented in futurefuture looks. The work presented here has both academic as well asand practical importance. Currently, the calibration of the sensor is time-consuming and requires a certain time period to get stabilized. In future looks, the focus will be on auto-calibration of the sensors and alsoand the drift analysis and compensation by means of algorithms.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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Table 1. Central Pollution and Control Board criteria for Water Quality (Central Polution Control Board, 2007)

Type of Water	Category	Quality Parameter Criteria
Drinking Water Source without conventional treatment but after disinfection	**'A'**	1. Total Coliforms Organism MPN/100ml shall be 50 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 6mg/l or more 4. Biochemical Oxygen Demand 5 days 20°C 2mg/l or less
Outdoor bathing (Organised)	**'B'**	1. Total Coliforms Organism MPN/100ml shall be 500 or less 2. pH between 6.5 and 8.5 ~~1.~~3. Dissolved Oxygen 5mg/l or more ~~2.~~4. Biochemical Oxygen Demand 5 days 20°C 3mg/l or less
Drinking water source after conventional treatment and disinfection	**'C'**	1. Total Coliforms Organism MPN/100ml shall be 5000 or less 2. pH between 6 to 9 3. Dissolved Oxygen 4mg/l or more 4. Biochemical Oxygen Demand 5 days 20°C 3mg/l or less 5. TDS 2000 mg/l
Propagation of Wildlife and Fisheries	**'D'**	1. pH between 6.5 to 8.5 2. Dissolved Oxygen 4mg/l or more 3. Free Ammonia (as N) 1.2 mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	**'E'**	1. pH between 6.0 to 8.5 2. Electrical Conductivity at 25°C micromhos/cm Max.2250 3. Sodium absorption Ratio Max. 26 4. Boron Max. 2mg/l

Table 2. Groups defined for water quality parameters

Range / Parameters	UNDES	DES	UNDES
pH	< 6.5	6.5-8.5	> 8.5
EC	< 300	300-1000	> 1000
ORP	< 200	200-800	> 800
DO	< 3	3-11	> 11
Temperature	< 2	2-35	> 35

* UNDES = undesirable
DES = desirable

Table 3 (a). Average values of samples for pH, DO & EC and their calculated PRE

Location	pH			DO (mg/l)			EC (µS/cm)		
	MSA	Commercial System	PRE (%)	MSA	Commercial System	PRE (%)	MSA	Commercial System	PRE (%)
1	7.45	7.51	0.8	8.20	8.16	0.49	385	387	0.51
2	7.62	7.68	0.78	7.90	7.89	0.13	435	426	2.1
3	6.95	6.99	0.57	9.50	9.47	0.32	510	515	0.97
4	8.1	8.2	1.2	9.23	9.21	0.22	390	385	0.13
5	7.8	7.87	0.88	8.05	7.98	0.88	445	455	0.22
6	8.2	8.21	0.12	7.8	7.7	1.2	1582	1576.2	0.36
7	8.1	8.04	0.75	7.5	7.4	1.35	1635	1621.8	0.81
8	8.1	8.01	1.12	7.5	7.4	1.35	1672	1662.1	0.59

Table 3 (b). Average values of samples for ORP & Temperature and their calculated PRE

Location	ORP (mV)			Temperature (ºC)		
	MSA	Commercial System	PRE (%)	MSA	Commercial System	PRE (%)
1	213	212	0.47	22.5	22.7	0.88
2	212	210	0.95	21.5	21.3	0.93
3	185	187	1.06	19.6	19.7	0.50
4	206	208	0.96	18.9	19.1	1.04

5	191	194	1.54	23.8	24.1	1.24
6	170.5	168.5	1.18	29.2	28.98	0.76
7	170.9	168.7	1.30	30.1	29.84	0.87
8	171.1	168.4	0.58	30.5	30.21	0.96

Table 4. Fuzzy water quality for all locations

Location	Fuzzy Water Quality (FWQ)
1	Good
2	Good
3	Satisfactory
4	Good
5	Good

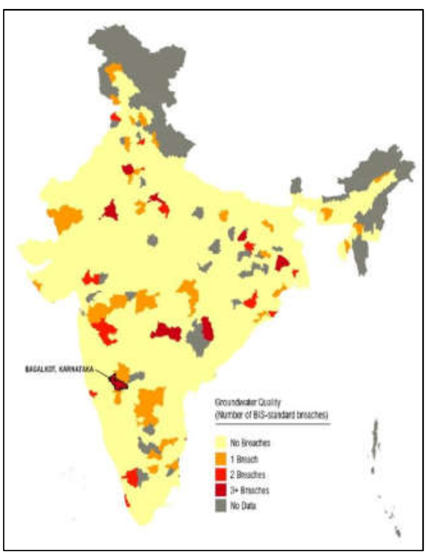
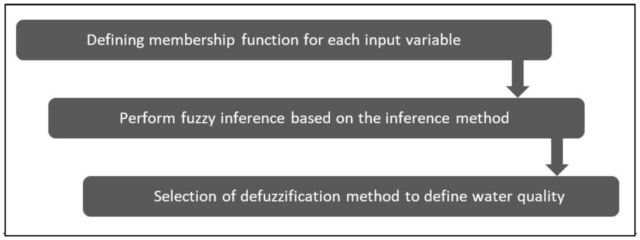


Figure 1 Groundwater Quality (Number of BIS standard breaches) (World Resources Institute, 2016)~~(Central Polution Control Board, 2007)~~



~~Figure 2 Fuzzy logic designing process~~

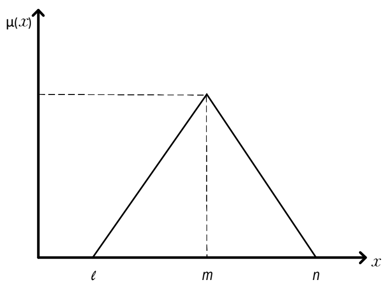
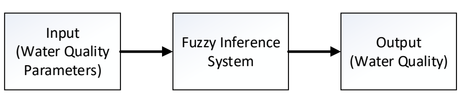
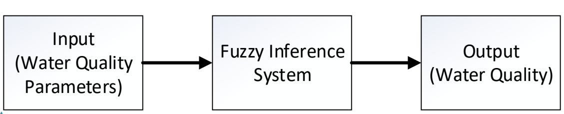


Figure 2~~3~~ Triangular Membership Function





Field Code Changed

Figure 34 Block Diagram of FuFISzzy Inference System used in the work

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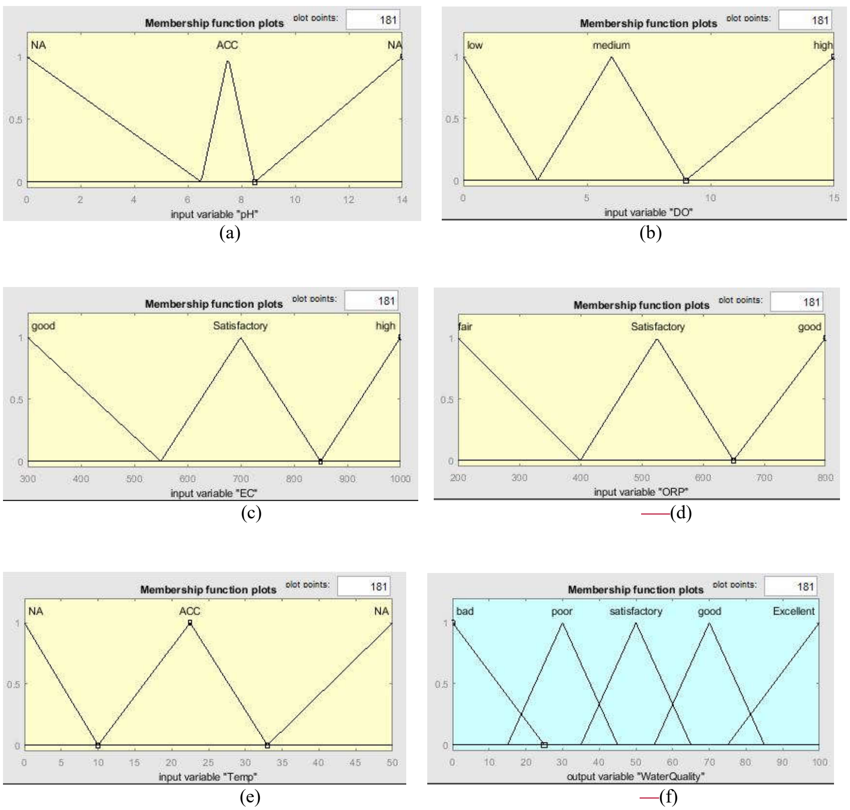


Figure 4~~5~~ Input and output membership functions

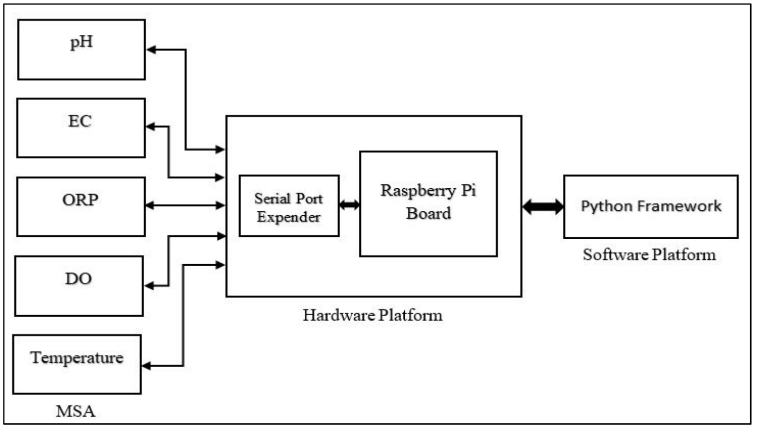
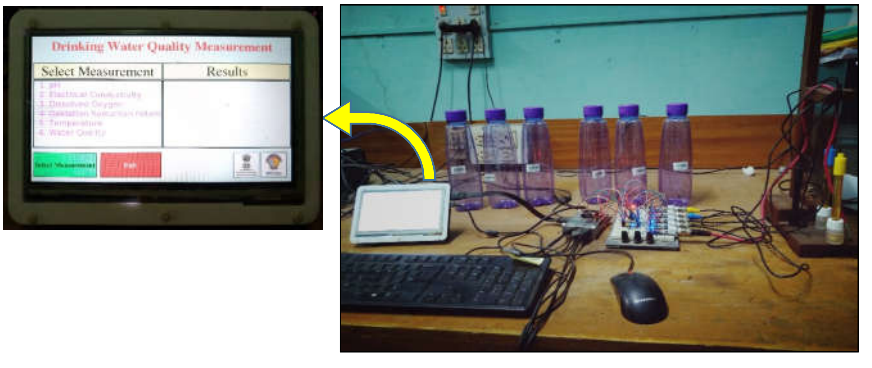
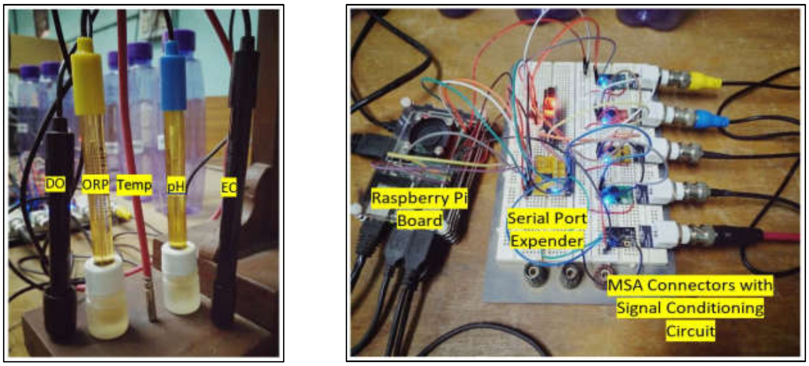


Figure 56 Block Diagram of Multi-Sensor Array (MSA) and It's Interfacing with Hardware and Software



(a)



(b) (c)

Figure 6~~7~~ (a) The proposed System (b) Multi-Sensor Array (MSA) (c) MSA integration with serial port expender and Raspberry Pi board

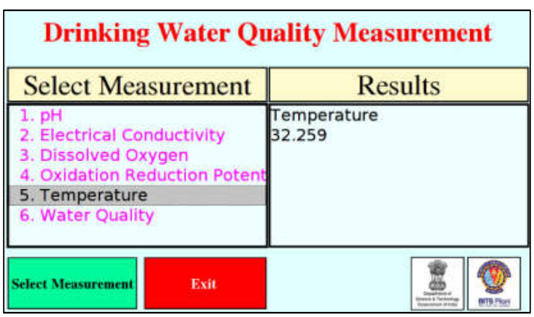


Figure 7~~8~~ Graphical User Interface

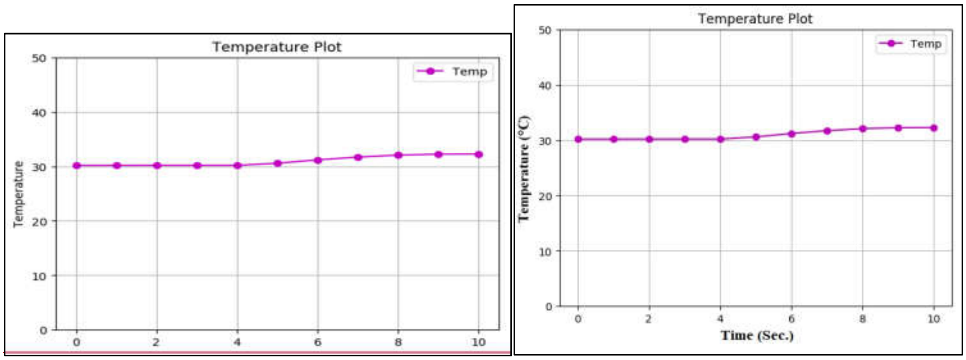


Figure 8 9 Temperature plot in GUI

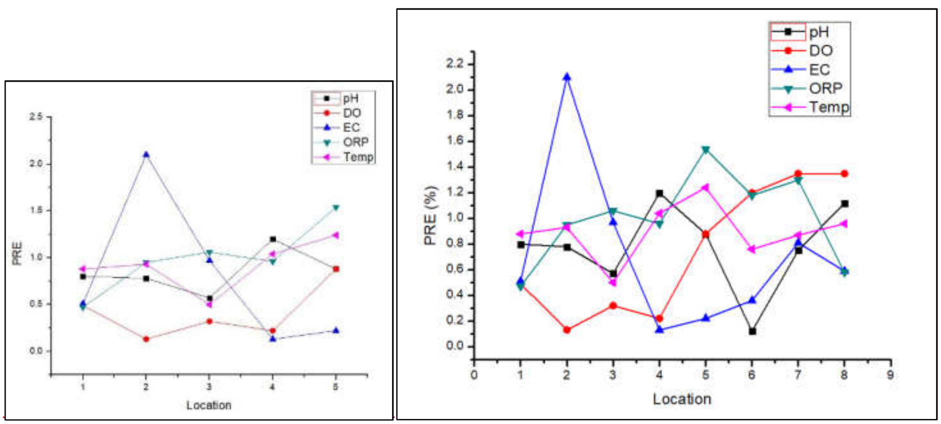


Figure 9 10 Percentage Relative Error (PRE) Plot for different water quality parameters