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DRINKING WATER QUALITY ESTIMATION USING FUZZY LOGIC TECHNIQUE

Twinkle Tayal [1], Dr. Prema KV [2]
[1 2] CS, FET
[1] M.Tech, 2nd year, MITS, RAJASTHAN
[2] HOD, CSE, FET, MITS,RAJASTHAN
[1] twinksgupta@gmail.com

ABSTARCT:

Water is the most vital natural resource for life next to air for not only the human community but for every other species existing on the earth. Increasing industrialization is increasing the pollution levels, thus, affecting the natural environment such as air, land, water, and alike. Drinking water quality is one of the core issues. It has been reported that the planet population is massively affecting due to the diseases having low water quality as source. So, unremitting observations and control of drinking water quality is an essential factor for any human community and for this purpose, great attempts are being made with a vision to develop an efficient, modern and complete systems to ensure water quality. So, in this research, a technique to estimate the drinking water quality is being proposed by using the fuzzy logic on the basis of several physical, chemical and microbiological indicators of water.

Keywords: *Drinking water quality; fuzzy logic; fuzzy; water quality estimation.*

1. INTRODUCTION

Drinking water quality is one of the issue that need continuous attention as it has been reported that worldwide, one out of five deaths of children under 5 is because of a water related disease. Moreover, exposure to contaminated drinking water leads to different disease like nausea, fevers, diarrhea and dehydration. Longer exposure can lead to heart disease, diabetes and even cancer. So, it is very- very important to drink water with low contamination to avoid such diseases. The human body can be called as a water machine, designed primarily to run on water and minerals. Every life giving and healing process that occurs inside our body happens with water. Our energy level is affected by the amount and quality of water we drink to a great extent. It has been evaluated that over 80% of our population undergoes energy loss due to inconsequential dehydration. Water quality can be depicted by specific microbiological, chemical and physical attributes of water. These attributes are generally maintained in a required range, predefined by upper and/or lower limits. So, in this study, the drinking water quality is being estimated by using the fuzzy technique**.** As fuzzy logic can be seen as an augmentation of classical logic, with a theoretical framework apposite for the treatment of problems possessing native subjectivity and with the linguistic terms, so, it's appropriate for the problem. In this paper, we attempt to develop a fuzzy based system which will evaluate the quality of drinking water based on the parameters like turbidity, nitrite content and so on. Based on the amount of indicators present, the water will be declared as accepted for drinking, partially accepted or not accepted. In this study, the water quality for drinking will be discovered by applying Mamdani Fuzzy Logic model. The compelling reason for selection of fuzzy logic model in this study is the natural fuzziness in the water quality and the difference of influence on water quality of each parameter.

2. FUZZY LOGIC

In 1965, L.A. Zadeh laid the basis of fuzzy set theory as a procedure to deal with the ambiguity of practical systems. Bellman and Zadeh wrote: "Much of the decision making in the real world takes place in an environment in which the goals, the constraints and the consequences of possible actions are not known precisely". This imprecision or vagueness is the core of fuzzy set. Fuzzy sets were projected as a generalization of classical set theory. The perception and application of fuzzy logic is becoming a imperative tool in addressing the issues of environmental science and policy. It's becoming a widespread practice to deal constantly with linguistic terms. Intuition is a fuzzy method that desires no introduction. It is derived from human ability of developing membership functions on the foundation of their own understanding. Fuzzy logic endeavours to model human thinking and reasoning and to relate the model to problems according to needs. It attempts to equip computers with the skill to process special data of humans and to work by using their experiences and understandings. When human logic unravels problems, it obtains verbal rules like "if <event realized> is this, then <result> is that". Fuzzy logic tries to accustom these verbal rules and the ability to make decisions of humans to machines/computers. It utilizes verbal variables and terms together with verbal rules. Verbal rules and terms used in human decision-making process are fuzzy or vague rather than exact, accurate or precise. Verbal terms and variables are expressed mathematically as membership degrees and membership functions. Fuzzy decision- making procedures use symbolic verbal phrases as a replacement of numeric values. Transferring these symbolic verbal phrases to computers is based on mathematics. The basis of this mathematical is fuzzy logic. Systems that use fuzzy logic are substitutes to the complexity of mathematical modelling of difficult non-linear problems and fuzzy logic meets mathematical modelling requirement of a system. Systems that use fuzzy logic can give effective results based on indistinct verbal knowledge like humans. In fuzzy logic, information is verbal phrases or we can say linguistic terms such as big, small, very, few etc. instead of numeric values. If a system's behaviour can be articulated by rules or requires very complex non-linear processes, then fuzzy logic approach can be applied in this system.

2.1. Mamdani's Fuzzy Inference Method

Mamdani's method was one of the first control systems that were built by using fuzzy set theory. Ebrahim Mamdani proposed it in 1975 as an effort to control a combination of steam engine and boiler by synthesizing a set of linguistic control rules acquired from experience of human operators. Mamdani's effort was based on Lotfi Zadeh's 1973 paper on fuzzy algorithms for complex systems and decision processes. Mamdani-type inference anticipates the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that requires defuzzification. It is possible and moreover competent in many cases to make use of a single spike as the output membership functions inspite of a distributed fuzzy set. This is sometimes called as a singleton output membership function, and can be deliberated as a pre defuzzified fuzzy set. It increases the effectiveness of the defuzzification process as it wholly simplifies the computation needed by the more general Mamdani method, which discovers the centroid of a two-dimensional function. It can be build by using either command line functions or with the graphical user interface (GUI) present in the Matlab. In the present study, water quality estimation is being done by building a Mamdani fuzzy inference system using the GUI tools , which basically consists of five editors which can be used to build, edit and view the system, as shown in figure 1, namely

- Fuzzy Inference System (FIS) Editor –this is the first editor that comes across in the procedure. It handles the high-level issues for the system like the number of input and output variables and their names.
- Membership Function Editor- this is the editor used to define the shapes and characteristics of all the membership functions related with each variable.
- Rule Editor- this editor forms the basis of the fuzzy inference system. It is used to edit the list of rules that defines the behavior of the system. Even by using this editor one can add, delete or make changes in the rules any time.
- Rule Viewer- this is a strictly read-only tool. It is basically utilized to view the fuzzy inference diagram. This viewer can be used as a diagnostic to see which rules are active on the corresponding input you have entered and how the individual membership function shapes persuade the results.
- Surface Viewer – this is also a read-only editor which can be used to view the reliance of one of the outputs on any one or two of the inputs. It is used to generate and plot an output surface map for the system.

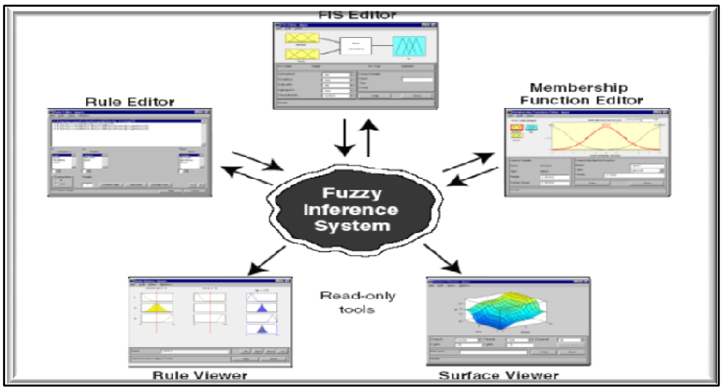

Fig.1. GUI editors in Mamdani fuzzy method.

3. DRINKING WATER QUALITY

Water is vital to sustain life, and a pleasing (adequate, safe and accessible) supply must be accessible to all. Improving availability to safe drinking water can result in sustainable benefits to health. As urbanization, industrialization and agricultural activities are growing continuously, it have been the principal causes of river pollution, soil degradation, so, every attempt should be made to attain a drinking- water quality as safe as feasible. Drinking water quality evaluation examines the 'goodness' of water for drinking. There are different techniques which can be used for this purpose. But due to the natural fuzziness in the water quality and the difference of impact on water quality of each parameter, the water quality evaluation may be regarded as a fuzzy problem. Basically, the drinking water quality can be estimated on the basis of presence of physical, chemical and microbiological indicators, as according to different standards by W.H.O. (World Health Organization), US EPA (United States environmental protection agency) and Indian government and many more organizations. Range of all the parameters are defined using the standards and based on these ranges, quality can be estimated. In this study, standards by W.H.O and US EPA are being used for drinking water quality estimation.

3.1. Water Quality Indicators

The parameters used for evaluating drinking water quality in this study are: turbidity, total hardness, presence of iron, BOD(biological oxygen demand), taste, pH, odor, colour, temperature, TDS(total dissolved solids), and presence of pathogens fecal_coliform. So, in total 11 inputs are used in this study. The effect of all of these parameters if present in water can be described as follows:

- Temperature- it has been reported that one shouldn't drink ice cold water as it can have an effect on your digestion. So, a certain temperature is suggested as a standard. Maximum allowable drinking water temperature is suggested as 15 degree Celsius.
- TDS (total dissolved solid)-Total dissolved solids (TDS) is the term that is used to describe the inorganic salts and small amounts of organic matter in solution in water. The existence of dissolved solids in water may have impact on its taste. The mineral salts that make up TDS pose a variety of certain health hazards.
- Turbidity -it is a measure of the quantity up to which the water drops its transparency because of the presence of suspended particulates. Higher turbidity levels are frequently related with microorganisms that can cause diseases such as viruses, parasites and some bacteria. These organisms can cause symptoms such as Nausea, Cramps, Diarrhea and headaches.
- Color- it is one of the evident water problems which is directly associated to almost every other drinking water quality parameter. Colored water imparts an adverse effect on human health and aquatic environment.
- Odor- it is really unwanted to have an odor or smell in the drinking water.

- Ph- The pH of water is a measure of degree of the acid–base equilibrium and, in largely natural waters, is controlled by the carbon dioxide–bicarbonate–carbonate equilibrium system. If exposed to extreme pH values, it may result in irritation to the eyes, skin, and mucous membranes.
- BOD-Biochemical oxygen demand is a measure of the quantity of oxygen used by microorganisms (e.g., aerobic bacteria) in the oxidation of organic matter. When unusual high levels of aerobic bacterial activity takes place, the level of dissolved oxygen can drop spectacularly.
- Hardness- Hard water is water having high mineral content in it. Both calcium and magnesium are essential minerals and valuable to human health in numerous respects. Insufficient intake of either nutrient can result in unpleasant health consequences.
- Iron- Iron is an indispensible element in human nutrition. The estimate of the minimum daily requirement for iron generally depends on age, sex, physiological status, and iron bioavailability and range from about 10 to 50 mg/day.
- Fecal_coliform-Health symptoms associated with drinking or swallowing water contaminated with bacteria generally ranges from no ill effects to cramps and diarrhea (gastrointestinal distress).

4. IMPLEMENTATION

The Fuzzy logic drinking water quality estimation model can be shown by help of Matlab Fuzzy logic toolbox editors as shown in the figure 2.

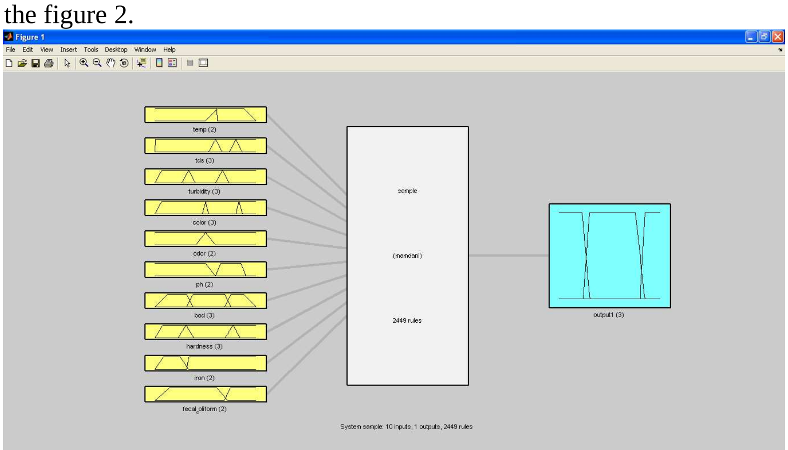

Fig.2. Fuzzy inference system for the model

4.1. Membership values

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

INDICATOR	VALUES
TEMPERATURE	• MINIMUM- 10 DEGREE CELSIUS • MAXIMUM – 15 DEGREE CELSIUS
TDS	• EXCELLENT-LESS THAN 300mg/l • GOOD- 300 – 600 mg/l • FAIR- 600- 900 mg/l

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	• POOR- 900-1200 mg/l • UNACCEPTABLE–GREATER THAN 1200 mg/l
TURBIDITY	• GOOD- LESS THAN 1 NTU • FAIR – 1-5 NTU • POOR- 5- 10 NTU • UNACCEPTABLE – GREATER THAN 10 NTU
COLOR	• NOT ACCEPTABLE – GREATER THAN 15 HAZEN UNITS
ODOR	• NOT ACCPETABLE – ABOVE 3
pH	• ACCETABLE – IN RANGE OF 6.5 – 8.5 • NOT ACCEPTABLE- BEYOND OR ABOVE THIS RANGE
BOD	• GOOD- LESS THAN 3 mg/l • POOR- 3-6 mg/l • UNACCEPTABLE- GREATER THAN 6 mg/l
HARDNESS	• GOOD- 80- 100 mg/L • FAIR- LESS THAN 200 mg/l • POOR- 200-500 mg/l • UNACCEPTABLE – GREATER THAN 500 mg/l
IRON	• GOOD- UPTO 0.3 mg/l • POOR – UPTO 1 mg/l • UNACCEPTABLE – ABOVE 1 mg/l
FECAL_COLIFORM	• ACCETABLE UPTO 5% OF THE 40 SAMPLES PER MONTH

Table 1 Membership values

For simplicity, some of the indicators are normalized. So that they can be represented easily by the membership functions. Like,

- In TDS, 100 mg/l is assumed to be 1 mg/l and the categories of EXCELLENT, GOOD and FAIR are grouped into ALLOWED range, whereas, POOR and UNACCEPTABLE are grouped into NOT_ALLOWED.

- In Turbidity, GOOD and FAIR are categorized into GOOD, POOR as POOR and UNACCEPTABLE as UNALLOWED.
- In Color, 2 hazen units are taken as 1 hazen unit and GOOD and FAIR are categorised to GOOD, and POOR is considered as POOR, UNACCEPTABLE as UNALLOWED.
- In Hardness, 50 mg/l is taken as 1 mg/l. GOOD and FAIR are considered to be GOOD. POOR as POOR and UNACCEPTABLE as UNALLOWED.
- In Iron, GOOD and POOR are considered to be in range of ALLOWED and UNACCEPTABLE as UNALLOWED.
- In fecal_coliform, 1% is taken as 1 unit on x axis.

4.2. Membership function editors

Different membership function editors for the inputs and output are shown in the figures below.

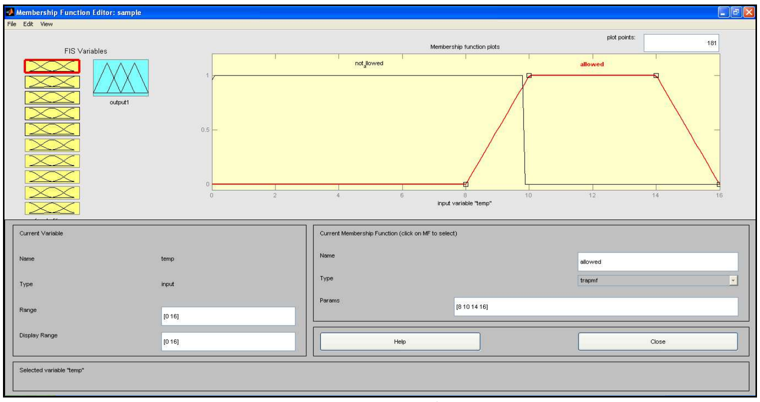

Fig -3: MF editor for temp

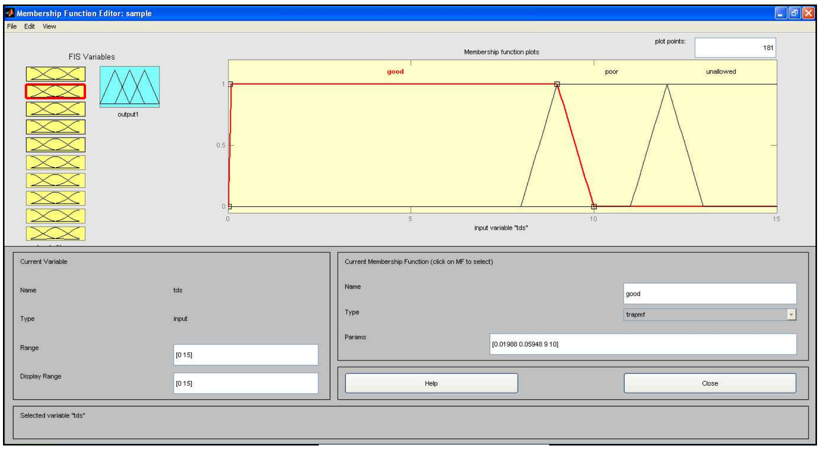

Fig -4 : MF editor for TDS

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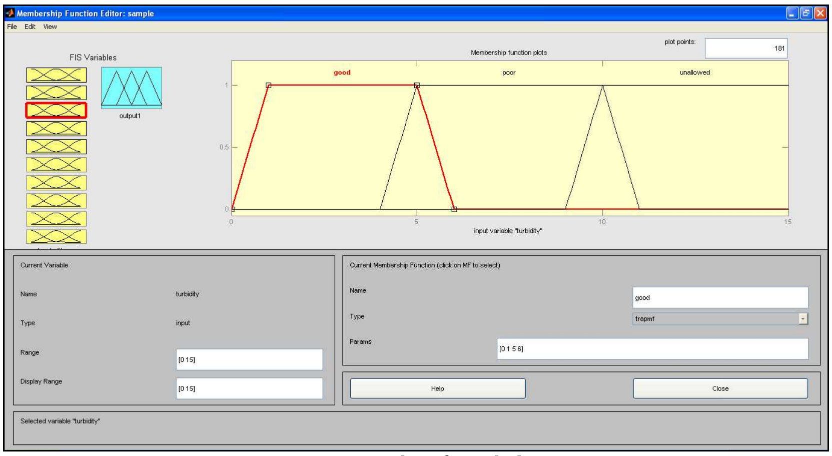

Fig -5: MF editor for turbidity

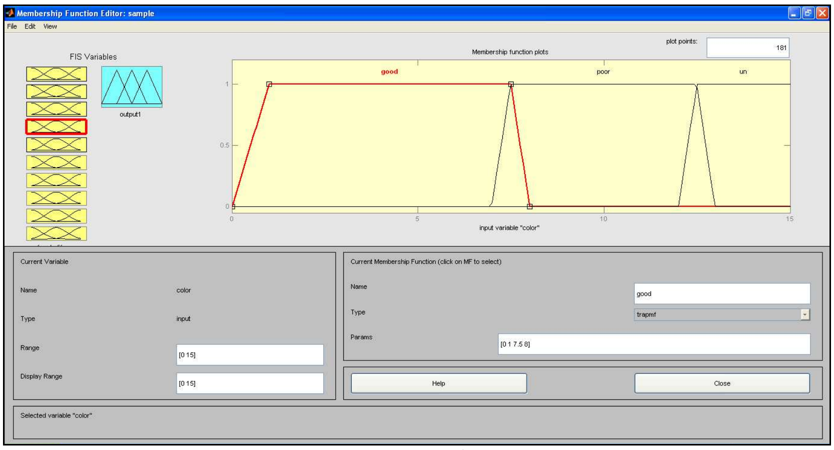

Fig -6: MF editor for color

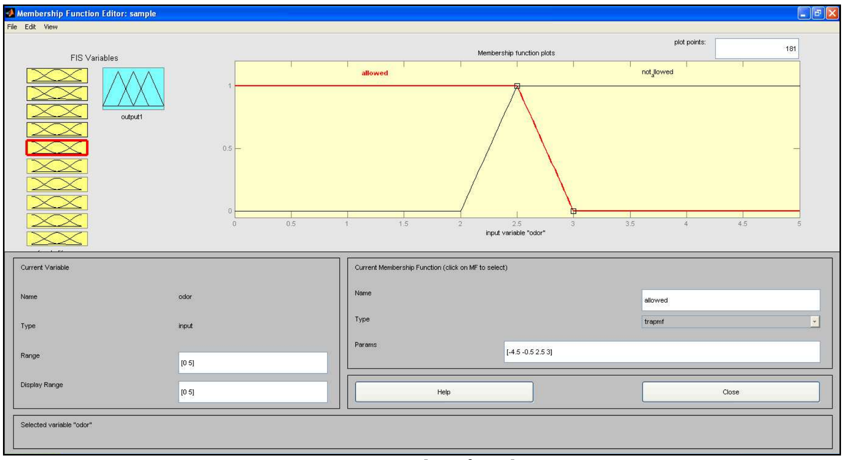

Fig -7: MF editor for odor

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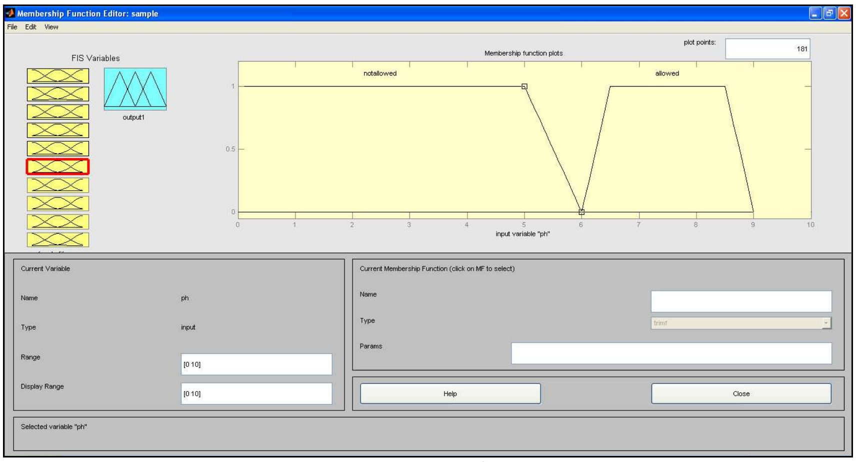

Fig -8: MF editor for pH

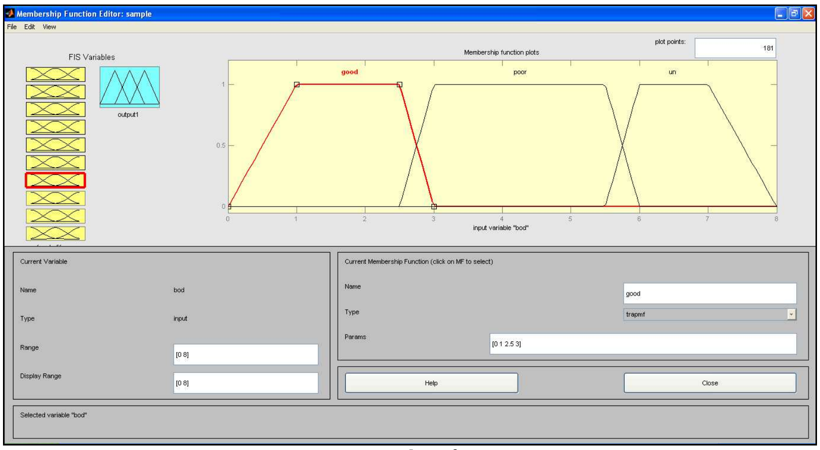

Fig -9: MF editor for BOD

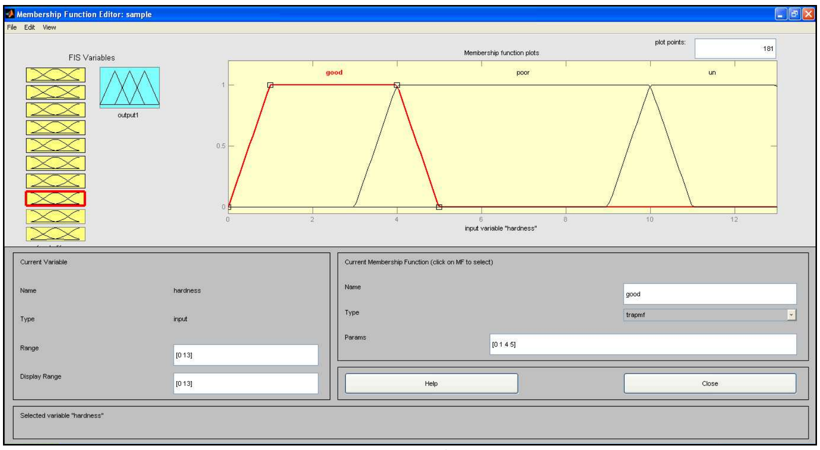

Fig -10: MF editor for hardness

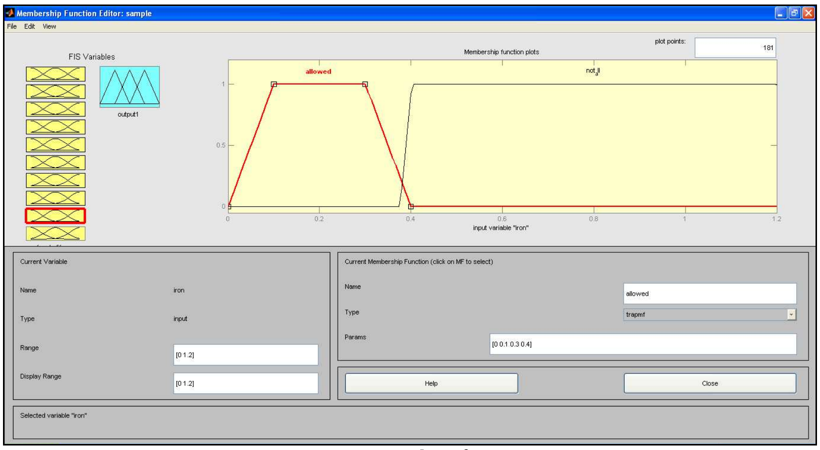

Fig -11: MF editor for iron

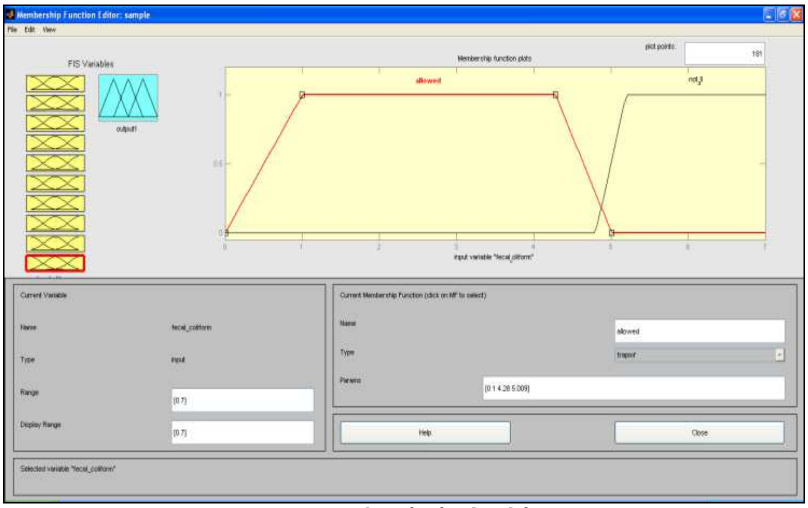

Fig-12: MF editor for fecal_coliform

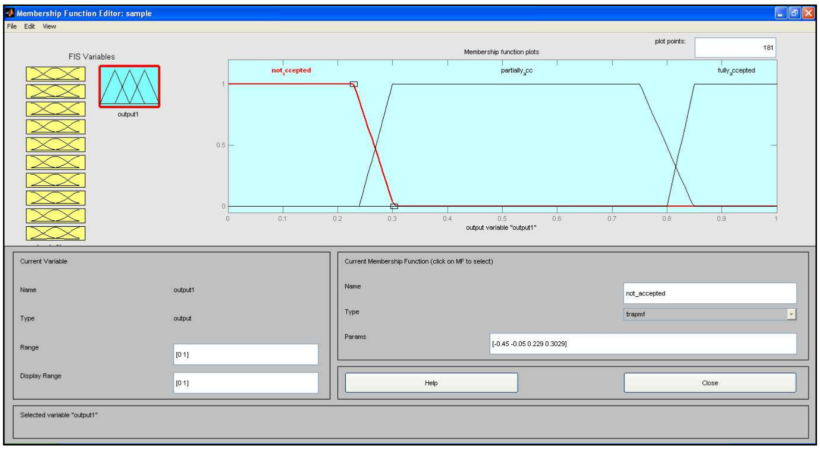

Fig -13: MF editor for output

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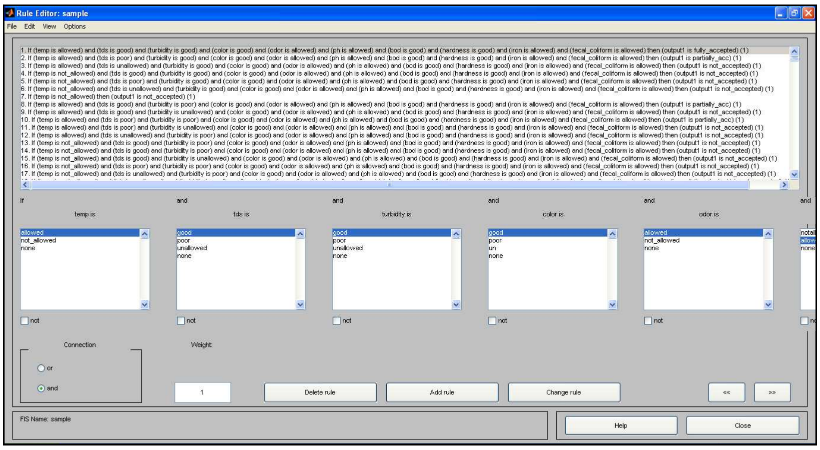

Fig -14: Rule editor for the system

4.3. Results

The rule viewer and surface viewer editors are used for getting the results. In this study, when taken different values for the different parameters, rule viewer shows a crisp output after defuzzifying the individual outputs. The defuzzification method used in the study is centroid method, as it is the most accurate and widely used defuzzification method. The surface viewer basically works well for 2 inputs, but if large no. of inputs is there, any two inputs can be taken which are considered to be as constant. The results are shown in figure 15 and 16.

For example, as input we take following values [8,7.5,7.5,7.5,2.5,5,4,6.5 ,0.6,3.5] for different parameters as explained in table 2, then, theoretically, output should be that water is NOT ACCEPTED for drinking as according to the standards that we have referred.

INDICATOR	VALUE TAKEN
TEMPERATURE	8
TDS	7.5
TURBIDITY	7.5
COLOR	7.5
ODOR	2.5
PH	5
BOD	4
HARDNESS	6.5
IRON	0.6
FEACL_COLIFORM	3.5

Table 2 values taken for the simulations

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The rule viewer when these values were taken is shown in the figure 15.

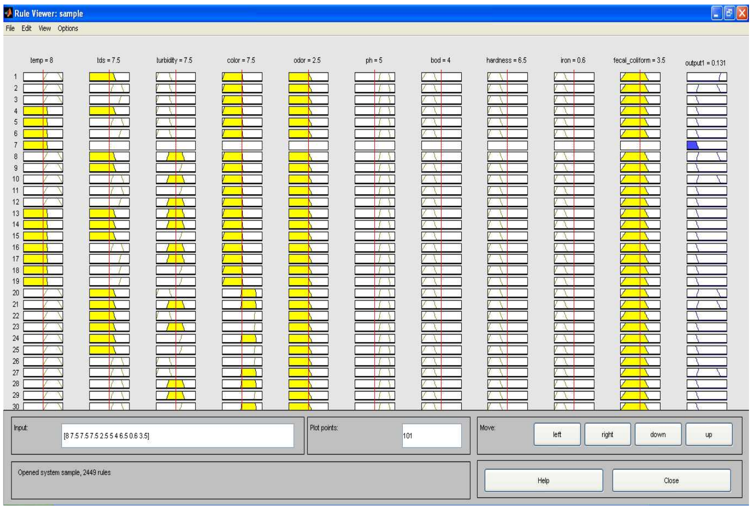

Fig -15: Rule editor for the system

Based on the values that we have taken, the result should come out be that drinking water quality is NOT_ ACCEPTED. As, the defuzzified output from the system is coming as 0.131 as shown in the rule viewer in figure 15. This value lies in the range of NOT_ACCEPTED, as according to the membership function taken for output as shown in the MF editor for output in fig. 13. The output of the current system designed by us can be shown by the snapshot of the command window of Matlab, as shown in fig. 16 and 17. As different surface views are possible on taking any two inputs as x and y axis, one such view when taken temp as x axis and tds as y axis is shown in figure 18.

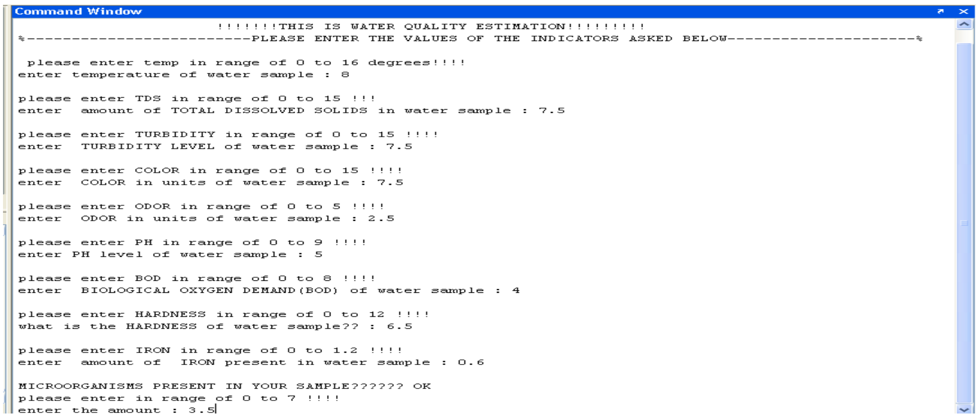

Fig -16: output window

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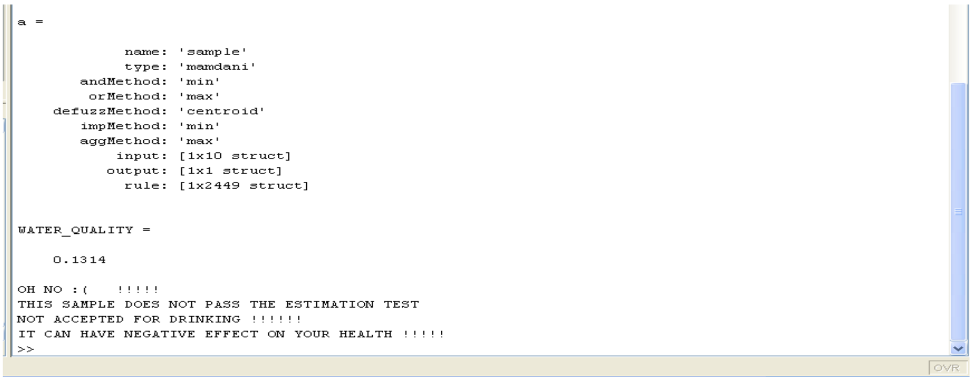

Fig. 17 output window

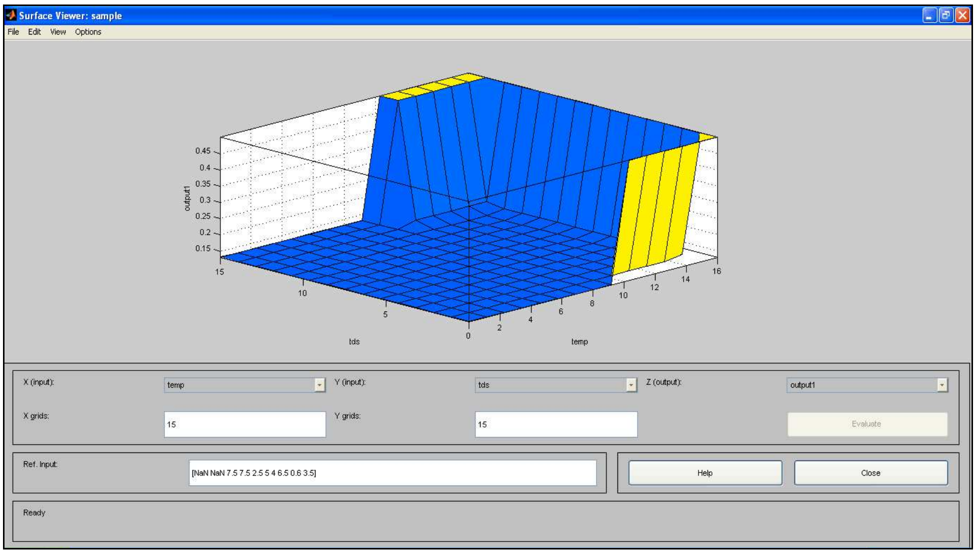

Fig -18: surface viewer for the system with temp and tds as inputs

5. CONCLUSION

Fuzzy logic provides a substitute to represent linguistic and subjective attributes of the real world in computing. The motive behind the selection of fuzzy logic model in this study is that system uses fuzzy logic model imparts effectual and real results depending on the uncertain, vague, indecisive and imprecise verbal knowledge just like logic of a human being. Moreover, it takes long time to use the other methods for such problem and by using fuzzy we can reach a general solution by doing only limited number of experiments. Mamdani has been designed in this study. The Method has been found capable of estimating the quality of drinking water. The obtained results appear to be a realistic and reasonable semblance with the desired results. The estimation scheme presented here can be considered as a step towards the water quality estimation, which can successfully be applied by taking other parameters into consideration.

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