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Fuzzy Information Processing for Assessment of Groundwater Quality

N. Venkat Kumar, Samson Mathew and G. Swaminathan
Department of Civil Engineering, National Institute of Technology, Tiruchirapalli, 620015, India

Abstract: Water quality management is an important issue in the modern times. In this study, the application of fuzzy set theory for decision making in the assessment of groundwater quality for drinking purposes. This is illustrated with thirty groundwater samples collected from Ariyamangalam zone of Tiruchirappalli, S. India. These 30 samples were analyzed for 10 physiochemical parameters. This fuzzy groundwater quality model approach, the groundwater quality is classified in three categories, just four samples comes in the desirable class certainty level of minimum 8% and a maximum of 79%. About 14 samples were classified in the acceptable category for drinking purpose with the maximum certainty level of 50%. Rest of the 13 sample were in not acceptable class with a maximum certainty level of 100%. This approach is capable of showing the water quality assessment for drinking.

Key words: Ground water quality, uncertainty level, desirable limit, degree of match

INTRODUCTION

The quality, quantity and availability of drinking water are one of the most important environmental, social and political issues at global level. Monitoring of water quality and qualitative decision-making on the basis of a data is challenge for environmental engineers and hydrologists as every step from sampling to analysis contains uncertainties. The regulatory limits for various pollutants/contaminants in drinking water proposed by various regulatory bodies like World Health Organization (2006), Bureau of Indian Standards (1991, 2003, 1975) for Medical Research, are having limitations due to variation in intake to water by individuals during various seasons throughout the year.

Prescribed limits from any regulatory body conation uncertainties as these are the extrapolated values from the data either from animal experiments or very trivial epidemiological studies (Khaiwal and Garg, 2006; Dahiya and Kaur, 1999; Garg *et al*.,1998).

Information on the status and changing trends in water quality is necessary to formulate suitable guidelines and efficient implementation for water monitoring, quality assessment and enforcement of prescribed limits by different regulatory bodies. Various methods are discussed in literature on drinking water quality revealed that deterministic approach in decision-making by comparing values of parameters of water quality with prescribed limits provided by different regulatory bodies is used without considering uncertainties involved at various steps throughout the entire procedure (Khaiwal and Garg, 2006; Dahiya and Kaur, 1999).

Decision making using comparison of water quality prescribed limits with various water quality indices has been developed to integrate water quality variables (Lious and Wang, 2004; Said *et al*., 2004; Chang *et al*., 2001). Garg (1998) have discussed the uncertainties involved in water quality using fuzzy membership with values ranging from 0 to 1 form an applicable fuzzy set instead of the conventional scale of 0-100 in WQI methodology. The decision on the water quality assessment gives that the water is desirable, acceptable and not acceptable as per the guidelines from various regulatory bodies. But, in the border line cases of water quality parameters, it becomes a Herculean task as different types of uncertainties are involved at various part of experimental and measurement process right from sampling, sample storage, processing and analysis. The sets of the monitored data and limits should not be as crisp set, but as fuzzy sets. One way of avoiding the difficulty in uncertainty handling in water quality assessment is to introduce a margin of safety or degree of precaution before applying a single value to drinking water quality standards as the same technique was also used by other workers in the field of environmental science (Lio and Lo, 2004; Schulz and Howe, 1999). These methodologies based on fuzzy set theory are tested with real environmental problems to handle the uncertainties in imprecise environment in decision-making on the

Corresponding Author: N. Venkat Kumar, Department of Civil Engineering, National Institute of Technology, Tiruchirapalli, 620015, India

drinking water quality can be handled. Keeping the importance of uncertainty handling in the drinking water quality assessment and versatility of the fuzzy set theory in decision-making in the imprecise environment, an attempt is made to classify the groundwater from Ariyamangalam block, Tiruchirappalli corporation, South India for the drinking purposes.

MATERIALS AND METHODS

Tiruchirapalli is situated in the centre of the Indian state of Tamil Nadu. The topology of Trichy is flat except for the river Cauvery running WNW-SSE through the city. It lies at an altitude of 78 m above sea level. Trichy is traversed by the river Cauvery and the river Kollidam the latter forms the northern boundary of the city. There are few hills located within the city, the prominent among them are Golden Rock, Rock Fort and the one in Thiruverumbur. There are reserve forests along the river Cauvery, located to the west/north-west of the city. The southern/south-western part of the district is dotted by several hills, which are thought to be an offset of the Western Ghat Mountain range and the soil here is considered to be very fertile. A total of 30 groundwater samples were collected from one of the zone II ariyamangalam, Tiruchirappalli, city were collected during August 2007 and applying the prescribed methodology for sampling (Khiwal and Garg, 2006). Water from these sources is used for drinking, house hold utilities and bathing. These samples were analysed for the 14 different physio-chemical water quality parameters as per standard procedure. Decision was made on the basis of deterministic analysis as per the standards provided by different regulatory bodies (BIS, 2003, 1991).

Fuzzy set theory: Fuzzy set theory is suited to make decision in complex systems when the context of the problem is often unclear. It has been commonly used for imprecise information in non probabilistic sense and allows integration of information of various parameters into the modeling and evolution process. The concept of fuzzy sets describing imprecision or vagueness was introduced by Zedeh (1965, 1975) and has been applied throughout the world in decision making and evaluation processes in imprecise environment (Chen *et al*., 2003; Li *et al*., 2001; Mujumdar and Sashiikumar, 2002). Fuzzy set theory may be regarded as a generalization of classical theory. A fuzzy set is defined in terms of its membership function. In classical set theory the membership function of a set is 1 within the boundaries of the set and is 0 out side. A fuzzy set is defined in terms of a membership function, which maps the domain of interest, e.g. Concentrations, onto the interval [0,1]. The shape of the

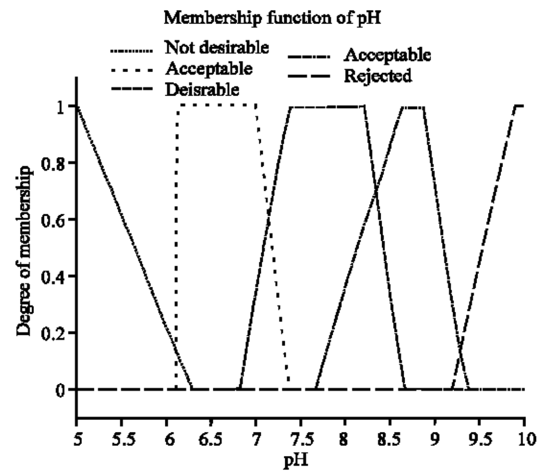

Fig. 1: MF for pH

curves shows the membership function for each set. The membership function represent the degree, or weighting, that the specified value belongs to the set. The membership function of the set A defined over a domain X takes the form

$$\mu A: X \rightarrow [0,1] \quad (1)$$

The set A is defined in terms of its membership function by

$$A = \{(\mu A(X)), x \in X, \mu A(X) \in [0,1]\} \quad (2)$$

Or

$$\mu A = \begin{Bmatrix} =1 \\ \in (0,1) \\ =1 \end{Bmatrix} \quad (3)$$

x = Full member of A.
x = Partial member of A.
x = Not a member of A.

In order to be considered a fuzzy set the membership function μA has to satisfy certain requirements. These ensure that the classical set theories concept of complement, union and intersection are carried over consistently to fuzzy set as well. The membership function μA may be normalized to ensure that μA takes the value one somewhere on x by dividing by the maximum value μA. The use of fuzzy numbers and aggregation of fuzzy sets are proposed as a suitable technique for handling the uncertainties in decision making on environmental quality criteria (Mamdani, 1976a; Mamdani, 1976b; Chitu and Suzanne, 2004). Fuzzy membership function for all the 10 parameters are either

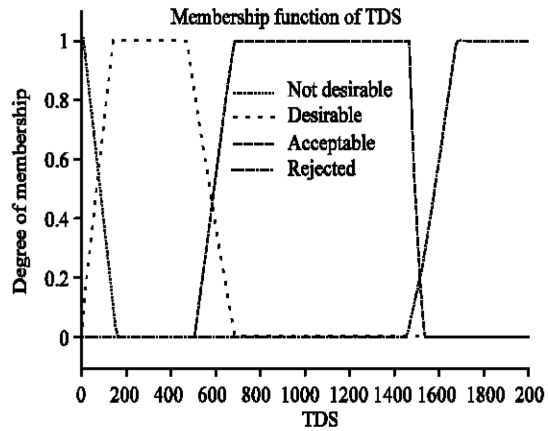

Fig. 2: MF for total dissolved solids

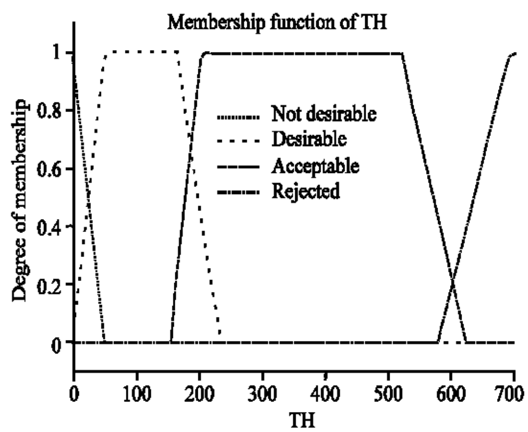

Fig. 3: MF for total hardness

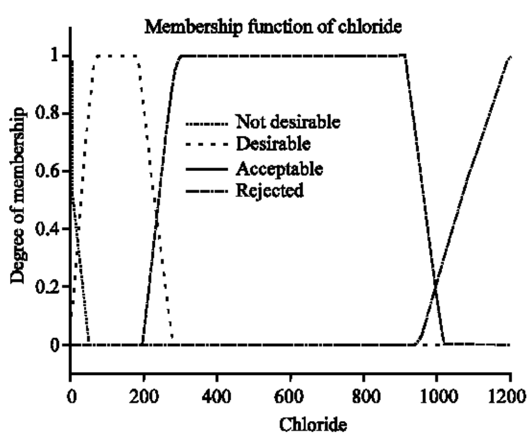

Fig. 4: MF for chlorides

triangular or trapezoidal (Fig. 1-4) on the basis of expert perception and prescribed limit in Table 1. Water quality model to classify the water quality groundwater is shown Fig. 5.

The typical example of one parameter pH is shown in the Eq. 4-6 (Dahyia *et al*., 2005, 2007).

Table 1: The limits prescribed by BIS and ICMR for the studied parameters

Water parameters	BIS (2003) Desirable	BIS (2003) Acceptable	ICMR/WHO (2006) Desirable	ICMR/WHO (2006) Permissible limit
pH	6.5-8.5	-----	7.0 – 8.5	6.5-9.2
TDS	500	2000	500	1500 (3000)
TH	300	600	300	600
TA	200	600	----	----
Ca^{2+}	75	200	75	200
Mg^{2+}	30	100	50	100
Cl^-	250	1000	200	1000
NO_3	---	45	20	Not>100
SO_4	200	400	200	400

Units are μg mL^{-1} except pH, BIS-Bureau of Indian Standards, ICMR-Indian Council for Medical Research, WHO-World Health Organization

$$\text{Desirable: } \mu pH = \begin{cases} 0, \text{if } x \le 6.8 \\ \dfrac{x-6.8}{7.3-6.8}, \text{ if } x \in [6.8, 7.3) \\ 1.0, \text{if } x \in (7.3, 8.1) \\ \dfrac{8.8-x}{8.8-8.1}, \text{if } x \in (8.1, 8.8] \\ 0, \text{if } x \ge 8.8 \end{cases} \quad (4)$$

$$\text{Acceptable: } \mu pH = \begin{cases} 0, \text{if } x \le 6.2 \\ \dfrac{x-6.2}{6.7-6.2}, \text{if } x \in [6.2, 6.7) \\ 1.0, \text{if } x \in (6.7, 7.2) \\ \dfrac{7.2-x}{7.4-7.2}, \text{if } x \in (7.2, 7.4) \\ 0, \text{if } x \in (7.4, 7.8) \\ \dfrac{x-7.8}{8.2-7.8}, \text{if } x \in (7.8, 8.2) \\ 1.0, \text{if } x \in (8.2, 8.9) \\ \dfrac{9.4-x}{9.4-8.9}, \text{if } x \in (8.9, 9.4] \\ 0, \text{if } x \ge 9.4 \end{cases} \quad (5)$$

$$\text{Not Acceptable : } \mu pH = \begin{cases} 1.0, \text{if } x \le 6.0 \\ \dfrac{6.4-x}{6.4-6.0}, \text{if } x \in [6.0, 6.4) \\ 0, \text{if } x \in (6.4, 9.2) \\ \dfrac{x-9.2}{9.6-9.2}, \text{if } x \in (9.2, 9.6] \\ 1.0, \text{if } x \ge 9.6 \end{cases} \quad (6)$$

An input membership function defines fuzzy sets by mapping crisp inputs from its domain (all possible concentrations of water quality parameter) to degrees of

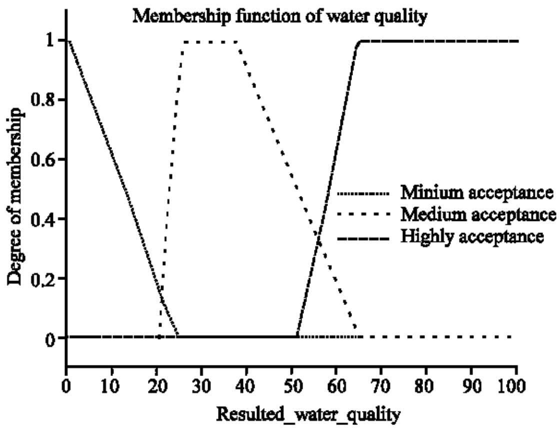

Fig. 5: Membership function of the output variable (Groundwater quality)

membership from 0 to 1. The constructed membership functions for the 10 parameters are trapezoidal on the basis of limit for drinking water quality and expert perception. Water quality was defined as desirable, acceptable in Fig. 5. Babb experts represent their knowledge concerning the classification of the object (water quality) in the from of rules. Each rule has as set of antecedent propositions comprising of attribute names for example: pH, TDS, TA, TH, Calcium, Magnesium, Chloride and Sulphate, attribute values or linguistic descriptions like desirable, acceptable and rejected. Theses linguistic descriptions are invariably imprecise keeping in view the inadequate information on the health implications of each parameters on the users and the integrated effect of all the parameters on human health. Linguistic groundwater quality model (Fisher *et al.*, 2003; Schulz and Howe, 1999), where both the antecedent and consequent are fuzzy proposition was used with a view to estimate, on the basis of membership numbers between the assertion and the antecedent part of the rule, in order to describe drinking water quality fuzzily with certain degree of certainty. Fuzzy set theory has extensively been applied since it has been designed to supplement the interpretation of linguistic or measured uncertainties for the real world random phenomenon. A well designed fuzzy groundwater quality model may be capable of covering the uncertainties existing in the sampling and analysis by comparing the analysis data of all the individual parameters by designing a suitable membership function and using the fuzzy operators (Liou and Lo, 2004). Groundwater quality model is designed to group raw data into different categories according to predetermined quality criteria, which can be normally described using a set of functions that are designed to reflect the absence of sharp boundaries betweeneach pair of adjacent criteria in this approach. Groundwater classes are defined fuzzy set as degrees of membership with flexible boundaries rather than binary/crisp sets. The decision making in fuzzy environments are require three steps:

- Fuzzification of crisp variables.
- Fuzzy decision using fuzzy operators.
- Defuzzification back to crisp values.

Many fuzzy operators have been suggested for all types of fuzzy decision. These suggestions vary with respect to the generality or adaptability of the operators and to the degree to which and how they are justified. Following Zadeh's definition, the 'and ' operator is described by the intersection of the two fuzzy sets, which is given as the minimum of both of the membership functions (Zedah, 1975):

$$\mu c(x) = \min (\mu A(x), \mu B(x))$$

For the or operator, the union of both fuzzy sets defined as the maximum of both membership functions is taken:

$$\mu c(x) = \max (\mu A(x), \mu B(x)).$$

Fuzzy distribution: The fuzzy distributions are used in the automatic generation of fuzzy membership functions. It consists of the following values defined from the time series:

Minimum value:

- Average of minimum and mean value (= angle point A).
- Average of mean and maximum value (= angle point B).

Maximum value: From the fuzzy distribution a weight point value is determined as a reference value. The reference value might be simply an arithmetic mean, weighted average, medium or mode value of a pre-processed data set Fig. 6. The width values of a fuzzy distribution can be defined as follows:

$$W = [\min - r_a] + [r_a - r_b] + [r_b - \max] = [\min - \max]$$

Where:
W = The width of the distribution.
min = The minimum value of the distribution.
max = The maximum value of the distribution.

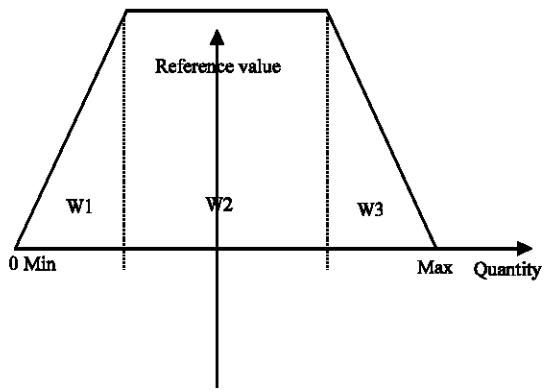

Fig. 6: Fuzzy distributution

r_a = Reference value A= angle point A.
r_b = reference value B = angle point B.

The height of the distribution is normalized to 1.0 (Deshpande and Raje, 1996, 2003). The sub widths can be defined as:

W1 = [min - r_a].
W2 = [r_a - r_b].
W3 = [r_b - max].

Where:
W1 = The width of the first triangle.
W2 = The width of the right-angled parallelogram.
W3 = The width of the second triangle.

The width values describe the shape of the fuzzy distribution. The larger Wi is, the broader the fuzzy distribution is supposed to describe the distribution of time series values on the physical domain. Therefore, the determination of membership functions from the above mentioned distribution has been done by dividing the described distribution into several parts depending on the number of linguistic levels under consideration.

Methodology: First of all water quality experts are identified and relevant field data is collected from selected sites. Additional data is generated if the available data is inadequate for analysis. Perception of experts about the linguistic description of Groundwater quality (for municipal supply of raw water to the city of Tiruchirappalli city in this case) is obtained through a questionnaire. After that modeling of uncertainty in the expert's perception by constructing fuzzy sets/fuzzy numbers and the uncertainty in the field data of water quality parameters using the concept of convex normalized fuzzy number is done. The limits for membership grade function are decided by using Delphi's Technique (Chitu and Suzanne, 2004). The parameters identified for defining all house hold water utility and bathing water quality by the experts are: pH, Ec, TDS, Ca, Mg and Total Hardness. Randomness in the water quality data can be transformed into a convex normalized fuzzy number A with membership grade function μA(x) thereby characterizing the dynamic behavior of the water quality parameters. Construction of fuzzy number or fuzzy sets for modeling the perception of the experts in classifying each parametric domain in linguistic terms such as Desirable, Acceptable, Not Acceptable, which allows for referencing all possible parametric values to be described.

Fuzzy rule evaluation: Fuzzy rules appear no different to standard rules. They take the familiar form IF x is a, THEN y is b", where x and y are linguistic variables and where a and b are linguistic values. Under classical logic, the THEN implication is true of the IF condition, known as the antecedent, is evaluated as true. For fuzzy rules, the implication is set to be true to the same degree as the antecedent. Considering two linguistic variables length and width and the rule IF length is a, THEN width is b, If a is instantiated to a value then b is assigned to the value such that the membership of b is the same as that for a, each to their respective fuzzy sets. This process is known as monotonic selection. Antecedents with >1 statement are not a problem as the earlier rules for fuzzy union (disjunction, OR) and intersection (conjunction and) are applied. Similarly, for consequents with multiple parts, the resultant antecedent membership is applied to all parts of the consequent.

Matching between fuzzy values: The fuzzy number for field data (A) on parameters and the fuzzy numbers (A') characterizing linguistic terms are matched together to arrive at a measure called a Degree of Match (DM) defined by (Erosy and Cho, 1992):

$$DM\ ff\ (AA') = \int \mu\ A \cap A'\ (x)\ dx\ / \int \mu A'\ (x)\ \Sigma\ dx,\ x \in X.$$

in which x denotes the universe and μA n A', x is membership grade for AnA'.

Furthermore, if A and A' are the discrete possibility distributions the measure is defined as:

$$DM\ ff\ (AA') = \Sigma\ \mu\ A \cap A'\ (x) / \Sigma\ \mu A'\ (x),\ x \in X.$$

Approach towards groundwater classification: A fuzzy rule based system is generated, in which users classify the water according to given data in Desirable, Acceptable, Not acceptable, Rejected quality with respect to different parameters, all connected using AND operator. The user's feedback is also taken with respect to overall quality for different parameters connected by AND operator. For example, one of the feedbacks taken may be like this, If TDS = good AND pH = medium and Sulphate = good then, overall water quality What? (Fig. 6).

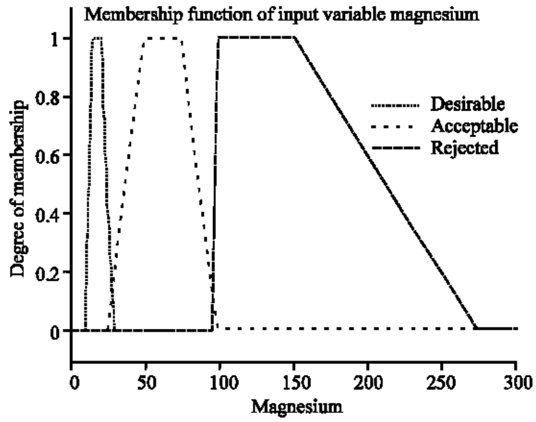

Fig. 7: MF for magnesium

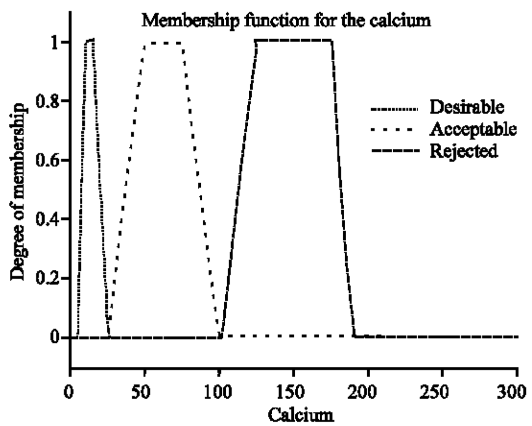

Fig. 8: MF for calcium

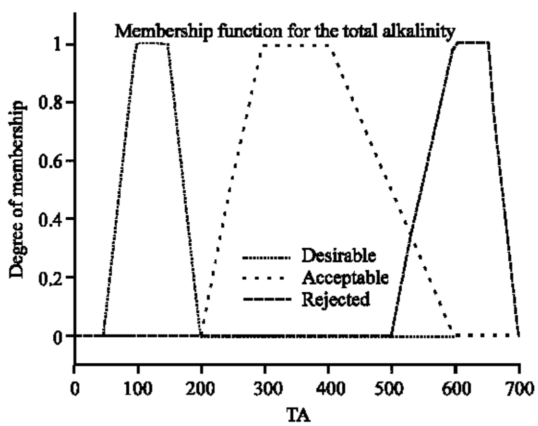

Fig. 9: MF for total alkalinity

After this, Delphi's technique is applied to converge the feedback of various users to a single value. A degree of match is computed between the user's perception and field data for different parameters and for every type of water quality viz. good (Desirable), medium (Acceptable) or bad (Not Desirable). The water quality for which degree

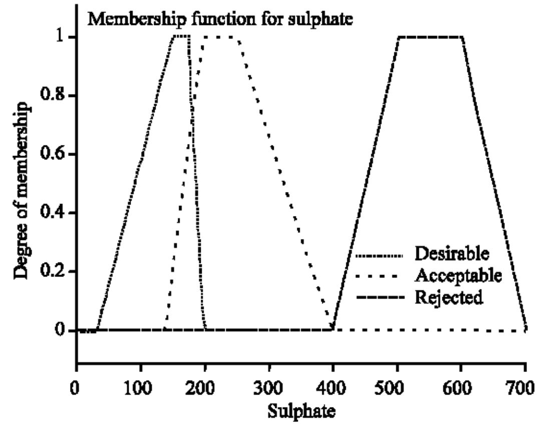

Fig. 10: MF for sulphate

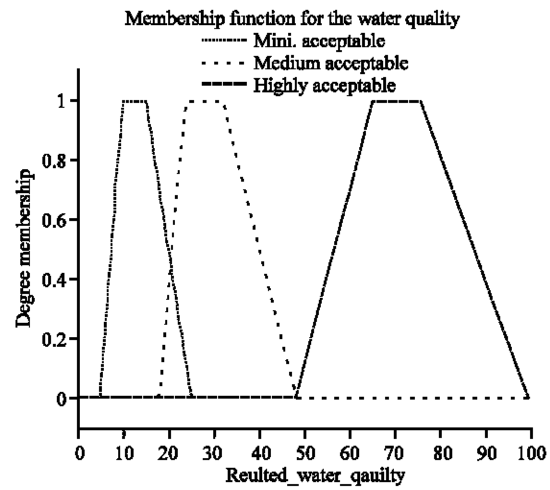

Fig. 11: Membership function of the output variable (Groundwater quality)

of match is the highest is considered to represent the quality of the water sample. MF of all parameters are shown in Fig. 1-5 and 7-11.

RESULTS AND DISCUSSION

Physio-chemical Groundwater quality assessment by deterministic method for drinking groundwater usage on the basis of 8 water quality parameters werecompared with the concentration in the water with point value prescribed limits. In case Groundwater quality model approach, these 8 parameters were divided in the four categories on the basis of expert opinion having their importance with respect to drinking water quality criteria. As per classification pH, TDS, Chloride, TH and Sulphate were kept in first group, Calcium, Magnesium, TA and Sulphate were categorized in second group (Fig. 7-9). In this analysis, nitrate and Fluoride is not considered for the study purposes. In this method membership matrix for all

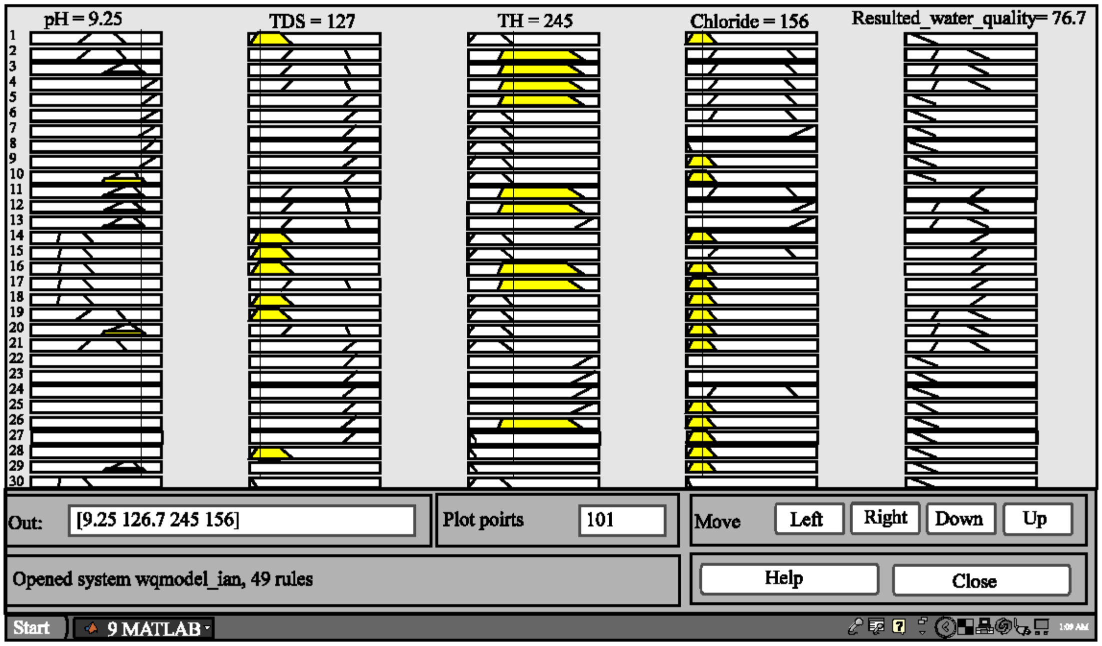

Fig. 12: Membership function of the output variable-percentage of GWQ

parameters for these qualities was formed for all samples individually on the basis of the membership curves, which are shown in Fig. 12. A total of 51 rules based on the drinking water quality expert's perception were fired using mamdani implification of max. min operator to assess the drinking water quality of the groundwater samples in the present study (Mamdani, 1976). Few samples rules designed by the water quality experts for all four groups are given below Fig. 12. The following are the two sample rules out of 14 rules designed on the expert knowledge basis for the physico chemical water quality parameters in group 1. Rule I If pH is desirable; TDS is desirable; chloride is desirable; TH is acceptable; Then: groundwater quality is desirable for drinking purpose. 2. Rule II. If pH is acceptable; TDS is desirable; chloride is desirable; TH is acceptable (Fig. 12). Then: groundwater quality is desirable for drinking purpose. In case o second group 2 sample rules are given below out of the 16 rules fired for the classification of drinking water quality classification on the basis of the parameter studied in the second group. 1. Rule I. If TA is desirable; Calcium is desirable; Sulphate is Acceptable; Then: groundwater sample quality is desirable for drinking purpose 2. Rule II If TA is desirable; Chloride is acceptable; Sulphate is desirable Then: groundwater quality is desirable for drinking purpose (Fig. 7-10).

For the remaining two groups there were single parameters. Results from group 1 and 2 were combined with group 3 and 4 to assess the final classification of water. A total of 24 rules were fired for the assessment of groundwater quality using the groundwater quality model. On the out put of the first and second group sown in Table 2. In max. min operator, the minimum value from each rule is taken and stored in a group using fuzzy min operator and then by choosing the maximum value from that group gives the belongingness of that groundwater sample quality to specific category. Defuzzification is the transformation that replaces a fuzzy set by single numerical value representative of that set. Mean of maxima defuzzification method was used in the present study. On this basis the results of all the 30 water samples were evaluated and are shown in Table 2. In the safety margin the uncertainties plays a vital role in decision making as the result in such case having higher probabilities of enforcing decision errors. This reveals that physcio chemical groundwater quality sample number 1-9 and 21 is desirable with highest certainty level of 79% (Table 3). The sample numbers 1-5 and 21 with certainty of 79%. in case of open well numbers using the deterministic method, pH, TDS, TH, Ca^{2+}, Mg^{2+} Cl^{-} fall in the desirable class, the parameters TA, Ca^{2+}, Mg^{2+} observed in acceptable category while, Sulphate was in the Rejected category (Dahyia *et al*., 2005, 2007). This is type of decision about the drinking quality of the sample give a very vague picture even for the scientist and engineers and it becomes a Herculean task if this is communicated to the public.

Table 2: The Physicochemical characteristics of groundwater of the tiruchirappalli city-zone II ariyamangalam (Aug. 2007)

Sample No.	pH	Temp.	EC	TDS	TH	TA	Ca^{2+}	Mg^{2+}	Cl^-	SO_4
1	6.94	21.8	1.930	1200	305	270	48	45	155	159
2	6.90	21.5	0.988	1050	475	295	106	51	185	129
3	6.95	22.3	0.733	750	415	290	80	52	145	78
4	7.30	15.5	1.848	550	410	260	74	55	125	78
5	7.40	21.6	1.207	3100	720	345	190	60	515	129
6	7.14	22.5	2.071	850	420	310	60	66	175	62
7	7.04	23.5	6.940	800	460	280	90	57	210	62
8	7.18	18.3	5.330	500	445	345	70	66	185	16
9	8.33	21.2	6.920	800	130	270	18	21	160	47
10	7.26	22.5	3.730	2200	830	320	226	64	485	62
11	6.96	18.7	2.730	2000	425	325	118	32	165	72
12	7.04	21.9	4.870	900	580	365	170	38	335	87
13	6.80	19.4	1.690	2800	700	340	180	61	405	98
14	6.90	21.8	2.150	1300	435	445	104	43	280	108
15	8.18	22.8	1.070	1200	140	155	22	21	55	27
16	7.37	23.6	1.042	1000	405	455	94	41	250	144
17	7.25	23.6	1.023	1400	320	365	56	44	140	73
18	7.39	24.3	0.890	400	310	225	58	40	80	113
19	7.07	23.8	0.988	2100	575	415	174	34	285	195
20	7.31	24.1	2.320	1400	355	430	68	45	175	83
21	6.77	20.0	1.045	4700	1630	570	568	51	2245	215
22	7.27	23.9	1.121	7300	2360	315	698	150	2220	231
23	7.60	24.6	1.031	3700	1220	445	2002	174	1295	220
24	6.97	24.7	0.950	7100	2455	420	792	115	1975	215
25	6.66	24.7	2.150	8800	1270	405	438	43	945	190
26	6.93	24.9	0.876	2000	770	225	268	24	610	185
27	6.92	24.8	0.635	3500	1640	250	362	179	1445	57
28	6.88	21.2	1.310	500	805	570	190	80	320	62
29	7.53	24.2	1.688	3300	1120	335	158	176	615	52
30	7.65	25.5	0.417	1600	40	400	56	80	180	57

All Units are in μg mL^{-1} except pH and EC, The unit of EC mS cm^{-1}

Table 3: Level of uncertainty for the groundwater quality

Sample No.	Uncertainty value for A (pH,TDS,Chloride,TH)	Uncertainty value for B TA,Ca^{2+},Mg^{2+}, SO_4
1	79.05	50
2	79.05	50
3	79.05	50
4	76.55	50
5	50.00	50
6	77.93	50
7	75.11	50
8	77.60	50
9	62.35	50
10	9.86	50
11	8.02	50
12	41.51	50
13	12.00	50
14	44.52	50
15	65.45	50
16	42.98	50
17	76.99	50
18	50.00	50
19	41.33	50
20	76.48	50
21	50.00	50
22	50.00	50
23	50.00	8.8412
24	50.00	50
25	50.00	50
26	8.54	50
27	50.00	50
28	50.00	50
29	50.00	50
30	59.87	50

All Units are in μg mL^{-1} except pH and Ec, The unit of EC mS cm^{-1}

CONCLUSION

Deterministic assessment of the drinking water quality on the basis of the measurements results according to the prescribed limits by either BIS, WHO, or ICMR will give the result in form of linguistic term like Desirable and Not Acceptable. For each parameter one separate class of water has been indicated whereas in Water Quality Index (WQI) approach the quality index will be which can give in desirable class even if some important parameter are having no weightage due the levels of that specific parameters. But in fuzzy groundwater quality model approach, the groundwater quality is classified in three categories, just four samples comes in the desirable class certainty level of minimum 8% (need further investigation in this groundwater samples and a maximum of 79%. Fourteen samples are classified in the acceptable category for drinking purpose with the maximum certainty level of 50%, Rest of the 13 sample are in not acceptable class with a maximum certainty level of 100%. Indicated that those not worth for drinking usage. it can be concluded that drinking water quality can be assessed in more logistic way and results on water quality classification can be described with a confidence level of belongingness of a specific samples to any of the well defined category of water for drinking. This approach can also be used successfully in other environmental systems like air pollution monitoring, waster water quality assessment, irrigation water quality assessment, Environmental health assessment, etc. and quality can be reported with a level of certainty on the basis of prescribed limits as well field experts.

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