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Development of New Water Quality Index Using Fuzzy Logic: A Case Study of Rivers in Calicut

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Abstract: ***Water quality monitoring involves the determination of various water quality parameters. But the use of individual water quality variable to describe water quality is not easily understandable by common people.In this paper a methodology based on fuzzy inference system to assess water quality index, Fuzzy water quality index (FWQI), was developed by exploring the limitations of conventional methods for water quality evaluation. The new method developed using fuzzy inference system reflects the actual environmental conditions. In the present study six fuzzy variables, pH, TSS, DO, BOD, nitrate and fecal coli forms, were employed to determine FWQI. Fuzzy inference system functions in a fuzzy logic mode which has a fuzzification unit, inference rule part and a defuzzification unit. The study was aimed at determining the water quality of various rivers within Calicut city. The result of the study clearly shows that the newly developed system has the ability to combine the qualitative and quantitative data of river system and express the water quality of rivers in a manner that reflects the actual environmental conditions.***

Keywords: Water Quality Index, Water Quality Monitoring, River Water Quality, Fuzzy Inference System.

1. Introduction

Water is an important natural resource as it is needed to sustain life on earth. Only 2.5% of water available on earth is fresh water, and 98.8% of that water is in ice and ground water. Less than 0.3% of all freshwater is in rivers, lakes, and the atmosphere. Though rivers and lakes forms small percentage of earth's water, this surface water is crucial. Safe drinking water is essential for humans and other forms of life This naturally flowing water course is of immense importance geologically, biologically, historically and culturally. Rivers and streams also provide habitat to many organisms, ranging from small, unicellular creatures to insects, vegetation, fish and mammals apart from drinking purposes. Rivers and streams are often breeding grounds for rare and exotic species of plants and trees and serve as home to ducks, beavers, otters and other creatures that build shelters along their shorelines.

Long time ago water resource engineers were concerned only about the quantity of water. But now the attention has also focused on quality of water resources due to its increased pollution. To ensure good quality, water bodies should be continuously monitored. Water quality of any specific area can be determined by physical chemical and biological parameters. Within each of these categories a number of quality variables are employed. But the use of individual water quality parameter to describe water quality is not understandable by common people (Shweta Tyagi et al, 2013). The suitability of a given water source for an intended use depends on the magnitude of these quality variables. (Prabhata K. Swamee, 2000). Water quality index (WQI) has been described as one of the most effective tool for describing quality of water. Water quality index was initially developed by Horton in 1965.The purpose of an index is not to describe separately a pollutant's concentration or the changes in a certain parameter.WQI allows analysts to aggregate the quantitative value of parameters into a single value for better interpretation. But to synthesize a complex reality in a single number is the biggest challenge in the development of a water quality index, since it is directly affected by a large number of environmental variables. Therefore, a clear definition of the goals to be attained by the use of such an index is needed (Andre Lermontov et al, 2011).

Water quality index is a single number that expresses the overall water quality in a particular stream at particular time, based on several water quality parameters. The object of the water quality index is to convert the complex water quality data into a simplified form that can be understandable. A water quality index allows combining information from various water quality parameters into a single value for easy and better interpretation. The main objective of these indices is to evaluate the general state of water, depending on a range of a group of established water quality parameters. But this single value is not able to depict all details about water quality since its accuracy depends on the number of parameters considered for the intended use. There are several methods for the determination of WQI. Some of them are National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI), Oregon Water Quality Index (OWQI), Weighted Arithmetic Water Quality Index Method etc.

Conventional water quality regulations contain quality classes which use crisp sets, and the limits between different classes have inherent imprecision. The methods which contain upper and lower limits have two ambiguities. Firstly, the traditional water quality evaluation methods use discrete form. This classification technique may cause a rough and imprecise approach for data, as in this approach, a parameter being close or far from the limit has equal impact for evaluation of concentration. Secondly, each quality parameter may belong to any quality classes. That is, all of the parameters may not be included in a single class. These established various quality classes in one sampling location may constitute confusion for quality definition of that sampling location. (Antara Sharma, Naman Udeshi et.al, 2014).

In modeling complex environmental problems, conventional methods often fail to make precise statements about inputs and outcomes, but fuzzy logic could be applied to the development of environment indices in a manner that solves several common problems, including the incompatibility of observations and the need for implicit value judgments. Fuzzy logic can be considered as a language that allows one to translate sophisticated statements from natural language into a mathematical formalism. Fuzzy logic formalism can deal with highly variable, linguistic, vague and uncertain data or knowledge and therefore has the ability to allow a logical, reliable and transparent information stream from data collection to data usage in environmental application system. There are at least six reasons why models based on fuzzy rules may be justified: first, they can be used to describe a large variety of nonlinear relations; second, they tend to be simple, since they are based on a set of local simple models; third, they can be interpreted verbally and this makes them analogous to Artificial intelligence models; fourth, they use information that other methods cannot include, such as individual knowledge and experience; fifth, the fuzzy approach has a big advantage over other indices, once they have the ability expand and combine quantitative and qualitative data that expresses the ecological status of a river, allowing to avoid artificial precision and producing results that are more similar to the ecological complexity and real world problems in a more realistic panorama; and sixth, fuzzy logic can deal with and process missing data without compromising the final result (Andre Lermontov,2011).

Md.Pauzi Abdulla et al. (2008) has defined fuzzy water quality index as a robust decision making tool for water management. In their study they have used fuzzy logic formalism to assess river water quality, by developing a water quality index based on fuzzy reasoning. In the effort to develop a new water quality index, Andre Hermmotov et al. (2011) have used nine water quality parameters. The parameters were classified based on linguistic description such as very excellent to very bad. The nine parameters were grouped into five such as group one with pH and temperature, group two including DO and BOD, group three consisting of fecal coliform, group four comprising of dissolved inorganic nitrogen and total phosphorous and group five containing total solids and turbidity. Trapezoidal membership function was used for very excellent class and rests were defined with triangular membership function. Babei Semiromi F et al. (2011) developed a model to predict the status of water quality and to show the type of water treatment to be used to meet different demands. Fuzzy water quality index could be used as a decision maker in the water management, according to Jaun D Gonzalez H et al. (2012). A study on irrigation water quality assessment based on fuzzy logic approach was done by Priya K L (2013). Asmaa Mourhir et al. (2014) proposed a new river water quality index for Morocco using Fuzzy inference system. The water quality was evaluated using six indicators, DO $BOD_{(5)}$, COD,FC,TP,NH_4^+. Membership functions for different water quality indicators were developed by considering the boundaries from Moroccan and Quebec standards. Nidhi Mishra and P Jha (2014) used fuzzy logic to develop a water quality index for drinking water. They believed that water quality is to be determined by physical chemical and biological characteristics. Trapezoidal and triangular membership functions were defined for the input parameters. J.Z Kuirski et al. (2015) developed a fuzzy model for the determination and assessment of groundwater quality for the city of Zrenjanin. In their work they have determined the chemical quality of groundwater for drinking purposes. They stated that fuzzy logic can successfully overcome the problem of degree of certainty and uncertainty I n common methods used for determination of water quality index. Trapezoidal membership functions are used for all eight chemical parameters used for analyzing water quality index.

In this study a model was developed for the determination of water quality index for river water using fuzzy inference system.

2. STUDY AREA

The newly developed fuzzy logic model was used to analyse water quality index for various Rivers in Calicut city. The sampling points were selected in Korapuzha river near Korapuzha bridge, River Chaliyar at Koolimad and near Feroke bridge, Kallai river and near Porakkateri bridge. The Chaliyar River is the fourth largest river that flows through Kerala after the Periyar, Baharatapuzha, and Pamba Rivers. It has a length of 169 and is one of the 44 rivers that flow eastwards and fall into the Arabian Sea. Korapuzha is a river which flows through the Kozhikode district of Kerala state. It is formed by the confluence of two streams, Agalapuzha and Punnoorpuzha. It is originated in the mountains of Wayanad district and utilized by many villages for irrigation, drinking and domestic purposes. The Korapuzha empties into the Arabian Sea at Elathur after flows 40 km with a drainage area of 624 km^2. Kallayi river originates in Cherikkulathur at an altitude of 45 m of western ghats and flows down 40 km through Kunnathupalam, Mankavu and Kallayi towns and ends in the Arabian Sea. It is linked to the river chaliyar by a man-made canal on the south side of the small timber village of kallai lying on its banks. Large amount of coconut husks are deposited in this river by the coir cottage-industry units for retting. These husks settle onto the bottom and due to the decay of these, black silt is formed on the substratum mixed with sand. Further, a large number of logs are kept in the

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river for seasoning all through the year which also fouls the water. Akalapuzha is a saltwater river in Kozhikode district. It is one of the starting points of the Korapuzha. This river is shallow and blessed with a lot of fish and shellfish. The river covers Purakkatteri village on its three sides . Station point in this river was near to purakkateri bridge.

3. SAMPLING AND TESTING

In order to assess the proposed fuzzy water quality index, a case study on water quality of rivers in Calicut city was performed. The sampling points were River Chaliyar at Koolimad and near Feroke bridge, Kallayi river near wood industry area, Korapuzha river and River Akalapuzha at purakkateri. Water samples were taken on a monthly basis for a period of 5 months, from January 2016 to May 2016. All measurements were conducted according to standard methods.

Samples were collected from well mixed section of river 30 cm below the water surface using weighed bottles and DO sampler by grab sampling. Sample containers were labeled properly. Samples for BOD and bacteriological analysis were stored at a temperature below 4^0C and in the dark. After sampling they were transported to laboratory. The physical, chemical and bacteriological analysis such as pH, TSS, DO, BOD, nitrate and fecal coliform were done within 24 hours of sampling. The data obtained were recorded. These data were summarized to get fuzzy water quality index using the developed model.

4. METHODOLOGY

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. A fuzzy logic system consists of four main parts - fuzzifier, rules, inference engine, and defuzzifier. In a fuzzy logic system initially a crisp set of input data are gathered and they are converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification. Afterwards, an inference is made based on a set of rules. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step.

Six input parameters, pH, total solids, dissolved oxygen, BOD, nitrate and fecal coliform, are considered to determine the output water quality index of river water. Although numerous water quality parameters are used to determine the water quality index, here only 6 input parameters are chosen because these are the most easily and commonly measurable parameters of all. The output parameter chosen is the water quality index. These parameters are the linguistic variables in fuzzy logic. Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values. A linguistic variable is generally decomposed into a set of linguistic terms. The above linguistic variables are decomposed into four linguistic terms such as excellent, good, satisfactory and poor.

	Excellent	Good	Satisfactory	Poor
DO	>7 mg/l	4 - 8 mg/l	2 - 5 mg/l	< 3 mg/l
BOD	< 1 mg/l	1 - 5 mg/l	4 - 15 mg/l	> 15 mg/l
NITRATE	< 11mg/l	11 - 22 mg/l	22 - 45 mg/l	> 45mg/l
FECAL COLIFORM	< 20	20 - 2000	2000 - 20000	> 20000
pH	6.5 - 7.5	7- 9 & 5 - 7	3 - 6 & 8 - 11	< 3 & >11
TSS	< 25 mg/l	20 - 50mg/l	45 - 100 mg/l	> 90 mg/l
FWQI	> 90	70 - 90	40 - 70	< 40

Next step is to define the membership function. A membership function is used to quantify a linguistic term. It is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. If a parameter is having a membership value 1 in a particular class, which means, that parameter is 100 percent included in the particular class. Membership value 0 for a particular parameter indicates that parameter is not included in that class. Membership value other than 0 and 1 indicates partial membership in the particular class. A fuzzy set is an extension of a classical set. If X is the universe of discourse and its elements are denoted by x, then a fuzzy set A in X is defined as a set of ordered pairs.

$$A = \{x, \mu_A(x) \mid x \in X\}$$

$\mu_A(x)$ is called the membership function (or MF) of x in A. The membership function maps each element of X to a membership value between 0 and 1. In the present study trapezoidal membership function, trapmf, is chosen for different classes of parametric variables. This simplest membership functions is formed using straight lines.

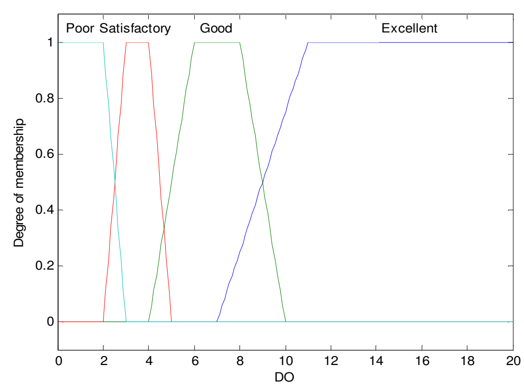

Figure 3.1. Membership Function for DO

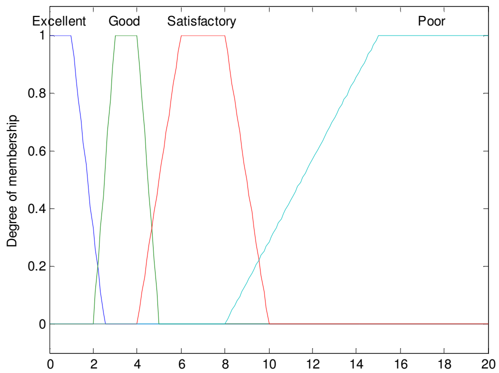

Figure 3.2. Membership Function for BOD

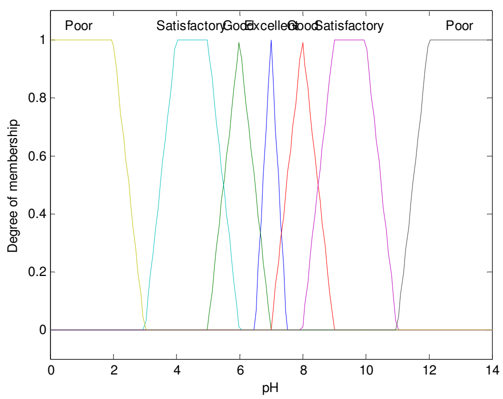

Figure 3.3. Membership Function for pH

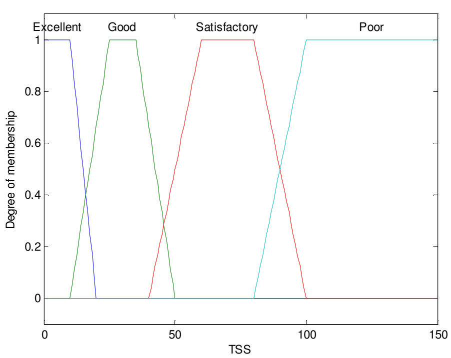

Figure 3.4. Membership Function for TSS

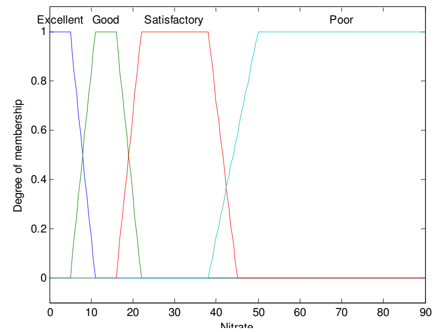

Figure 3.5. Membership Function for Nitrate

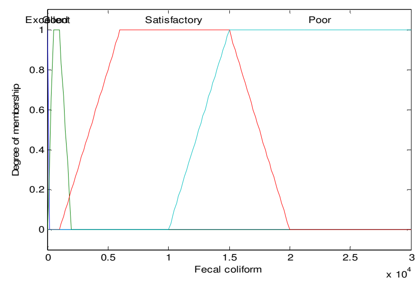

Figure 3.6. Membership Function for fecal coliform

After defining membership function, next step is the construction of rule base. In a Fuzzy logic system, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion. In making a fuzzy rule, the concept of "and", "or", and sometimes "not" is used. As there are six input parameters and each parameter is decomposed into four classes. So by forming combination of all parameters with different class there will be altogether 4096 (4^6) rules. Defining all 4096 rules will make the system more complex. So a trimming process is done to reduce the number of rules. The six input parameters were grouped into four. Group 1 consists of Dissolved oxygen and BOD, since they are the chemical parameters of water quality. Group 2 with Nitrate alone which is the parameter giving the nutrient information of water. Group 3 contains only fecal coliform which is the biological parameter determining the water quality. pH and TSS comprise of group 4 since they are the physical parameter of water quality. Initially rules were defined for group 1 and group 4 separately. The output result of group 1 and group 4 were combined, as input parameters, with group 2 and group 3 to define the final output water quality index. For example, fuzzy rules are choosen, “if the level of BOD is excellent and DO is excellent, then water quality is excellent. In fuzzy description it could be pronounced as follows: Rule 1. If BOD5 is excellent and DO is excellent then FWQI is excellent. Similarly the rule combining all four groups may be pronounced as follows: Rule 1. If FWQI of group 1(BOD and DO) is excellent and Group 2(Nitrate) is excellent and

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group 3(fecal coliform) is excellent and FWQI of group 4 (pH and TSS) is excellent then final FWQI is excellent. Rule 2. If FWQI of group 1(BOD and DO) is poor and Group 2(Nitrate) is poor and group 3(fecal coliform) is satisfactory and FWQI of group 4 (pH and TSS) is satisfactory then final FWQI is poor. Similarly all other rules can be formed.

The membership function and set of rules were fed into the system in determining the response. The evaluation of inference rules includes the application of fuzzy operations to multiple part antecedents, the application of implication methods from the antecedent to the consequent for every rule, and the use of an aggregation method to join the consequents across all the rules. Each rule in the system is considered very important and critical to generate the predictions in numeric form.

The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number. However, the aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order to resolve a single output value from the set. In this paper defuzzification method used is the centroid calculation, which returns the center of area under the curve.

5. RESULTS AND DISCUSSION

The water quality for the Rivers in Calicut has been assessed with the FWQ index. An index-based framework to assess water quality of the rivers of Calicut has been developed. Values of currently monitored indicators have been used to test this fuzzy index. In most cases water quality is good or satisfactory. The reason for this is due to high value of fecal coliform present in water. Parameters except dissolved oxygen and fecal coliform are within the class of excellent in most cases. Dissolved oxygen falls in the class of good. Among the parameters selected the only parameter that affects the water quality of rivers in Calicut is fecal coliform. When the value of fecal coliform lowers, the water quality seems to be increasing.

Fuzzy water quality allows the quality parameters to get distinguished into various classes. Final water quality is only determined by considering the class of each parameter and rules combing each parameter. Thus fuzzy water quality follows the human way of thinking if the model is developed by an experienced person. The more the linguistic terms for each parameter the more will be the accuracy of final water quality. But this may cause the construction of rule base very complex. The construction of rule base really requires knowledge and experience in the relevant field. If the water quality determination was based on physico chemical parameters the output of the study would have been good, which is not the actual case. So this clearly reflects the need for wise selection of quality parameters. The selection of water quality parameters thus should be according the intended use of water. Since river water quality is considered, priority has been given to DO, BOD and fecal coliform in this study.

Table 5.1. Water quality of river Korapuzha

pH	TSS	BOD	DO	Nitrate	Fecal Coliform	FWQI	Remarks
7.3	12	1.5	4.9	0.1	700	80	Good
7.7	6	2	6.2	0.7	800	80	Good
7.8	10	2.8	5	0.32	80	80	Good
7.4	12	1.2	4.8	0.13	900	80	Good
7.2	10	1.2	5.5	0.58	500	80	Good

Table 5.2. Water quality of river Kallai

pH	TSS	BOD	DO	Nitrate	Fecal Coliform	FWQI	Remarks
8	10	2	4	0.1	700	80	Good
7.7	8	4.6	1.2	1.3	12000	12.5	Poor
7.7	10	1.2	4.8	0.16	500	80	Good
7.5	10	1.4	2.2	0.1	900	13.5	Poor
7.6	12	1.2	4.8	0.45	800	80	Good

Table 5.3. Water quality of river Chaliyar at Koolimad

pH	TSS	BOD	DO	Nitrate	Fecal Coliform	FWQI	Remarks
7.5	10	0.5	7	0.05	80	80	Good
7.4	10	0.8	7.3	0.03	400	80	Good
7.5	10	0.5	7	0.02	200	80	Good
7.5	10	1.4	2.2	0.1	900	13.5	Poor
7.6	12	1.2	4.8	0.45	800	80	Good

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Table 5.4. Water quality of river Feroke

pH	TSS	BOD	DO	Nitrate	Fecal Coliform	FWQI	Remarks
7.2	10	1.4	6.6	0.1	880	80	Good
7.5	10	0.8	5.4	0.1	0	97.5	Excellent
7.5	10	0.8	6	0.3	800	80	Good
7.5	10	0.8	6	0.3	800	80	Good
7.1	10	0.8	6.6	0.45	1800	80	Good

Table 5.5. Water quality of river Akalapuzha

pH	TSS	BOD	DO	Nitrate	Fecal Coliform	FWQI	Remarks
7.5	10	0.5	7	0.05	80	80	Good
7.4	10	0.8	7.3	0.03	400	80	Good
7.5	10	0.5	7	0.02	200	80	Good
7.5	10	1.4	2.2	0.1	900	13.5	Poor
7.6	12	1.2	4.8	0.45	800	80	Good

6. CONCLUSIONS

In this study a robust decision making tool for water quality evaluation in the form of fuzzy water quality index was developed. The new index is a simple representation of an extensive and complex variables that govern the overall quality of surface water that is intended for specific use. The obtained water quality index was used for the classification of river water in order to make water quality assessment more understandable especially for public consideration.

The present study has assessed water quality of various river water bodies in Calicut city using physical, chemical and biological determinants such as pH, TSS, DO, BOD, nitrate and fecal coliform. The water quality index shows that the water quality of rivers in Calicut city is just good or poor. The low water quality is due to high amount of fecal coliform present in water. In many studies only physical and a chemical parameters are considered. If the current study is done only by considering physical and chemical parameters result would have been a good or excellent water quality, which is not the case, as the actual water quality is poor due to high content of biological parameter, the fecal coliform. So a judicious selection of water quality parameters, according to intended use and real situation of water body, has to be done as not to interpret the final water quality wrongly. The Fuzzy water quality is also able to support environmental authorities in order to implement corrective measures and adjustments to the river environmental assessments because this index is more demanding

Fuzzy water quality considers the quality classes of parameters which make the final water quality more accurate and reflect the real environmental condition. Furthermore the new fuzzy water quality index allows result to be interpreted quantitatively or qualitatively along with membership grades. Thus fuzzy water quality index can assist decision makers in reporting the actual status of water quality

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