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Assessment of Ground Water Quality Using Fuzzy Based Water Quality Index

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Abstract:- Ground water is a vital source of fresh water in both urban and rural regions of the world. In Kerala, ground water meets the drinking needs of more than 60% population. Thrissur is the central district of Kerala, with a special well culture. Mostly each and every home has a dug well and ground water is the major source of drinking water in the district. Hence it is necessary to evaluate the ground water quality of Thrissur to ensure safe drinking water. Water quality index evaluation is an essential step to monitor, control and prevent the ground water pollution. The water quality index calculated for 56 observation wells of study area indicates the suitability of drinking water in each well. However there exist some uncertainties in the conventional method of water quality index evaluation. Fuzzy logic implemented in water quality index evaluation makes it more reliable in conveying the accurate status of ground water quality. Mamdani fuzzy inference system model with 10 inputs and single output was created for index evaluation. Trapezoidal membership function plots were assigned for both inputs and output and a total of 412 possible rules were created based on the water quality data and water quality standards. Fuzzy index reveals that 70% of drinking water in the study area belongs to excellent category, 16% belongs to good category and remaining 14% belongs to poor category that is unfit for drinking. According to fuzzy index Kodungallur, Keechery and Azhikode were the major ground water contamination sites identified in the study area. Relative root mean square error value of 1.2 % was obtained by comparing both index values. From the year 2015 to 2019 the percentage of poor water category has changed from 6% to 14% which indicates an increasing ground water contamination issue that needs immediate attention.

I. INTRODUCTION

Water is one of the basic necessities of life. With rapid increase in population, the demand for water is also increasing. Ground water is a reliable source of fresh water and it is under enormous pressure to satisfy the increasing demand of population. India is one of the largest consumer of ground water in the world. India is facing ground water crisis due to it's over exploitation as well as growing contamination from point and non-point sources of pollution. The main sources of groundwater contamination are anthropogenic activities and many well-known and unexpected processes occurring in aquifer such as chemical reaction, soil interaction with accumulated water, aquifer lithology, etc. Also the pollutants in the form of waste disposed in streams or in atmosphere and over time, such wastes may accumulate in aquifer due to seepage or transport and increase related hazards of groundwater contamination. Therefore, there is an urgent need to develop efficient management strategies for the sustainable utilization and protection of vital groundwater resources.

One possible management alternative is through the development of water quality indices to provide an overall assessment of groundwater quality. Water Quality Index (WQI) is a simple mathematical tool that can provide a distinct picture of overall water quality status over an area based on important water quality parameters. Groundwater Quality Index is easy to calculate by incorporating different groundwater quality parameters and the results are very convenient to interpret. However, one of the major issues with the traditional WQI is that they fail to deal with the uncertainty and subjectivity that are inherent in the assessment of environmental problems, especially while classifying water quality near the parameter-threshold boundary. To overcome this subjectivity and to incorporate environmental uncertainty in the groundwater quality evaluation process, the application of Artificial Intelligence based computational methods are highly recommended. Fuzzy Logic (FL) is extensively used to deal with complex water-related environmental problems, owing to its capability to deal with non-linearity and uncertainty involved in environmental systems. In addition to this, FL serves as an effective tool for conveying the results to the public and beneficiaries in a much understandable linguistic format.

II. MATERIALS AND METHODOLOGY

A. Study Area

Thrissur is one of the important historical cities of Kerala, which is known as the cultural capital of Kerala. The district has an area of 3032 sq.km and is located in the central part of the State. Thrissur district lies between North latitudes 10° 10' 22'' and 10° 46' 54'' and East longitudes 75° 57' 20'' and 76° 54' 23''. Thrissur district accounts for 7.8% of the area of the state. The district has seven taluks viz. Chavakkad, Talappilli, Thrissur, Kunnamkulam, Chalakkudy, Kodungallur and

Mukundapuram which comprises 16 blocks spread over a total of 97 panchayaths and 7 municipalities. Thrissur district comprises three river basins viz. parts of Ponnani, Keecheri & Karuvannur basins (Kole lands) and Chalakudy. Groundwater occurs under water table conditions in alluvium, laterites and weathered mantle of the crystalline, where as in the deeper fractured crystalline the groundwater occurs under semi confined to confined conditions. The hard rock and laterite aquifers constitute major aquifer system of the district while the sedimentary aquifers are seen along the coast and river courses. Acute water scarcity being faced in the hilly areas in summer period due to drying up of dug wells and hand pumps. Dug wells in midland region get dried up if monsoon is delayed or if there are no summer showers.

The increased dependence on bore wells in midland areas leads to drying up of dug wells which affects the drinking water needs of the areas. The coastal areas stretching from Engandiyoor to Chettuva and the villages of Eriyad, Nattika and Chamakala experiences severe coastal erosion frequently which leads degrading ground water quality nearby coastal aquifer. In Kole land and adjoining areas are water logged about six months in year in those areas the conjunctive use of both ground and surface water to be adopted for irrigation and industrial uses. In Kole land the salinity has been observed more during high tides and less during low tides and increasing from February to May.

B. Data collection

A total of 56 observation wells of Thrissur District were selected for the study. Details regarding these observation wells were collected from the Central Ground Water Board (CGWB), Kerala Region, Trivandrum for a period from 2015 to 2019. The various water quality parameters collected from the CGWB includes pH, Total Dissolved solids, Total Hardness, calcium, Magnesium, Chloride, Sulphate, Nitrate, Fluoride and Bacteriological presence (total coliforms). The results were then compared with drinking water standards (IS 10500-2012). The samples were collected during the month of April representing the pre-monsoon quality so as to minimize the effects of biological activities and pollution from point sources.

C. Calculation of ground water quality index

To get a comprehensive picture of overall quality of groundwater, the water quality index can be used. WQI is defined as a rating reflecting the composite influence of different water quality parameters on the overall quality of water. The water quality index is computed through three steps. In the first step each of the 10 parameters (pH, TDS, total hardness, Ca, Mg, SO_4, Cl, F, NO_3, and total coliform) were assigned a weight (wi) according to their relative importance in the overall quality of water for drinking purposes.

The water quality parameters were assigned weights between 1 and 5 based on their relative significance in the water quality evaluation. In the second step, relative weight (W_i) of each water quality parameter was computed using the following equation (1).

$$W_i = \frac{wi}{\sum_{i=1}^{n} wi} \quad (1)$$

Where, W_i is the relative weight; w_i is the weight of each parameter, and n is the number of parameters. In the third step, a quality rating scale (q_i) for each parameter was assigned by dividing their concentration in each water sample by its respective standard according to guidelines (BIS, 2012) and the result is multiplied by 100 (2).

$$q_i = (C_i/S_i) * 100 \quad (2)$$

Where, q_i is the quality rating, C_i is the concentration of each water quality parameter in water sample in mg/L and S_i is the Indian drinking water standard for each water quality parameter in mg/L [3]. WQI was calculated by summation of the sub index (SI) values determined for each water quality parameter, as given below.

$$SI_i = W_i * q_i \quad (3)$$

$$WQI = \sum_{1}^{n} SI \quad (4)$$

Where SI_i (3) is the sub index of i_{th} parameter; W_i is relative weight of i_{th} parameter; q_i is the rating based on concentration of i_{th} parameter and n is the number of water quality parameters. The computed WQI (4) values were classified into five categories: excellent water (WQI < 50); good water (WQI - 50–100); poor water (WQI - 100–200); very poor water (WQI - 200–300); and water unsuitable for drinking (WQI >300). Identification of water quality index is an essential step to monitor, prevent and reduce ground water pollution. WQI provides a feedback on the quality of water to the policy makers and environmental decision makers. It provides a single number expressing overall water quality status at a particular time and location.

D. Development of fuzzy based ground water quality index

Fuzzy Logic (FL) is used to induce human knowledge and experience to deal with the uncertainty and vagueness involved while assessing natural systems. Fuzzy Logic maps input to output using Fuzzy Inference System (FIS) that combines FL and experts knowledge through four main components viz., fuzzification, fuzzy inference rules, aggregation and defuzzification. Two most important fuzzy inference systems are Mamdani FIS and Sugeno FIS. Mamdani FIS is most widely used for environmental applications due to its simplicity and practical application.

Fuzzification: A process in which the crisp inputs are transformed into fuzzy inputs. The fuzzification of the input and output is done by constructing Membership Functions (MFs). Membership Function (MF) is a curve which shows the degree of belongingness (membership value) of the data to a particular class. Because of the importance of the "shape" of the membership function, a great deal of attention has been focused on development of these functions. The membership value was determined using experts' knowledge and drinking water quality standards of WHO and BIS.

Fuzzy inference rules: The fuzzy inference rules are in the form of antecedent and consequent form format. They map the input class categories to the output class categories. Each fuzzy rules were incorporated as per the WHO guidelines, subject expert and literature survey.

Aggregation of fuzzy rules: Most rule-based systems involve more than one rule. The process of obtaining the overall consequent (conclusion) from the individual consequents contributed by each rule in the rule-base is known as aggregation of rules. Once the fuzzy inference rules were designed, the next step was combining all the designed fuzzy inference rules. The aggregation of the consequent part of the fuzzy inference rules is needed to calculate a single fuzzy output, which is FWQI.

Defuzzification: There may be situations where the output of a fuzzy process needs to be a single scalar quantity as opposed to a fuzzy set. Defuzzification is the conversion of a fuzzy quantity to a precise quantity. Finally, defuzzifying the aggregated output value was carried out to convert the fuzzy sets to a numeric value. The final numeric score obtained is 'Fuzzy Ground Water Quality Index (FWQI)'.

All the FL operations were carried out in MATLAB R2020b software. Mamdani Fuzzy Inference System (FIS) was used to create a 10 input and single output fuzzy model for the study. The parameters were defined based on BIS standards by plotting trapezoidal membership functions (MF).

The fuzzyfier takes input values and determines the degree to which they belong to each of the fuzzy set through these membership functions. For all selected parameters, the rules were derived based on the number of variables as well as the membership functions. A total of 412 rules were derived for this model. Accuracy of the model was increased by increasing the membership function overlapping. The rules were developed for each factor by MATLAB programming which can execute a series of statements. Further values corresponding to the input variables generated were subdivided and recorded into groups with specific range as low, moderate and high category. This helped in creating the membership functions for fuzzy modelling within the permitted range. For input a total of 30 trapezoidal membership function plots were created. For output 5 membership function plots were created from a range of 0 to 500, for classifying the water quality index values as class similar to that of arithmetic index values.

E. Comparison of fuzzy based index and WQI

Calculated WQI value was used to evaluate the predicted fuzzy index. For model validation the fuzzy water quality index was compared with the observed WQI. A comparative evaluation of the WQI and FWQI model indicates the relative performance of these models in predicting actual groundwater quality status in the study area. Relative root mean square error (RRMSE) was calculated (5) to determine the accuracy of fuzzy index values. If the RRMSE value is less than 10%, then the model accuracy is considered excellent. It is calculated by:

$$RRMSE = \sqrt{\frac{\frac{1}{n}\sum(E_i-P_i)^2}{\sum Ei}} \text{ x } 100 \quad (5)$$

Where E_i is the experimental index value that is WQI and P_i is the predicted value that is FWQI.

III. RESULTS AND DISCUSSION

A. Water quality analysis

Water quality of 56 observation wells were analysed according to BIS 10500:2012 standards. From the collected water quality data it was found that pH, TDS, Calcium, Magnesium, Nitrate and total coliform were the parameters that exceeded their permissible limit as per standards.

B. Water quality index calculation

Water quality index evaluation requires physical, chemical and biological parameters. In the present study 10 water quality parameters were considered.

The WQI values were calculated for each observation wells from 2015 to 2019. The WQI values suggest that majority of the ground water samples belong to excellent category of drinking water. It also reveals the increasing ground water contamination in the Thrissur District. The percentage of excellent water has reduced from 87 to 73 % from 2015 to 2019 (fig.1). About 5% ground water belongs to poor water that is unfit for drinking due to excess amount of nitrate, calcium, TDS and coliform content.

The objective of the WQI is to classify the water relative to their chemical and physical characteristics for defining their possible use. However, there exist some uncertainties in arithmetic WQI method of classification. Azhikode, Kecheri, and Mathilakam are classified under 'Good' and Mupliam belongs to 'Excellent' category of WQI. But Nitrate content in these areas exceed its permissible limit with no relaxation of 45 mg/l. Similarly Kottapadi and Kundannur are classified under 'Poor' WQI category because of high value of TDS. All other parameters including Nitrate are within safe limits in these areas. High levels of Nitrate are toxic to humans and animals. It affects the oxygen carrying capacity of hemoglobin in the blood stream and can cause methemoglobinemia (blue baby syndrome) in infants. It can also cause decreased blood pressure, increased heart rate, birth malformations and gastric cancer disorders. Hence Nitrate intake is a serious health concern that we have to consider in drinking water sources. Water containing Nitrate above the permissible limit cannot be considered as a safe water.

The WQI underestimated the water quality without considering the proximity of parameter to its limit. It gives only a numerical score regarding the water quality. From the perspective of health concern the existing arithmetic WQI needs to be improved.

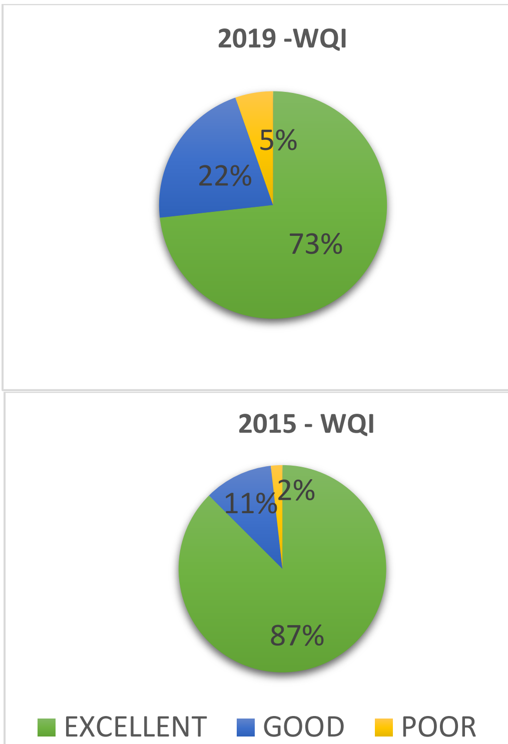

Fig.1 Water Quality Index Variation

C. *Fuzzy water quality index*

The FWQI combines individual physical, chemical and biological parameters with help of membership functions and rules of inference to give information about the real status of water quality. The fuzzy index values followed the same trend of calculated WQI values.

According to FWQI in the year 2015 about 87 % of water in the study area belongs to excellent category of ground water (fig.2) and 7% of water belongs to good category and remaining 6% belongs to poor category that is unfit for drinking. Similarly for the year 2019 only 70% of the water in study area belongs to excellent category, 16% of water belongs to good category and remaining 14% belongs to the poor category.

Fuzzy index evaluates the concentration values and prescribed standards of each and every parameter in the final index calculation. This was made possible with the help of membership functions created for each parameter and the inference rules created. The rules were created by referring journals and observing available data sets for the study area. The number of rules depends on the number of input parameters and membership functions.

The fuzzy logic can be considered as a mathematical tool that converts complicated statements into mathematical terms and again converts them into simple outputs. The output vector data are based on some set of rules and assigned values for output data. The fuzzy set can be used to directly introduce imprecise data into mathematical models with minimum input data requirements.

D. *Comparison of FWQI and WQI*

The comparative evaluation between WQI and FWQI for the year 2019 is shown in fig.3 and fig.4.

The peaks value points shows the places where the WQI showed uncertainties in accurate indication of the pollution points. In such points FWQI gave more reliable and accurate status regarding the water quality. In the year 2019, in the regions Azhikode, Guruvayur, Keecheri, Mathilakam and Mupliam water quality parameters including TDS, total hardness, nitrate and total coliform were found to be above the acceptable limits.

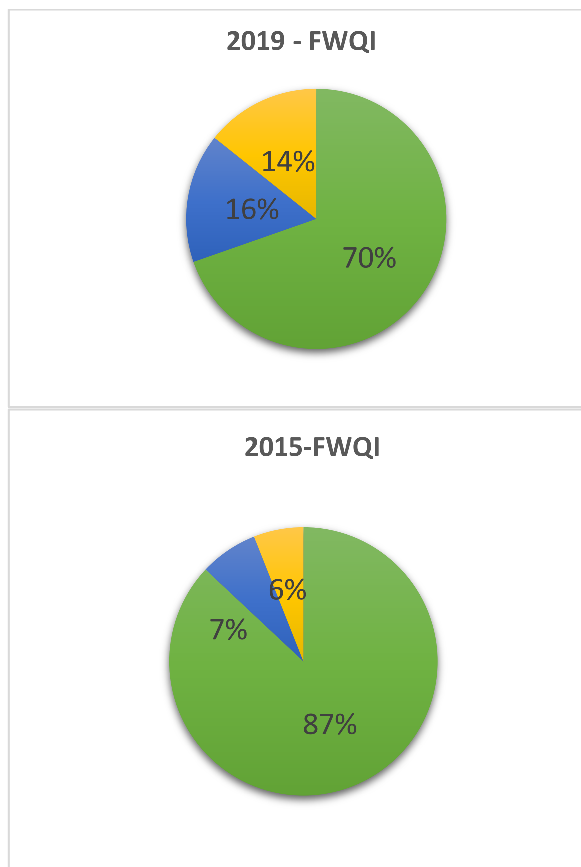

Fig.2 Water Quality Index Variation

By WQI values these regions belongs to good or excellent water suitable for drinking.

But according to fuzzy index values, that incorporate both environmental standards and health aspects through inference rules, these regions belong to poor water that is unfit for drinking.

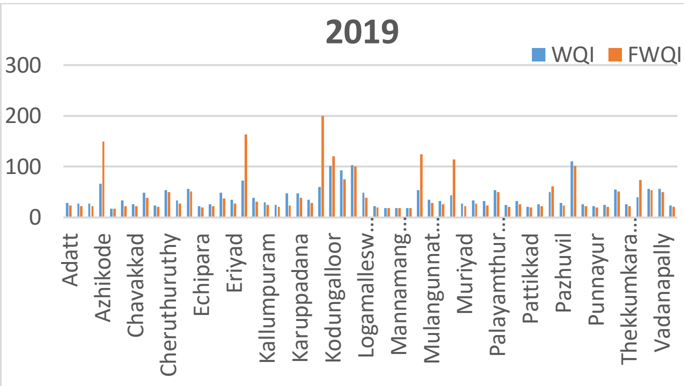

Fig.3 Comprison of Index Values

For observations wells having concentration of all water quality parameters lower than permissible limits, FWQI are almost similar or slightly less than the WQI values. Similar trends were seen in the year 2018, 2017, 2016 and 2015. The index behaviour in 2018 is compared as shown in fig.4.

A regression model was developed for comparing both indices. The plot obtained was shown in Fig.5.

FWQI can be calculated from arithmetic WQI using the regression equation (6).

$$y = 0.6891\,x + 3.909 \quad (6)$$

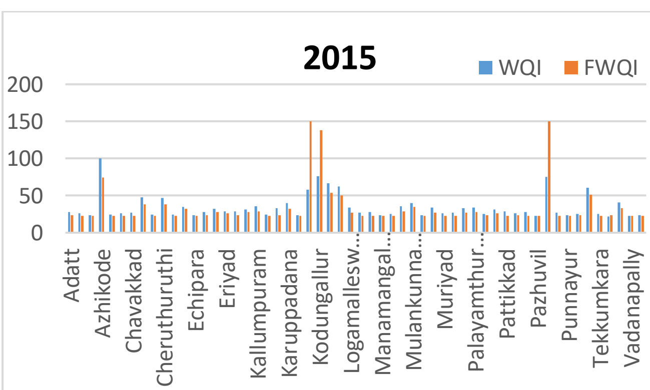

Fig.4 Comprison of Index Values

It is therefore evident that the use of fuzzy logic for development of a water quality index is effective, since the results obtained in this study were in line with those provided by the arithmetic index.

RRMSE value of 1.2 % was obtained by comparing both index values. The results obtained by the fuzzy system were more rigorous, due to the fact that the water quality data were assessed by all the basis rules incorporating water quality standards, in contrast to the WQI, which employs a formula, an objective method that always calculates the index in the same way, without taking account of interrelations between the parameters. Hence, fuzzy logic is suitable for applications that involve subjective or uncertain data.

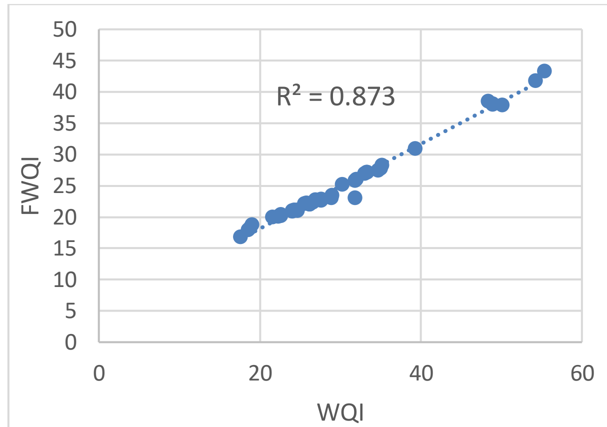

Fig.5 Correlation of Indices

IV. CONCLUSIONS

70 % of ground water in Thrissur district belongs to 'Excellent' category. This shows majority of water belongs to safe drinking class. From the year 2015 to 2019 the percentage of 'Poor' water has increased from 6% to 14%. This shows that the ground water quality is under the threat of degradation in study area. Hence it's necessary to monitor and control the increasing pollution of ground water sources. Water quality Index combined the complex water quality data to a single numeric index. But there exist some uncertainties in the arithmetic calculation of water quality index. 5 % of water in study area belongs to poor category according to water quality index classification. Fuzzy index shows 14% of ground water in study area belongs to poor class that is unfit for drinking.

The main groundwater contamination sites identified were Keecheri, Kodungallur and Azhikode region. Fuzzy water quality index obtained for these areas were above 100 which indicates the ground water in this region is unfit for drinking. Such contaminated water, when used for drinking purpose, may cause serious effects on human health.

When fuzzy logic is implemented in water quality index calculations, it gave more reliable results. Mamdani fuzzy inference system with trapezoidal membership function plot was an efficient tool to predict water quality index considering both environmental and health aspects. Fuzzy logic approach is equally sensitive to all parameters and provides flexibility to choose different parameters. Fuzzy based index can truly represent the water quality status even in minute or high levels of pollution, which cannot be depicted by arithmetic index. Proper remedial measures can be implemented based on accurate water quality index values for a healthy water management system. Ground water is an asset where the quantity and quality needed to be carefully controlled, protected and preserved.

REFERENCES

[1]. A. K Mohamed, D Liu, Kai Song,. Mohamed, Elsiddig Aldaw and B.A. Elubid, "Hydrochemical Analysis and Fuzzy Logic Method for Evaluation of Groundwater Quality in the North Chengdu Plain, China", International Journal Environmental Research Public Health, Vol.16:302, pp. 1-21, 2019.

[2]. A.P Singh, A. Khakolia, S. Tavanshetti, J. Yadav, "Groundwater quality assessment using gis and fuzzy logic- a case study of Jhunjhunu district", EM International, ISSN 0257–8050, Vol. 38, pp. 655-662, 2019.

[3]. Asif Mahmud, S. Shraboni and Jagadish C. J, "Assessment of ground water quality in Khulna city of Bangladesh in terms of water quality index for drinking purpose", Applied water Science-Springer, Vol. 10:226, pp. 1-14, 2020.

[4]. A. Selvaraj, S. Subbarayan and J.J Jesudasan, "Mamdani fuzzy based decision support system for prediction of groundwater quality: an application of soft computing in water resources, Environmental Science and Pollution Research, Vol.1, pp.1-18, 2020.

[5]. B. Agoubil, F. Souid, A. Kharroubil, A Abdallaou, "Assessment of hot groundwater in an arid area in Tunisia using geochemical and fuzzy logic approaches", Environment Earth Science, Vol. 75:1497, pp. 1-12, 2016.

[6]. C Tirupathia,T Shashidhara, V.P Pandey, S Shrestha, "Fuzzy-based approach for evaluating ground water sustainability of Asian cities", Sustainable Cities and Society, 44, pp. 321–331, 2019.

[7]. G Gnanachandrasamy, C Dushiyanthan, J.T Rajakumar, Y Zhou, "Assessment of hydrogeochemical characteristics of groundwater in the lower Vellar river basin: using Geographical Information System (GIS) and Water Quality Index (WQI)", Environment, Development and Sustainability, Vol.7, 018-0219, 2019.

[8]. Krishna Kumar, N.S Bharani, M Prince, S. Godson, N. Chandrasekar, "Hydrogeochemistry and groundwater quality appraisal of part of south Chennai coastal aquifers, Tamil Nadu, India using WQI and fuzzy logic method", Applied Water Science, Vol.4, pp. 341–350,2014.

[9]. M.K Jha, A Shekhar, M.A Jenifer, "Assessing groundwater quality for drinking water supply using hybrid fuzzy-GIS-based water quality index", Water Research, Vol. 179, pp. 1-16, 2020.

[10]. Mity Thambi, Tom Cherian, Anju Therese Jose, Sunaina Jamal, "Physico-chemical characteristics of ground water samples from different areas of Thrissur district, Kerala state, India", International Journal Of Environment, Vol.4, ISSN 2091-2854, 2015.

[11]. P. Priju, V.V Prasad, K.R Athira, "Spatial and temporal pattern of groundwater quality in keecheri-puzhakkal river basins, central kerala, india", International Journal of Research in Engineering and Technology, Vol.5, eISSN: 2319-116, 2016.

[12]. P.S Harikumar, Anisha Aravind, V Sandra, "Assessment of Water Quality Status of Guruvayur Municipality", Journal of Environmental Protection, Vol-8, 159-170, 2017.

[13]. S Shwetanka, J.K Chaudhary, "A Comparative Study of Fuzzy Logic and WQI for Groundwater Quality Assessment", Procedia Computer Science, Vol.171, pp.1194–1203, 2020.