Abstract—Water is a pivotal resource not only for human community, but for every single species existing on this earth. Water is used for different purposes, but primarily, it is used for drinking. But the rapid industrialization and urbanization is continuously increasing the pollution level in the water. This makes the drinking water quality an issue of concern. As it has been reported that one of the every five deaths of the children is due to a water-related disease. This is why continuous monitoring and control of drinking water quality is an essential factor for any human community and for this purpose, great efforts are being made with a view to develop efficient, modern and complete systems in order to ensure the water quality. In this research, we are proposing a Fuzzy based drinking water quality estimator, which will be able to tell the quality of drinking water, i.e. fully accepted, partially accepted or not accepted for drinking. The WHO and US EPA databases are used in this work. The reason why fuzzy logic has been chosen is the natural fuzziness in the impact of different parameters on water. Also, our system performance is compared with one of the existing works published in IEEE conference and the performance of our system is found to be better.

Keywords—Drinking water, Drinking water quality, Estimation of water quality, Fuzzy logic, Fuzzy logic technique, Water quality estimator.

I. INTRODUCTION

The human body can be called as a water machine, which is designed primarily to run on water and minerals. Every life giving and healing process that happens inside our body happens because of water. In just the last decade medical science has begun to focus more on the tremendous healing ability our body has and how much that ability depends on water. Our body instinctively knows how and strives to sustain youthful longevity, and in its every effort, water is the key. The human body is made up of over 70% water. Our blood is more than 80%, our brain over 75%, and the human liver is amazing 96% water! Our energy level is greatly affected by the amount and quality of water we drink. It is estimated that over 80% of our population suffers energy loss due to minor dehydration [1]. It has been reported that worldwide, one out of five deaths of children under 5 is due to a water related disease. Moreover, exposure to contaminated drinking water leads to different diseases like nausea, fevers, diarrhea and dehydration. Longer exposure can even lead to heart disease, diabetes and even cancer. So, it is very important to drink water with low contamination to avoid such diseases. There are several ways of calculating the quality of drinking water. Basically, there are different indicators which can be used as parameters to estimate the water quality. These indicators are given certain ranges by the different government and the private authorities. Water quality can be described by specific microbiological, chemical and physical attributes of water. These attributes are generally maintained in a desirable range, predefined by upper and/or lower limits [2]. So, in this study, the drinking water quality is being estimated by using the fuzzy technique. As fuzzy logic can be seen as an extension of classical logic, with a conceptual framework suitable for the treatment of problems possessing intrinsic subjectivity and with the linguistic terms, it’s suitable for the problem. So, in this paper, we attempt to develop fuzzy based technique which evaluates 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. All these indicators or factors after being estimated will be used in the model of fuzzy logic Mamdani type. In this study, the water quality for drinking will be discovered by applying Mamdani Fuzzy Logic model. The 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. The different indicators have different ranges standardized by the authorities like WHO, EPA, FDA and so on. As guidelines for all the parameters are not provided by one particular authority, so, in this study, standards by WHO (World Health Organization) and EPA (Environmental Protection Agency) are being used.
II. FUZZY LOGIC SYSTEM

In 1965, L.A. Zadeh laid the foundations of fuzzy set theory [3] as a method to deal with the imprecision of practical systems. Bellman and Zadeh write: “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” [4]. This “imprecision” or fuzziness is the core of fuzzy sets or fuzzy logic applications. Fuzzy sets were proposed as a generalization of convention set theory. Partially as result of this fact, fuzzy logic remained the preview of highly specialized and mathematical journals for many years. This changed abruptly with the highly visible success of several control applications in the late 1980s [5]. The concept and application of fuzzy logic is becoming a vital tool in addressing the issues of environmental science and policy. It’s becoming a common practice to deal constantly with linguistic terms [6]. Fuzzy logic aims to model human thinking and reasoning and to apply the model to problems according to the needs. It tries to equip computers with the ability to process special data of humans and to work by making use of their experiences and insights. When human logic solves problems, it creates verbal rules such as “if <event realized> is this, the <result> is that”. Fuzzy logic tries to adapt these verbal rules and the ability to make decisions of humans to machines/computers. It uses verbal variables and linguistic terms together with verbal rules. Verbal rules and terms used in human decision-making process are fuzzy rather than precise. Adapting human logic system to computers/machines will increase problem-solving ability of computers/machines. Verbal terms and variables are expressed mathematically as membership degrees and membership functions. Fuzzy decision-making mechanisms use symbolic verbal phrases instead of numeric values. Transferring these symbolic verbal phrases to computers is based on mathematics. This mathematical basis is fuzzy logic. Systems that use fuzzy logic are alternatives to the difficulty of mathematical modelling of complex non-linear problems and fuzzy logic meets mathematical modelling requirement of a system. Systems that use fuzzy logic can produce effective results based on indefinite verbal knowledge as humans. In fuzzy logic, information is verbal phrases or can say linguistic terms such as big, small, very, few etc. instead of numeric values. If a system’s behaviour can be expressed by rules or requires very complex non-linear processes, fuzzy logic approach can be applied in this system [7].

A. Mamdani’s Fuzzy Inference Method

Mamdani’s fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani’s method was among the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced 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 expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output membership functions rather than a distributed fuzzy set. This is sometimes known as a singleton output membership function. It can be build by using either command line functions or with the graphical user interface (GUI) present in the Matlab. In this study, we used the Mamdani method for the compelling reasons as it is spontaneous, commonly used, widely accepted and it is suited to system requiring human intervention. In the present study, the GUI tools are used , which basically consists of five editors to build, edit and view the system, as shown in figure 1, namely

1. Fuzzy Inference System (FIS) Editor -to handle the high-level issues for the system like number of input and output variables and their names.

2. Membership Function Editor- to define the shapes of all the membership functions associated with each variable.

3. Rule Editor- to edit the list of rules that defines the behavior of the system.

4. Rule Viewer- to view the fuzzy inference diagram. This viewer is used as a diagnostic to see, for example, which rules are active, or how individual membership function shapes influence the results.

5. Surface Viewer -to view the dependency of one of the outputs on any one or two of the inputs. It generates and plots an output surface map for the system [8].
III. DRINKING WATER QUALITY

Water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking water can result in tangible benefits to health. As growing urbanization, industrialization and agricultural activities have been the principal causes of river pollution, soil degradation, so, every effort should be made to achieve a drinking-water quality as safe as practicable. Drinking water quality assessment determines 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 influence on water quality of each parameter, the water quality evaluation may be regarded as a fuzzy problem [9].

A. Water Quality Indicators

The parameters used for defining drinking water quality in this study are: Turbidity, Temperature, Dissolved Oxygen (DO), and Presence of ammonia, Nitrite, hydrogen sulphide and of pathogen Fecal_coliform. The effect of these parameters (if present in water) can be described as follows:

1. Temperature- It has been reported that one shouldn’t drink ice cold water as it can affect your digestion. So, a certain temperature is suggested as standard. Maximum allowable drinking water temperature is suggested as 15 degree Celsius.

2. Turbidity - Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates. Higher turbidity levels are often associated with disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as Nausea, Cramps, Diarrhea, and Headaches [10].

3. Ammonia- Human beings and higher animals are less sensitive to ammonia in water, but long-term ingestion of water containing more than 1 mg/l (ppm) may be damaging to internal organ systems. Solutions having concentrations greater than 1000 mg/l (ppm) can cause severe burns and scarring of sensitive skin and mucous membranes [11].

4. Nitrite- There are two health concerns when drinking water has high levels of nitrates or nitrites. The first health concern is with infants being at risk for “blue baby syndrome”, also called methemoglobinemia. The second health concern with nitrates and nitrites is the formation of chemicals called nitrosamines in the digestive tract. Nitrosamines are being studied for long term links to cancer [12].

5. Hydrogen Sulphide- At the concentrations it is found in groundwater, it is generally not harmful, but at higher concentrations it can make you sick [13].

6. Fecal_coliform- Health symptoms related to drinking or swallowing water contaminated with bacteria generally range from no ill effects to cramps and diarrhea (gastrointestinal distress) [14].

IV. METHODOLOGY

Fuzzy system for water quality estimator can be designed by applying following procedure in the Matlab Fuzzy Logic Toolbox:

1. Examine the problem to be solved and select the input and output variables. In this study, input variables used are temp, turbidity, DO, ammonia, nitrite, hydrogen_sulphide and fecal_coliform and output variable used is waterquality.
2. Selecting the fuzzy inference rules. This generally depends on human experience and trial-and-error. The interference rule is selected based on the degree of match and the results of the standards by WHO and EPA. The values are rounded off to fit linguistic terms.

3. Fuzzy membership functions for each of the input and the output. Fuzziness in a fuzzy set is characterized by its membership functions. It classifies the element in the set, whether it is discrete or continuous. This involves determining the position, shape as well as overlap between the adjacent membership function, as these are major factors in determining the performance of the fuzzy logic. In defining membership function, different geometric shapes such as triangular, trapezoidal, or curved etc are used. The selection is dependent on the one’s knowledge and understanding of the process. In this study, we are considering trapezoidal membership function as it is most commonly used shape and moreover, it is best describing the current problem.

4. Performing fuzzy inference based on the inference method. Smoothness of the final control surface is determined by the inference and defuzzification methods.

5. Select a defuzzification method to estimate the water quality. Defuzzification means the fuzzy to crisp conversions. As the output through the fuzzy system is also fuzzy. So, to use it practically, it needs to be converted into a crisp value. There are different methods used for defuzzifying the fuzzy output functions, like, Centroid method, weighted average method, Centre of sums, Centre of largest area and so on. Most commonly used method is centroid method, which is being used in this study.

In summary, a fuzzy decision is the result of weighing the evidence and its importance in the same manner that humans make decisions. Fuzzy logic reflects human like thinking where the human can deduce an imprecise conclusion from a collection of imprecise premises.

A. Input/ output membership functions

There are 7 inputs in this system. Each input is described by using the different membership functions such as good, bad, poor, allowed and not allowed as according to their ranges. The output water quality is described by the membership functions good, fair and bad. The output of assessing the quality of water decides whether the water quality is fully accepted if good, partially accepted if fair and not accepted if bad. These functions represent a degree of a binary value, 1 being the highest and 0 being the lowest [6]. All the inputs and output are described by using trapezoidal membership function. It will create uniformity in the system. All the membership functions are shown in the following figures.
3. Membership Function for input Turbidity

4. Membership Function for input DO

5. Membership Function for input Ammonia

6. Membership Function for input Nitrite

7. Membership Function for input Hydrogen_sulphide

8. Membership Function for input Fecal_coliform

9. Membership Function for output waterquality

B. Fuzzy Rules

Fuzzy rules play the most important part in the fuzzy system. These rules can be decided on the basis of one’s knowledge or understanding. As here, we are using the standardized data for all the inputs; fuzzy rules are dependent on them. The fuzzy rules basically are in the form of IF x then y. In the Matlab Fuzzy Logic Toolbox, there is a rule editor to enter the rules and edit them if required. 250 rules are used for the current water quality estimator. The rule editor for our quality estimator is shown in the figure 10.
There are three formats in which rules can be entered in the rule editor, that are either verbose, which is being used in the current study, or symbolic or indexed. A rule is defined in the following way:

If (temp is allowed) and (turbidity is good) and (DO is allowed) and (ammonia is good) and (nitrite is allowed) and (hydrogen_sulphide is allowed) and (fecal_coliform is allowed) then (waterquality is GOOD).

C. Simulations

We have conducted a number of experiments by entering the different values of the inputs and every time the system is giving correct output as it was assumed according to the standards. Rule viewer can be used to enter your inputs and see how each and every rule is behaving on your input. Finally, it gives one defuzzified crisp output based on the method you had used. We are using centroid method in the current study. For example, when we input the values such as [12 3 8 0.1 1 0.02 3]. According to the standards, the output should be water is highly and fully accepted for drinking as all the parameters are within the allowed range. When simulated from the system we have designed, the results are coming to be as, shown in figure 11.
V. RESULTS AND ANALYSIS

On conducting a number of experiments with different data sets, each time we are getting the correct output. As when we input the data as described above the result should be that drinking water is fully accepted. When applied, we are crisp output value as 0.914, which is coming under the range of GOOD. So, the result according to the fuzzy model is also that water is accepted for drinking. In the same way, for different inputs we are getting correct results as expected.

We have compared our work with the work in the IEEE research paper “Caldo, R.B.; Dadios, E.P., “Fuzzy Logic Control of Water Quality Monitoring And Surveillance For Aquatic Life Preservation In Taal Lake” in TENCON 2012 IEEE Region 10 Conference, © IEEE. Doi: 10.1109/TENCON.2012.6412268”. We have taken the same number of inputs as they had taken; even the parameters are also same. They had also implemented the problem in the Matlab Fuzzy Logic Toolbox as we have. But they had estimated the water quality for the aquatic life survival; we have estimated the quality for drinking. Moreover, they hadn’t used any actual data, they had just taken a dummy data, where as we have taken standardized data according to the well known authorities WHO and EPA and defined our membership functions for each input according to the standard ranges. They had taken 125 rules to describe the system, where as we have taken 250 rules in our system. We have uniformity in our system as we have described all the inputs by the trapezoidal membership functions. They had divided the different parameters into three categories, namely physical, chemical and bacteriological. They had calculated individual output for the three of the inputs and then combined them, whereas we are taking all the input parameters together, which is more realistic situation. Moreover, when compared with this existing system, our system is found to be more capable and is giving better results.

VI. CONCLUSIONS

Fuzzy logic provides an alternative way to represent linguistic and subjective attributes of the real world in computing. The reason for selection of fuzzy logic model in this study is that the system uses fuzzy logic model enables to provide effective results depending on uncertain verbal knowledge just like logic of human being. The quality of fuzzy logic model usage here is to reach a general solution by doing only limited experiments. It takes long time to use the other methods for such problem.
The fuzzy logic provides the quickest solution to the problem prevents to lose. Mamdani has been designed in this study. In Present work, the method has been found capable of estimating the quality of drinking water. The obtained results appear to be a reasonable resemblance with the desired results. The estimation scheme presented here can be considered as a step towards water quality estimation, which can successfully be applied by taking other parameters into consideration. Moreover, when compared with the existing system, it’s found to be more capable and is giving better results.

References


