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Analysis of groundwater quality using fuzzy synthetic evaluation

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Abstract

This paper reports the application of fuzzy set theory for decision-making in the assessment of physico-chemical quality of groundwater for drinking purposes. Methodology based on fuzzy set theory used to express the quality of water in the imprecise environment of monitored data and prescribed limits given in a non-probabilistic sense. Fuzzy synthetic evaluation model gives the certainty levels for the acceptability of the water based on the prescribed limit of various regulatory bodies quality class and perception of the experts from the field of drinking water quality. Application of fuzzy rule based optimization model is illustrated with 42 groundwater samples collected from the 15 villages of *Ateli* block of southern Haryana, India. These samples were analysed for 16 different physico-chemical water quality parameters. Ten parameters were used for the quality assessment using this approach. The analysis showed that four samples were in "desirable" category with certainty level of 35–58%, 23 samples were in "acceptable" category whose certainty level ranged from 37 to 75% and remaining 15 samples were in "not acceptable" category for drinking purposes with certainty levels from 44 to 100%. This concludes that about 64% water sources were either in "desirable" or "acceptable" category for drinking purposes.

Keywords: Water quality; Fuzzy set; Linguistic terms; Membership function; Fuzzy rule; Degree of certainty; Fluoride; Nitrate; Haryana; India

1. 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 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, Bureau of Indian Standards and Indian Council of Medical Research [1–3] are having limitations due to variation in intake of water by individuals during various seasons through out the year. Prescribed limits from any regulatory body contain uncertainties as these are the extrapolated values from the data either from animal experiments or very trivial epidemiological studies [3–6]. 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 criteria and decision-making. But most of the reports on the 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 through out the entire procedure [4–10]. But, one of the most popular and commonly used methods during last few decades was water Quality Index (WQI). Horton [11] made a pioneering attempt to study the general indices, selecting and weighting different water quality parameters. This methodology was, developed by National Sanitation Foundation (NSF), USEPA using delphi technique as a tool in formal assessment procedure [12]. Decision-making using comparison of water quality prescribed limits with various water quality indices has been developed to integrate water quality variables [13–16]. This approach has few drawbacks such as some parameters in the index equations can influence the final score of WQI dramatically without valid scientific justification. There are limitations

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on which a wrong decision can be taken as it is dependent on the fix weightage assigned to different parameters, where as the weightage should be varied on the basis of season, rainfall and water intake of individual, ambient temperature, occupational, residential and other environmental factors. These indices are lacking to deal with uncertainties involves at various steps in decision-making [17–19]. Due to these limitations of deterministic and WQI approach, an advanced classification method is required, which is capable of accounting for imprecise, vague and fuzzy information in decision-making on drinking water quality. Sii et al. [20] have discussed the uncertainties involved in water quality using fuzzy membership with values ranging from 0 to 1 to form an applicable fuzzy set instead of the conventional scale of 0 to 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 borderline cases of water quality parameters, it become 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

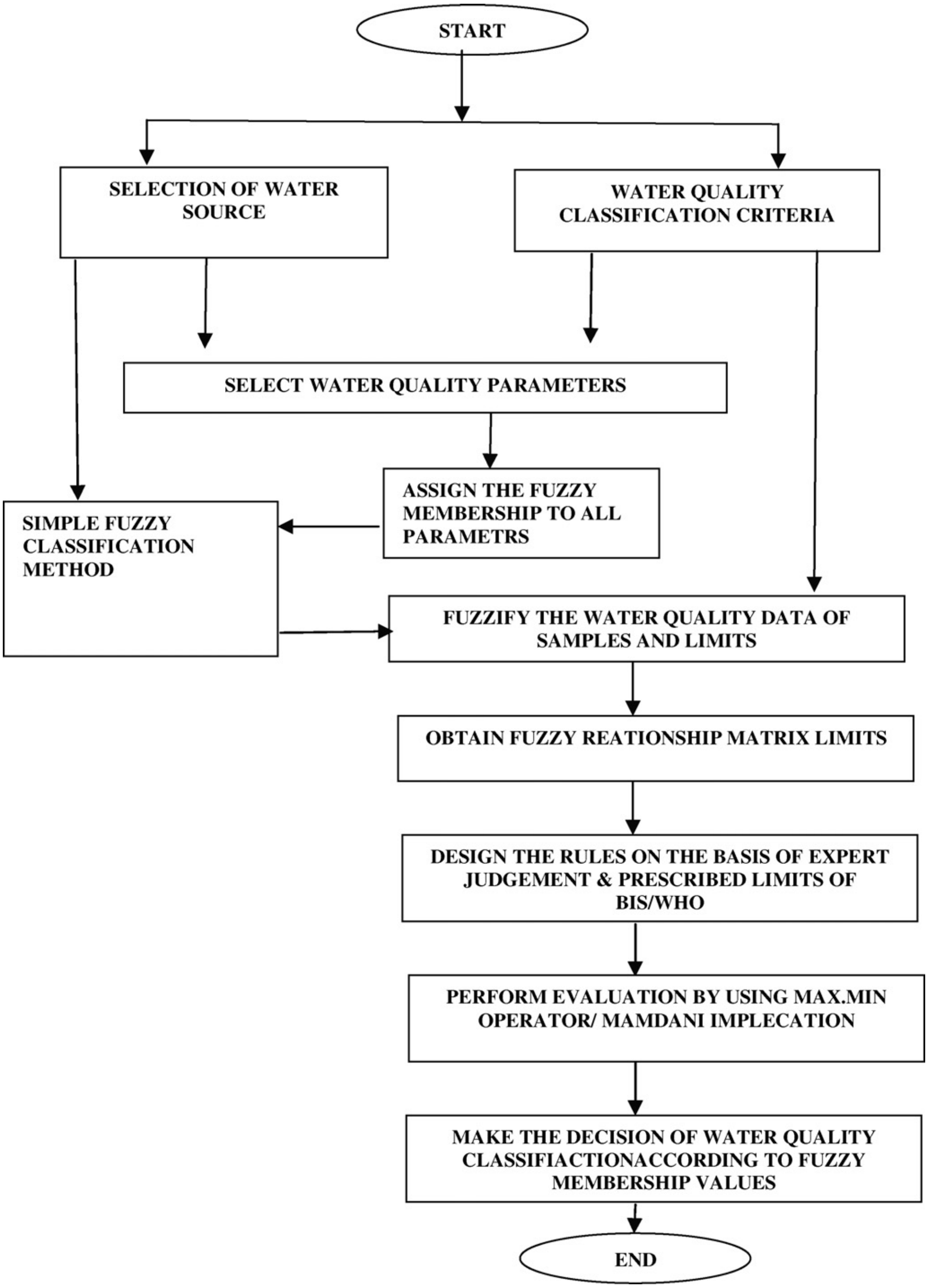

Fig. 1. Analytical procedure of the fuzzy synthetic evaluation analysis.

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 sciences [21–23]. These methodologies based on fuzzy sets theory are tested with real environmental problems to handle the uncertainty in imprecise environment in decision-making tools [17,24]. It is proposed that methods based on fuzzy sets theory should be applied to the way the uncertainties in the decision-making on the 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 the decision-making in the imprecise environment, an attempt is made to classify the underground water from the Ateli block, Haryana of northern India for the drinking purposes.

2. Materials and methods

A total of 42 ground water samples were collected from the 15 villages of the rural area of *Ateli* Block (Mahendragarh District), Haryana, India applying the prescribed methodology for sampling [4]. Water from these sources is used for drinking purposes. These samples were analysed for the 16 different physico-chemical water quality parameters as per standard procedure [25]. Decision was made on the basis of deterministic analysis as per the standards provided by different regulatory bodies [1,2]. Difference in the decision on the drinking water quality on the basis of deterministic and FSE methods for groundwater have been reported by other workers [4–8]. Results of the present study were taken for the fuzzy synthetic evaluation (FSE) model to assess the groundwater quality for drinking purposes using 10 parameters, viz., pH, total dissolved salts (TDS), total alkalinity (TA), total hardness (TH), chloride, calcium, magnesium, sulphate, nitrate and fluoride. Out of 16 analysed parameters these 10 parameters have been suggested as key parameters in water quality [5,6].

2.1. Fuzzy set theory

Fuzzy set theory is suited to make decisions in complex systems when the context of the problem is often unclear. It has been commonly used for imprecise information in a non-probabilistic sense and allows integration of information of various parameters into the modeling and evaluation process. The concept of fuzzy sets describing imprecision or vagueness was introduced by Zadeh [26] and has been applied throughout the world in decision-making and evaluation processes in imprecise environment [9,10,27]. Fuzzy set theory may be regarded as a generalization of classical set 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 outside. 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 curves shows the membership function for each set. The membership functions 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

$$\mu_A : X \to [0, 1] \tag{1}$$

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

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

or

$$\mu_A : \left\{ \begin{array}{ll} = 1 & x \text{ is full member of } A \\ \in (0, 1) & x \text{ is partial member of } A \\ = 1 & x \text{ is not member of } A \end{array} \right\} \tag{3}$$

In order to be considered a fuzzy set the membership function μ_A has to satisfy certain requirements. These ensure that the classical set theoretic concepts of complement, union and intersection are carried over consistently to fuzzy sets as well. The membership function μ_A may be normalized to ensure that μ_A takes the value one somewhere on *X* by dividing by the maximum value of μ_A. 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 [28–30]. Fig. 1 shows the complete analytical procedure for the fuzzy synthetic evaluation model. Fuzzy membership functions were constructed for all the 10 parameters are either triangular or trapezoidal on the basis of expert perception and prescribed limits (Table 1) for FSE model to classify the water quality is shown in Fig. 2. A typical example of one parameter pH is shown in the Eqs. (4)–(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 membership (from 0 to 1). The constructed membership functions for the 10 parameters are either triangular or trapezoidal on the basis of limit for drinking water quality and expert perception. Water quality was defined as "desirable", "acceptable"

Table 1
The limits prescribed by Bureau of Indian Standards (BIS) and Indian Council of Medical Research (ICMR) for the studied parameters

Parameter	BIS		ICMR	
	Desirable	Acceptable	Desirable	Permissible limit
pH	6.5–8.5	–	7.0–8.5	6.5–9.2
TA	200	600	–	–
TH	300	600	300	600
TDS	500	2000	500	1500 (3000)
Ca^{2+}	75	200	75	200
Mg^{2+}	30	100	50	100
Cl^{-}	250	1000	200	1000
$SO_4{}^{2-}$	200	400	200	400
$NO_3{}^{-}$	–	45	20	Not > 100
Fluoride	1.0	1.5	1.0	1.5

Units are μg/mL except pH.

and “not acceptable”.

$$\text{Desirable}: \quad \mu_{\text{pH}} = \begin{cases} 0, & \text{if}\, x \leq 6.8 \\ \dfrac{x-6.8}{7.3-6.8}, & \text{if}\, x \in [\,6.8, 7.3) \\ 1.0, & \text{if}\, x \in (7.3, 8.1) \\ \dfrac{8.8-x}{8.8-8.1}, & \text{if}\, x \in (8.1, 8.8] \\ 0, & \text{if}\, x \geq 8.8 \end{cases} \tag{4}$$

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

$$\text{Not acceptable}: \quad \mu_{\text{pH}} = \begin{cases} 1.0, & \text{if}\, x \leq 6.0 \\ \dfrac{6.4-x}{6.4-6.0}, & \text{if}\, x \in [6.0, 6.4) \\ 0, & \text{if}\, x \in (6.4, 9.2) \\ \dfrac{x-9.2}{9.6-9.2}, & \text{if}\, x \in (9.2, 9.6] \\ 1.0, & \text{if}\, x \geq 9.6 \end{cases} \tag{6}$$

In a fuzzy rule based system, the experts represent their knowledge concerning the classification of the object (water quality) in the form of rules. Each rule has a set of antecedent propositions comprising of attribute names for example: pH, TDS, TA, TH, calcium, magnesium, chloride, sulphate, nitrate and fluoride, attribute values or linguistic description like desirable, acceptable and not-acceptable. These linguistic descriptions are invariably imprecise keeping in view the inadequate information on the health implications of each parameter on the users and the integrated effect of all the parameters on human health. Furthermore, the field data on the parametric concentrations are often inadequate resulting into imprecise assertions. Linguistic FSE model [19,20], where both the antecedent and consequent are fuzzy proposition was used in this study. A computational scheme of FSE has been 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 real world random phenomenon. A well designed fuzzy synthetic evaluation (FSE) method may be capable of covering the uncertainties existing in the sampling and analysis by comparing the analysis data of all the individual parameters values with the prescribed limit in the fuzzy environment by designing a suitable membership function and using the fuzzy operators [13]. FSE 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 between each pair of adjacent criteria. In this approach, water classes are defined as fuzzy sets as degrees of membership with flexible boundaries rather than binary/crisp sets.

The decision-making in fuzzy environments requires 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:

$$\mu_{\text{c}}(x) = \min\,(\mu_A(x), \mu_B(x))$$

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

$$\mu_{\text{c}}(x) = \max\,(\mu_A(x), \mu_B(x)).$$

3. Result and discussions

Physico-chemical water quality assessment by deterministic method for drinking water usage on the basis of 10 water quality parameters was by comparing the concentration in the water with the point value prescribed limits. In case FSE approach, these 10 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 and sulphate were kept in first group, calcium, magnesium, TA and TH were categorized in second group while nitrate and fluoride were individually considered as separate group due to their importance in drinking water quality criteria. In FSE method, membership matrix for all the parameters for three qualities was formed for all samples individually on the basis of the membership curves which are shown in Fig. 2. A total of 55 rules based on the drinking water quality expert perception were fired using mamdani implication of max.min operator to assess the drinking water quality of the groundwater samples in this study [29]. Few samples rules designed by the water quality experts for all four groups are given below. 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. Schematic diagram of fuzzy rule application is shown in Fig. 3.

- Rule 1
  If pH is desirable; TDS is desirable; chloride is desirable; sulphate is acceptable;
  Then: groundwater sample quality is desirable for drinking purpose.
- Rule 2
  If pH is acceptable; TDS is desirable; chloride is desirable; sulphate is acceptable;
  Then: groundwater sample quality is desirable for drinking purpose.

In case of second group 2 sample rules are given below out of the 14 rules fired for the classification of drinking water quality classification on the basis of the parameter studied in the second group. Detail of firing of fuzzy rules is shown in Fig. 4.

- Rule 1
  If TA is desirable; TH is desirable; calcium is desirable; magnesium is acceptable;
  Then: groundwater sample quality is desirable for drinking purpose.

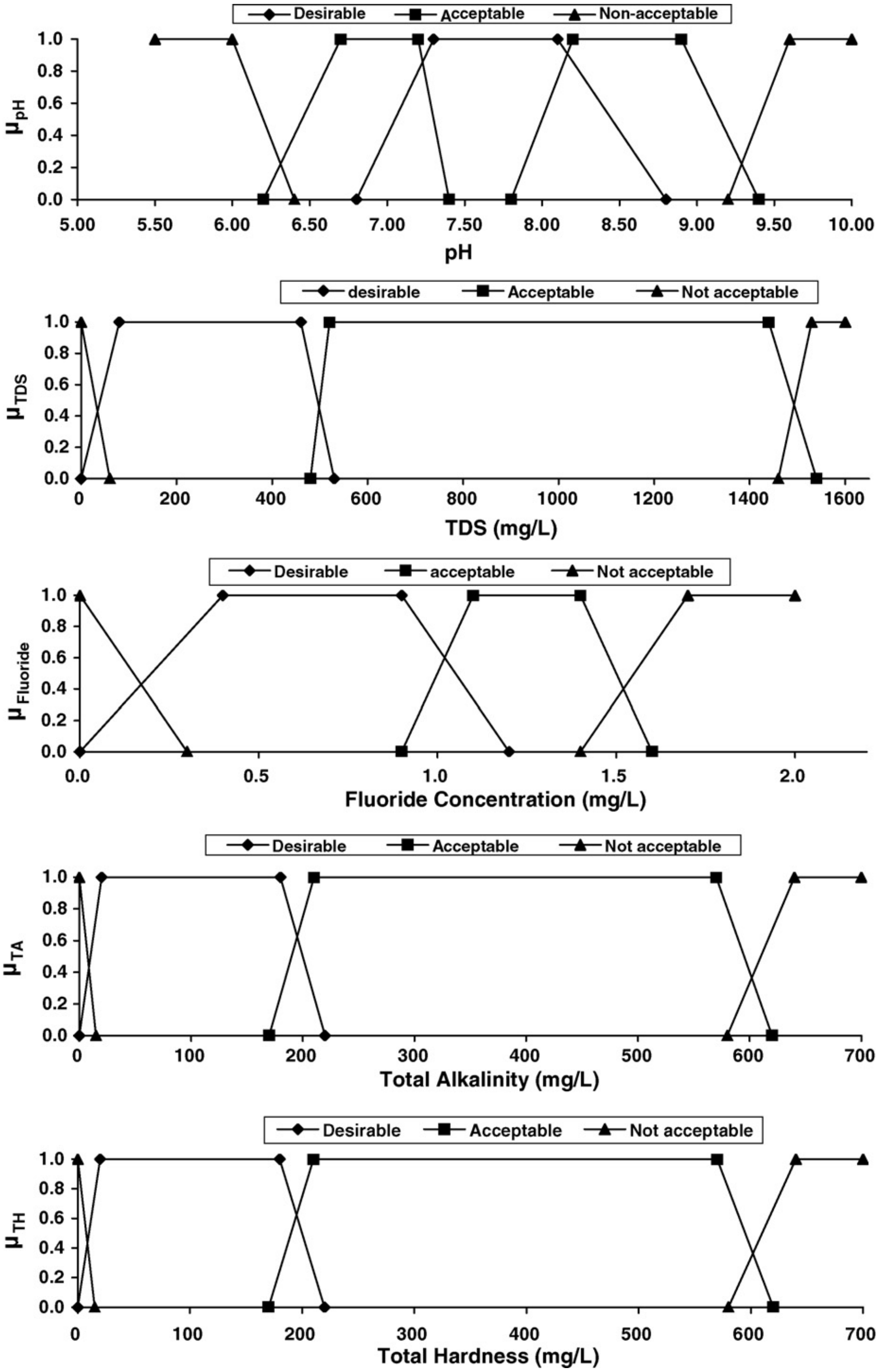

Fig. 2. Membership functions defined for water quality parameters used in the study.

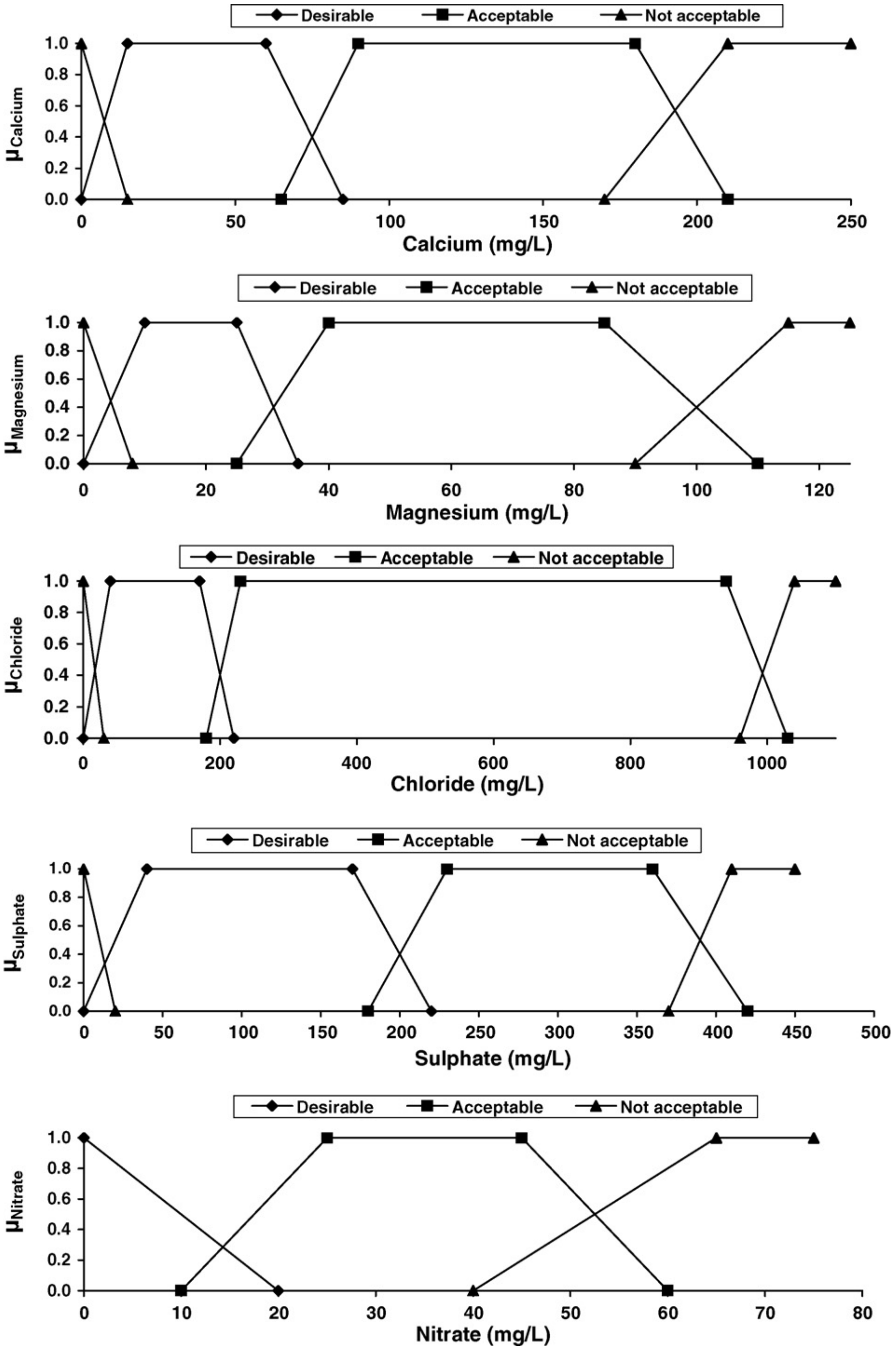

Fig. 2. (*Continued*).

- Rule 2
  If TA is desirable; TH is acceptable; chloride is acceptable; sulphate is desirable;
  Then: groundwater sample quality is desirable for drinking purpose.

For the remaining two groups there were single parameters. Results from group 1 and group 2 were combined with group 3 and 4 to assess the final classification of water. A total of 27 rules were fired for the assessment of water quality using FSE on the output of first and second group and parameters in third and fourth group (Fig. 5). Two samples rules fired on all the four groups are as follows:

- Rule 1
  If group 1 quality is acceptable; group 2 quality is desirable; nitrate is desirable; fluoride is desirable;
  Then: groundwater sample quality is desirable for drinking purpose.

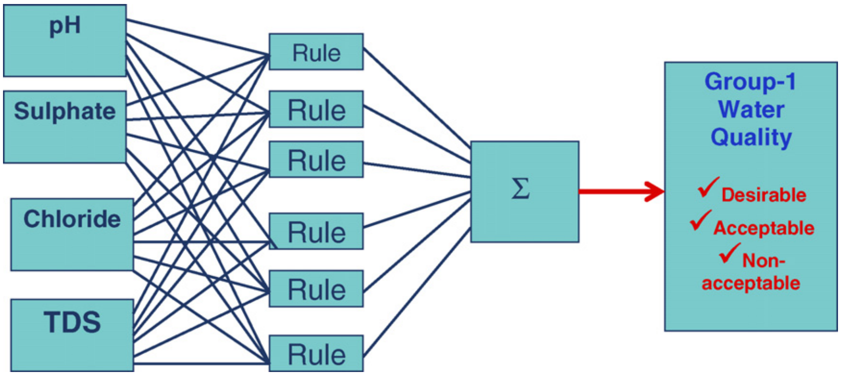

Fig. 3. Input–output map for the groundwater quality assessment for drinking usage in fuzzy synthetic evaluation system for parameters in group 1.

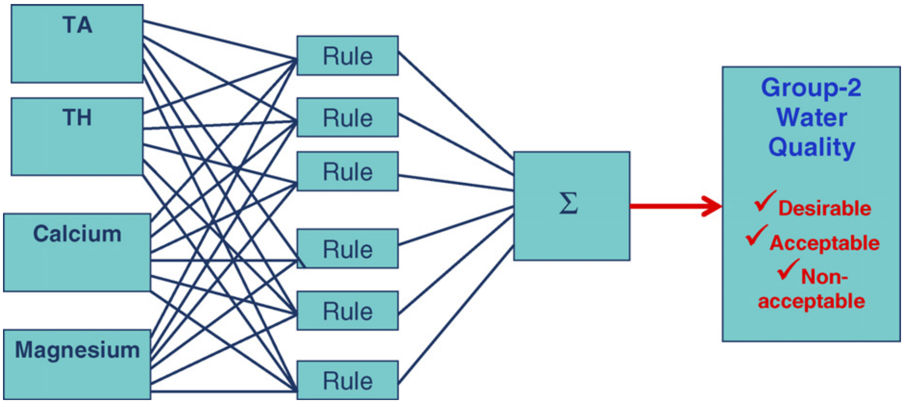

Fig. 4. Input–output map for the groundwater quality assessment for drinking usage in fuzzy synthetic evaluation system for parameters in group 2.

- Rule 2

  If group 1 quality is acceptable; group 2 quality is acceptable; Nitrate is desirable; Fluoride is acceptable;
  Then: Groundwater sample quality is acceptable for drinking purpose.

Considering the fluoride as one of the most important parameter, as its presences in the drinking water higher than 3.0 mg/L cause crippling fluorosis in addition to dental fluorosis, one exclusive rule was fired on the membership function that if any sample is having fluoride content more than 3.0 mg/L will be considered as non-acceptable, but the level of certainty will be decided on the basis on other parameters as well. 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 water sample quality to the 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 this study. On this basis, the results of all the 42 samples were evaluated and are shown in Table 2. FSE method shows its importance in samples, where the parametric values fall in the safety margin. In the safety margin the uncertainties plays vital role

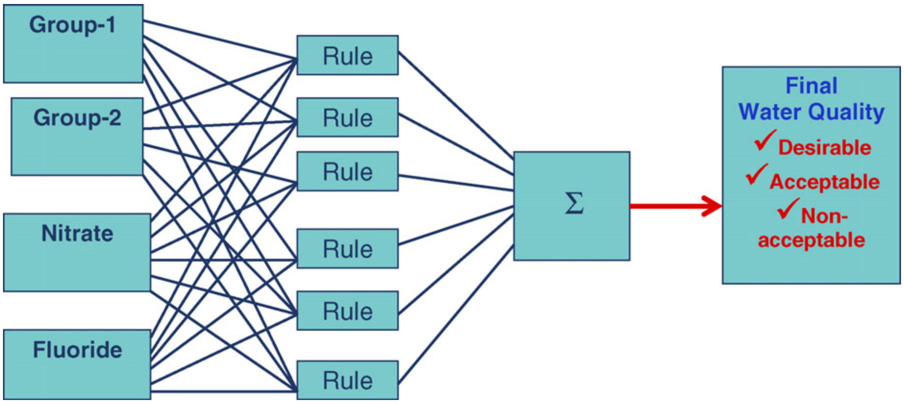

Fig. 5. Input–output map for the groundwater quality assessment for drinking usage in fuzzy synthetic evaluation system for all the studied parameters.

Table 2
Detail on groundwater quality for drinking purposes by using FSE method and deterministic method (as per BIS standards)

TW (no.)	Decision using FSE method	Decision using deterministic method		
		Desirable	Acceptable	Not-acceptable
1	Acceptable (50)	pH, TDS, Ca^{2+}, Mg^{2+}, Cl^-	TA, TH, NO_3^-	SO_4^{2-}, F^-
2	Not-acceptable (83)	pH, Ca^{2+}, Mg^{2+}, Cl^-	TDS, TA, NO_3^-	TH, SO_4^{2-}, F^-
3	Not-acceptable (69)	pH, Ca^{2+}, Cl^-	TDS, TH, NO_3^-	TA, Mg^{2+}, SO_4^{2-}, F^-
4	Not-acceptable (50)	pH, TDS, Ca^{2+}, Cl^-	TA, SO_4^{2-}, NO_3^-	TH, Mg^{2+}, F^-
5	Not-acceptable (64)	pH, Ca^{2+}, Cl^-	TDS, TA, SO_4^{2-}, NO_3^-	TH, Mg^{2+}, F^-
6	Not-acceptable (58)	pH, TDS, Ca^{2+}, Cl^-	TA, SO_4^{2-}, NO_3^-	TH, Mg^{2+}, F^-
7	Not-acceptable (44)	pH, Ca^{2+}, Cl^-	TDS, SO_4^{2-}, NO_3^-	TA, TH, Mg^{2+}, F^-
8	Acceptable (75)	pH, Ca^{2+}, Cl^-	TDS, TA, SO_4^{2-}, NO_3^-, F^-	TH, Mg^{2+}
9	Not-acceptable (100)	pH, Cl^-, Ca^{2+}	SO_4^{2-}, NO_3^-	TDS, TA, TH, Mg^{2+}, F^-
10	Not-acceptable (40)	pH, Cl^-, SO_4^{2-}, Ca^{2+}	TDS, TA, NO_3^-	TH, Mg^{2+}, F^-
11	Not-acceptable (44)	pH, SO_4^{2-}, Cl^-, Ca^{2+}	TDS, NO_3^-	TA, TH, Mg^{2+}, F^-
12	Not-acceptable (65)	pH, SO_4^{2-}, Cl^-, Ca^{2+}	TDS, TH, Mg^{2+}, NO_3^-	TA, F^-
13	Not-acceptable (54)	pH, SO_4^{2-}	TA, Ca^{2+}, Cl^-, NO_3^-,	TDS, TH, Mg^{2+}, F^-
14	Not-acceptable (83)	pH	TA, Ca^{2+}, SO_4^{2-}, NO_3^-,	TDS, TH, Cl^-, F^-, Mg^{2+}
15	Acceptable (60)	pH, SO_4^{2-}	TDS, TA, Ca^{2+}, Cl^-, NO_3^-, F^-	TH, Mg^{2+},
16	Acceptable (48)	pH	TDS, TA, Ca^{2+}, Cl^-, NO_3^-, F^-	TH, SO_4^{2-}, Mg^{2+}
17	Acceptable (59)	pH, SO_4^{2-}, Cl^-, Ca^{2+}	TDS, TA, NO_3^-	TH, Mg^{2+}, F^-
18	Acceptable (40)	pH, Cl^-	TDS, TA, TH, Mg^{2+}, NO_3^-, Ca^{2+}	SO_4^{2-}, F^-
19	Not-acceptable (62)	pH, Cl^-, SO_4^{2-}	TDS, TA, NO_3^-, Ca^{2+}	TH, F^-, Mg^{2+}
20	Acceptable (52)	pH, Cl^-, Ca^{2+}	TDS, TA, SO_4^{2-}, NO_3^-	TH, Mg^{2+}, F^-
21	Acceptable (56)	pH, Cl^-, Ca^{2+}	TDS, TA, TH, NO_3^-, SO_4^{2-}	Mg^{2+}, F
22	Acceptable (61)	pH, TH, Mg^{2+}, SO_4^{2-}, Cl^-, Ca^{2+}	TDS, TA, NO_3^-	F^-
23	Acceptable (67)	pH, TH, Mg^{2+}, SO_4^{2-}, Cl^-, Ca^{2+}	TDS, TA, NO_3^-	F^-
24	Desirable (52)	pH, TDS, TH , Mg^{2+}, Cl^-, Ca^{2+}	TA, NO_3^-, F^-	SO_4^{2-}
25	Acceptable (60)	pH, TH, Mg^{2+}, SO_4^{2-}, Cl^-, Ca^{2+}	TDS, TA, NO_3^-	F^-
26	Acceptable (66)	pH, TH, Mg^{2+}, SO_4^{2-}, Cl^-, Ca^{2+}	TDS, TA, NO_3^-	F^-
27	Desirable (58)	pH, TDS, TH, Mg^{2+}, Cl^-, Ca^{2+}	TA, Ca^{2+}, NO_3^-, F^-	SO_4^{2-}
28	Acceptable (41)	pH, SO_4^{2-}, F^-	TA, Ca^{2+}, Cl^-, NO_3^-	TDS, TH, Mg^{2+}
29	Acceptable (50)	pH, SO_4^{2-}, F^-	TA, Ca^{2+}, Cl^-, NO_3^-	TDS, TH, Mg^{2+}
30	Acceptable (33)	pH, SO_4^{2-}, F^-	TDS, TA, Ca^{2+}, Cl^-, NO_3^-	TH, Mg^{2+}
31	Acceptable (37)	pH, F^-	TDS, TA, Mg^{2+}, Ca^{2+}, NO_3^-, Cl^-, SO_4^{2-}	TH
32	Acceptable (56)	pH, TH, Mg^{2+}, SO_4^{2-}, Cl^-, Ca^{2+}	TDS, TA, NO_3^-	F^-
33	Desirable (35)	pH, SO_4^{2-}, F^-	TDS, TA, TH, Mg^{2+}, Ca^{2+}, NO_3^-, Cl^-	
34	Not-acceptable (45)	pH, F^-	TA, NO_3^-	TDS, TH, Mg^{2+}, SO_4^{2-}, Cl^-, Ca^{2+}
35	Not-acceptable (68)	pH, F^-	TA, NO_3^-	TDS, TH, Mg^{2+}, Cl^-, SO_4^-, Ca^{2+}
36	Acceptable (44)	pH, Cl^-	TDS, TA, Ca^{2+}, NO_3^-, SO_4^{2-}, F^-	TH, Mg^{2+}
37	Acceptable (44)	pH, Cl^-, TDS	TA, Mg^{2+}, Ca^{2+}, NO_3^-, SO_4^{2-}, F^-	TH
38	Acceptable (40)	pH, Cl^-, TA	TDS, TH, Mg^{2+}, Ca^{2+}, F^-	SO_4^{2-}
39	Acceptable (63)	pH, Cl^-	TDS, Ca^{2+}, NO_3^-, F^-	TA, TH, Mg^{2+}, SO_4^{2-}
40	Acceptable (50)	pH, Cl^-	TDS, TA, TH, Mg^{2+}, NO_3^-, Ca^{2+}, F^-	SO_4^-
41	Desirable (56)	pH, TH, Mg^{2+}, Cl^-, Ca^{2+}	TDS, NO_3^-, TA, F^-	SO_4^{2-}
42	Acceptable (72)	pH, F^-	TDS, TA, Ca^{2+}, NO_3^-, SO_4^{2-}, Cl^-	TH, Mg^{2+}

Number in parenthesis indicates level of certainty. TA: total alkalinity (as $CaCO_3$); TH: total hardness (as $CaCO_3$); TDS: total dissolved salts.

in decision-making as the result in such case having higher probability of enforcing decision errors. Comparison of the FSE model based decision with the deterministic evaluation decision is shown in the Table 2. This reveals that physico-chemical water quality of sample number 27 is desirable with highest certainty level of 58% followed by sample number 41 with certainty value 56%. In case of tube well number 27 using deterministic method, five parameters (pH, TDS, TH, Mg^{2+}, Cl^-, Ca^{2+}) fall in desirable class, four parameters (TA, Ca^{2+}, NO_3^-, F^-) observed in acceptable category while sulphate was in the not-acceptable category. This type of decision about the drinking water quality of a sample give a very vague picture even for scientist and engineers and it become a Herculean task if this decision has to be communicated to the population.

The difference in the decision level between the FSE method and deterministic method is clearly indicated in the samples number 19 and 20. In both the samples three parameters namely TH, Mg^{2+} and F^- are in not acceptable category, for sample 19 four parameters (TDS, TA, NO_3^- and Ca^{2+}) are in acceptable, whereas in sample 20 again four parameters (TDS, TA, NO_3^- and SO_4^{2-}) are in acceptable class (Table 2). In desirable categories both samples are having three parameters, i.e. pH, Cl^- and SO_4^{2-} for sample 19 whereas pH, Cl^- and Ca^{2+} for sample 20 (Table 2). But, the decision using FSE approach is totally different as sample 19 is in “not acceptable” category with certainty level of 62% in comparison to sample number 20, which is in acceptable class with certainty level of 52%. This is mainly due to one parameter, which is having concentration higher than the permissible for both samples, but in sample 20 the concentration is marginally higher than the permissible limit and comes in the domain of fuzzy membership function for acceptable and not-acceptable both, whereas for sample 19 the concentration is very high and levels belongs to the not-acceptable category only causes the difference in results. In this way this method can play an important role in the decision-making for the drinking water quality assessment in which both prescribed limit of regulatory bodies and the expert judgement are involved.

4. Conclusion

Deterministic assessment of the drinking water quality on the basis of the measurements results according to the prescribed limits by either BIS or ICMR will give the results in form of linguistic term like “desirable”, “acceptable” 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 parameters are having no weightage due the levels of that specific parameters. But in fuzzy synthetic evaluation approach, the drinking water quality is classified in three categories with level of certainty of belongingness to different categories, just four samples comes in the desirable class with certainty level of minimum 35% and a maximum of 58%. Twenty-three samples are classified in the “acceptable” category for drinking purpose with a maximum certainty level of 55%. Rest of the 14 samples are in not acceptable class with a maximum certainty level of 100% indicates 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 system like air pollution monitoring, wastewater quality assessment, irrigation water quality assessment, etc. and quality can be reported with a level of certainty on the basis of prescribed limits as well field expert judgement.

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