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Assessment of Groundwater Quality using Fuzzy synthetic evaluation

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Abstract. Groundwater quality is depends upon the physiochemical parameters. Challenges in groundwater quality determination modelling are, e.g.1) Ambiguity and uncertainty involved in collection and measurement of water sample 2) Effective groundwater quality parameter selection with respect to the water use 3)The higher interpretability and lower complexity of prediction models. To address these challenges, groundwater Quality class prediction model using fuzzy rule-based system (FRBS), Water quality index approach, and Pipper's Diagram is proposed in the paper. The developed FRBS Model is the core component for the groundwater Quality prediction. FRBS approach is used as an improvement technique to overcome the ambiguity of boundary layer Pipper's Diagram. FRBS Model shows 70.3% agreement with Pipper's Diagram. Sample following in Temporary hardness in Pipper's Diagram classify in Saline water type by developed FRBS which improved error effects in hydro chemical experiment. The proposed FRBS model produces satisfactory accuracy compared to some existing models.

Introduction

In urban as well as in rural parts ground water is a major source of water supply for drinking, agriculture and domestic purpose. The determination of groundwater quality is important to observe the suitability of water for a particular use. Multivariate analysis and effect of various cations and anions as a part of geochemical studies of groundwater provide a better understanding of possiblechanges in quality as development progresses.A comparative assessment of numerous physical and chemical parameters and soluble constituent is necessary in determining the degree of pollution and water quality inthe environmental management systems of water resources where quality is important [1].
However, interpretation of data sets and suggestion about final water qualitycomprising analyses of several anions and cations is complicated which are discussed by various methods.But different regulatory agencies is not taken into consideration the uncertainties involved at various steps of water quality assessment while using the deterministic approach in decision- making of water quality when comparing values of parameters of water quality with prescribed limits provided by different regulatory agencies[2-5]. But,one of the methods of comparing the results of chemical analyses of ground water is with a trilinear diagram.Pipper's [15] approach of simplifying multivariate data is to generate and use a single value and plotting of the data in the graphical form, which may subsequently be used for comparative purpose is fuzzy logic Modelling[6-8].Fuzzy logic plays a significant role in

converting complex input variables into simple output, when there exist a difficulty in making precise statements of inputs and outputs during complex modelling [8-9].Fuzzywater quality index to assess the degree of drinking water quality considering 9 chemical parameters including cations and anions was derived by[1] .Water quality index (WQI) for evaluating the influence of natural and anthropogenic activities based on several key parameters on groundwater chemistry was developed by[10].Analysis of irrigation water quality with fuzzy inference system (FIS) proves that FIS gives more reliable results[8,11].The chemical analysis can be represented in graphical formby Pipper's Diagram to makes understanding of complex groundwater system simpler and quicker[8].The uncertainties involved in water quality using fuzzy membership with values ranging from 0 to1 to form an applicable fuzzy set instead of the conventional scale of 0 to 100 in WQI indices was discussed byH.I.Sii el. at.[12].

The attempt has been made to establish the relation between water type from Pipper'sDiagram and Fuzzy rule base model.

Materials and Methods

Thirtywells were studied every year seasonally in May (pre-monsoon) during 2007–2011 to assess the variation of groundwater quality of Vadodara district of Gujarat, India. Groundwatersamples were collected applying the prescribed methodology for sampling [13, 14].Water for these sources is used for drinking and irrigation purpose. These samples are analysed for the 14 physic-chemical water quality parameters as per standard procedure[13].

The results of the present study were taken for the Fuzzy rule based system (FRBS) model to assess the groundwater type using 9 parameters,viz., Ca^{2+}, Mg^{2+}, Na^{+} K^{+} ,CO_3^{-2}, HCO_3^{-},Cl^{-} ,$SO_4^{-2}$and TDS. Out of 14 analysed parameters these 9 parameters have been used in Pipper's diagram andfuzzy synthetic evaluation as input parameters. The data were checked by ion balanced calculator, taking the relationship between the total cations (Ca^{2+}, Mg^{2+}, $Na^{+}$and K^{+}) and the total anions (CO_3^{-2}, HCO_3^{-}, Cl^{-}, $SO4^{-2}$, $NO_3^{-}$and F) for each set of complete analysisof water sample, is observed to be within the range of acceptability of (±5%).

Trilinear Diagram

Trilinear diagrams are often used in water chemistry studies to classify natural waters[8].Pipper's[15]graphical presentation method was used to assess the nature of hydro geochemistry of the aquifers by representing and comparing water quality analyses. The cations and anions are shown by separate ternary plots.The apexes of the cation plot are calcium, magnesium and sodium plus potassium cations. The apexes ofthe anion plot are sulphate, chloride and carbonate plus bicarbonate anions. The two ternary plots are then projected up onto a diamond gives single point is thus uniquely related to the total ionic distribution. The diamond is a matrix transformation of a graph of the anions and cations. In Pipper's diagrams the concentrations are expressed as %meq/L.Composition is represented as a percentage.Similarities and differences amonggroundwater samples can be revealed from the trilinear plot because water of similar qualities will tend to plot together as groups and it will show the trends in the type of water. Distinct groundwater qualities can be quickly distinguished by their plotting in certain areas of the diamond field.

The analytical value obtained from the groundwater is plotted on Pipper's diagram to understand the hydro geochemical regime of the study area as shown in figure 1. The diamond shaped fields of Pipper's diagram are further divided into fivewater type classes, namely Saline (SO_4^{-2}-Cl^{-} and Na^{+}-K^{+}),Alkali Carbonate(HCO_3^{-}-$CO_3^{-}$and Na^{+}-K^{+}), Temporary Hardness (HCO_3^{-}-$CO_3^{-}$and Ca^{+2}-Mg^{+2}), Permanent Hardness(SO_4^{-2}-Cl^{-}) and Ca^{+2}-Mg^{+2}),Mixing Zone(No Ion Effect).The dominant cationsof the study area are in the order of mixed Na^{+} >Ca^{+2} > Mg^{+2}> K^{+} and anions shows SO_4^{-2} >Cl^{-}> HCO_3^{-} as shown in Figure1.The diagram can evaluate the hydrochemistry of groundwater with the help of USGS software version 1.26.0.0.Dominant cations and anion are Na^{+}-K^{+} and SO_4^{-2}-Cl^{-}indicate the seawater intrusion process by overexploitation followed by domestic wastewater, septic tank waste infiltration and ionic exchange process[16].Water type classification of groundwater samples based on Pipper'strilinear plot is given in Table 3.

In the dominant facies, Na–Cl type contributes to 91.3%of samples andthe second most dominant facies, mixed Ca–Mg–Cl type, contributes to 86.9%.This indicates that alkali (Na^+-K^+) and strong acids (SO_4^{-2}-Cl^-) dominate over alkaline earth (Ca^{+2}-Mg^{+2}) and weak acids. Elevated Na^+Concentrationscoupled with low Ca^{+2}suggest that $Ca^{+2}$and Na^+ion exchange process is an important geochemicalprocess for the Na–Cl type of groundwater [10].

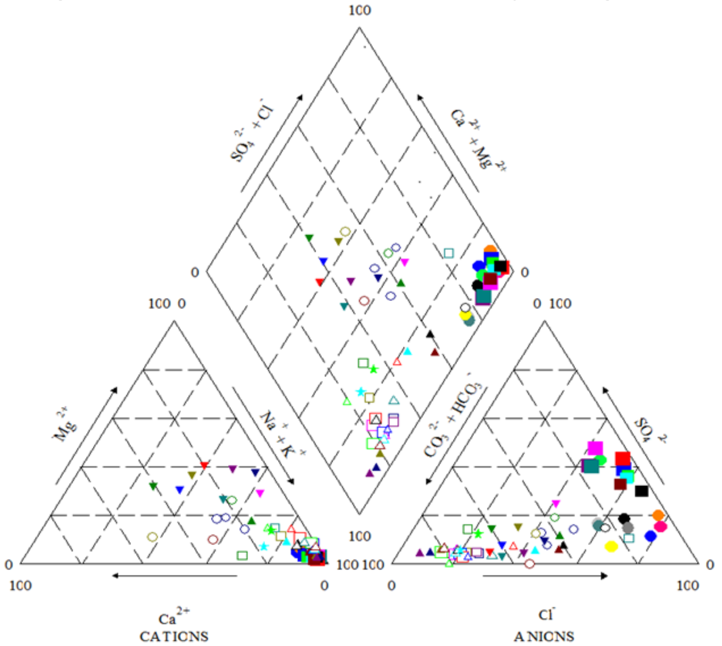

Figure 1. Ground water hydro geochemical facies plot (Pipper's plot) of the study area

Fuzzy Rule Base System (FRBS) and Water Type Index

FRBS model is generated by Mamdani method by which the linguistic variables have been used as input variables and the range of these data forms the fuzzy sets.It is an interface between the real world parameters and the fuzzy system and transforms the output set to crisp (non-fuzzy).The concept of fuzzy sets describing imprecision or vagueness was introduced by Zadeh [24] and has been applied throughout the world in decision-making and evaluation processes in imprecise environment [4].

The knowledge based in FRBS model includes the information given by the experts in the form of linguistic variables (fuzzy if-then rules), in which the first component is a data base which contains the linguistic term sets considered in the linguistic rules and the input-output membership function define the semantics of the linguistic variable[17].The second component is a Rule Base that defines the collections of linguistic rules joined by the operator [3, 18].

Determination of membership functions

Fuzzy membership functions constructed for all the selected input parameters are triangular and trapezoidal for output on the basis of knowledge based expert perception.Membership functions were assigned to nine variables inputs as Low, Moderate and High as per Figure2a-2iand one output variables as water type is chosen for water quality evaluation in the Vadodara District and water quality classes of Saline, Temporary Hardness, Permanent Hardness, Alkali Carbonate and mixing zone as per Figure3.

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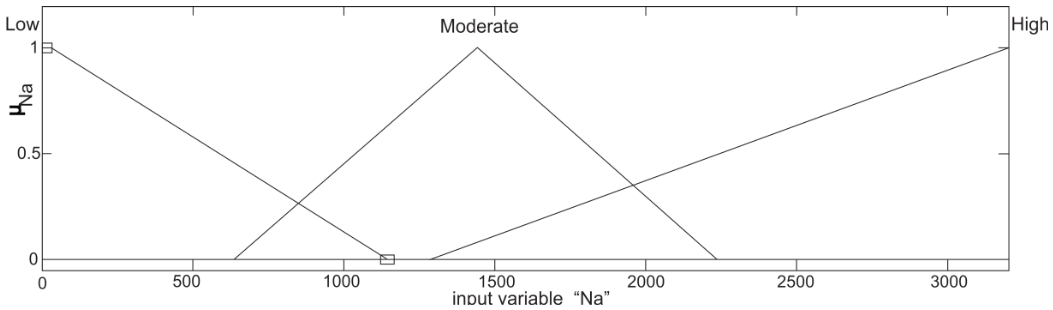

Figure 2a. Fuzzy Input Membership function of Na

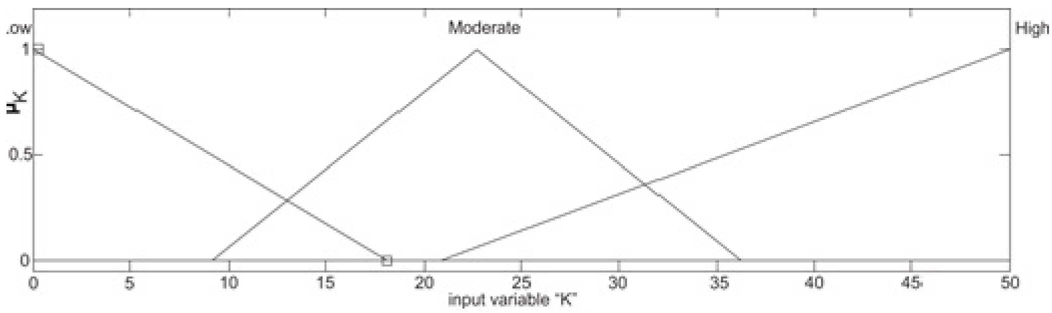

Figure 2b. Fuzzy Input Membership function of K

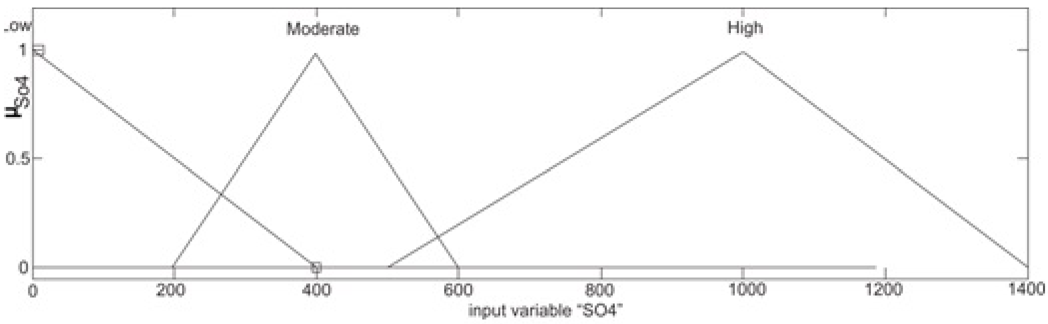

Figure 2c. Fuzzy Input Membership function of SO_4

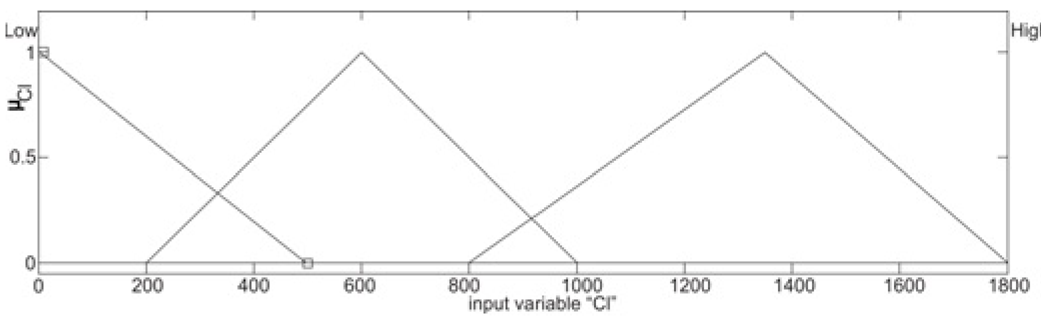

Figure 2d. Fuzzy Input Membership function of Cl

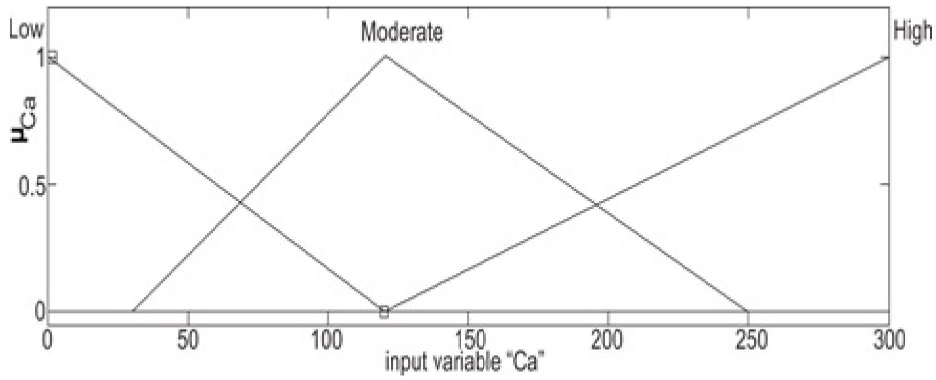

Figure 2e. Fuzzy Input Membership function of Ca

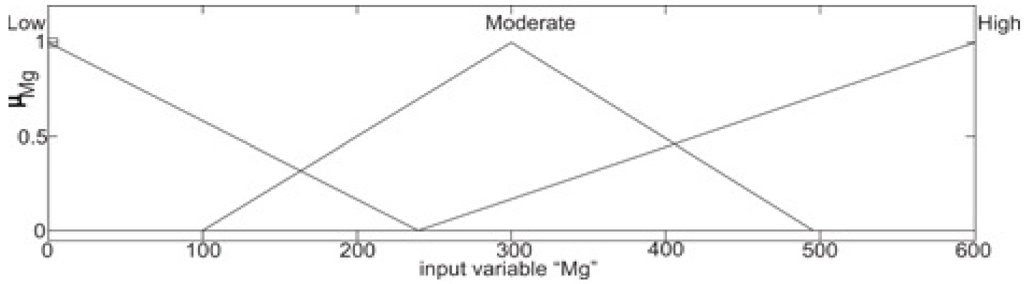

Figure 2f. Fuzzy Input Membership function of Mg

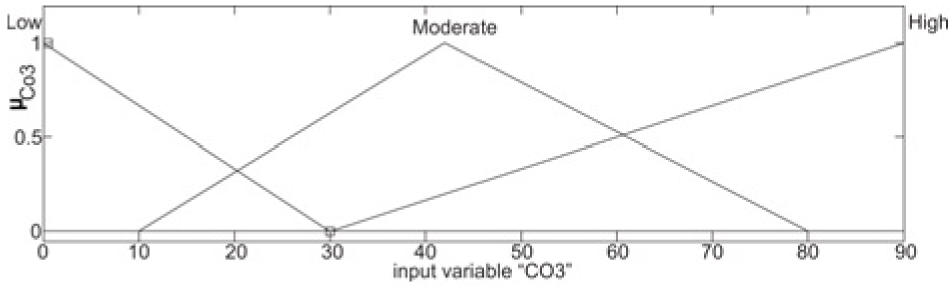

Figure 2g. Fuzzy Input Membership function of CO_3

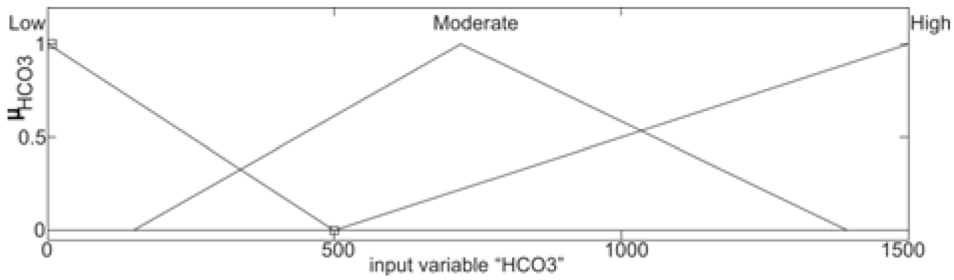

Figure 2h. Fuzzy Input Membership function of HCO_3

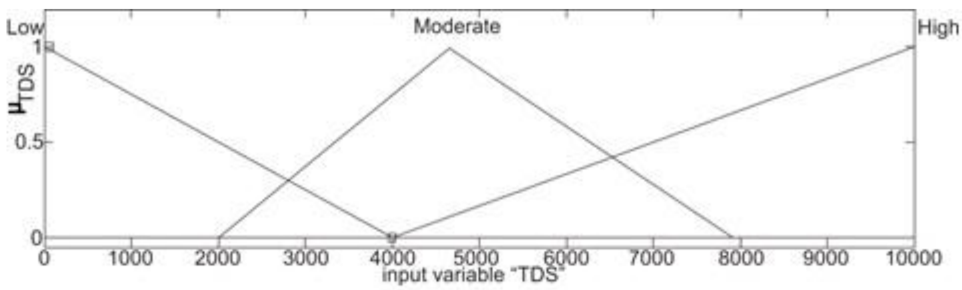

Figure 2i. Fuzzy Input Membership function of TDS

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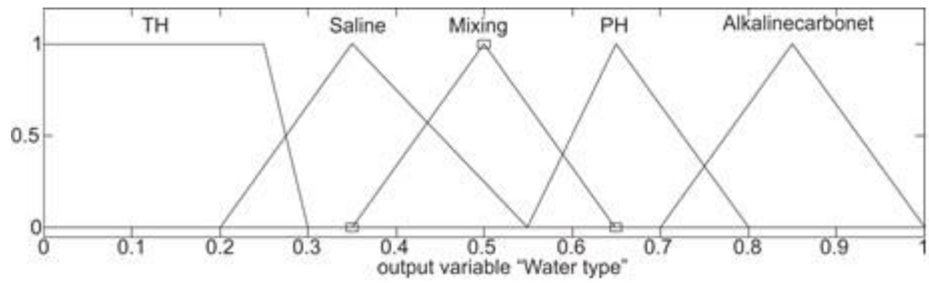

Figure 3. Fuzzy output Membership function of water type

Water Type Index

Inherent in anywater type are govern by the combination of concentration of cation and anion. Important parameters that give the water type are taken into the consideration for final water type determination.As a consequence, a numerical ranking system is developed between the cation and anion after establishing the statistical correlation between the cation and anion. Each parameter is evaluated with respect to the other to determine the relative importance of each other by assigning a relative weight from 1 to 5 as per shown in the Table1.The range of each water type parameter is assigned a rating to reflect the relative significance of each range with respect to water type. As an example, parameter Ca is divided into nine ranges, as illustrated in Table 2.The most vulnerable range is given a rating of 10, and 1 is assigned to the least vulnerable. This evaluation system allows the user to determine a numerical value for any setting by the following additive model[19].

$$\mathrm{WTI} = \mathrm{CarCaw} + \mathrm{MgrMgw} + \mathrm{NarNaw} + \mathrm{KrKw} + \mathrm{CO3rCO3w} + \mathrm{HCO3rHCO3w} + \mathrm{ClrClw} + \mathrm{SO4rSO4w} + \mathrm{TDSrTDSw} \quad (1)$$

In which WTI=Water type indexand subscripts r and wrefer to ratings and weights respectively.

A fuzzy rule base system (FRBS) has distinct theoretical advantages over the water type index. The proposed fuzzy system benefits from a knowledge base that employs a set of rules upon which the decisions are formed and its versatility in the decision-making in the imprecise environment. The rules may be formed based on expert knowledge. Although this research employs the expert knowledge from the water type index, in an ideal condition,one may benefit fromknowledge of local experts to improve the rules and system performance based on local conditions.As an example, if the value of Ca is ranges between 5 to 550, WTI will not respond to this variation. By changing any subspaceof input to the fuzzy system, the FRBS system will respond to the variations significantly. So, fuzzy system is able to adjust itself with the range of variation of input indices.

Fuzzy Rules Determination

In a fuzzy inference system the experts represent their knowledge concerning the classification of the water quality in the form of rules. Dividing each input domain into 3 sub domains i.e. "Low", "Medium" and "High" and considering nine inputs and one output parameters, a total of 19683 rules will form. At this stage rules can be eliminated by expert knowledge.The total no of rules in the rule base was reduced to1353.In the study, a triangular and trapezoidal membership function, a minimum Mamdani inference, and a central gravity defuzzification method is used. In this research the FIS in Fuzzy logic toolbox version 7.0 of MATLAB was selected to evaluate and classify the available groundwater quality samples to define water type and to compare the results of the FRBS model with the output given by the Pipper's Diagram for the study Area.

The fuzzy rule base comprisesthe following fuzzy IF-THEN[20]

$$\text{Rule}(1)\text{: IF} x1 \text{ is } A1L, \text{THEN } y \text{ is } BL \qquad (2)$$

$$\text{Where } U = U1 \times U2 \times \ldots\ldots Un \in R^n; A_i^L \text{ and } B^L = \text{Fuzzy sets in } {}_{U_i} \in R \text{ and } V \in R, \text{respectively; and } x(x1, x2, \ldots\ldots xn)T \in U \text{ and } y \in V = \text{input and output variables of the fuzzy system, respectively.}$$

Let M be the number of rules in the fuzzy rule base; that is L=1, 2...M. By considering the above fuzzy IF-THEN rules, human knowledge has to be presented in the form of the mentioned rules. The theory of fuzzy systems ensured that these rules provide quite knowledge representation scheme[20].In general, fuzzy rule-based system is organized by expert's knowledge.

In this study, the developed knowledge base benefits from the general knowledge of the experts who developed water type Index. Theknowledge may be constructed on the framework of the rules defined by the experts. As an example,

IF(Na is Moderate)AND (K is Moderate) AND (SO_4 is high)AND(Cl is Moderate) AND (Ca is Moderate)AND (Mg is Moderate) AND (CO_3 is Low)AND(HCO_3 is Low)AND (TDS is Low) THEN (Water type is Saline) (3)

To be able to compare the output of water type index (WTI) with that of the proposed fuzzy system, the WTI is normalized. Since maximum and minimum values of the Water Type index are 470 and 62, respectively, then the normalized index may be introduces as,

$$In = \frac{Iw - 62}{470} \qquad (4)$$

The boundary values of the normalized index, $I_n$and the assigned ranking is given in Table3.
By realizing the normalized boundaries, membership functions of the output domain are defined in Figure 3.

Table1.Weight for Water Type Index

Parameter	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	TDS
Weight	4	4	4	4	2	2	3	2	5

Table 2. Range and there relative coefficient for Ca

Rating Coefficient	10	9	8	7	6	5	4	3	2
Range (mg/l)	0-20	20-40	40-60	60-80	80-100	100-125	125-150	150-175	>200

Table 3.Normalized values of Water Type Index

Water Type	Range
Temporary Hardness	<0.3
Saline	0.20-0.55
Mixing Zone	0.35-0.65
Permanent Hardness	0.55-0.80
Alkali Carbonate	>0.70

Fuzzy Model Validation

37 water samples have been used for validation of fuzzy rule base model of year 2012. The validity of the output of fuzzy model was evaluated by comparing the results of developed fuzzy model and results obtain by Pipper's diagram considering validation dataset.Table 4 depicted the results of the fuzzy model obtained for validation dataset.

If the model output is in text form and there is no meaningful error describing values (such as the sum of squared error), the best way to validate the model is based on qualitative approaches [21]. For validation of the developed fuzzy model, first the validation set total 37 random samples have taken for validation of the model from data set. The model outputs and expert responses were expressed in terms of numbers and the accuracy of classification was calculated by[22].

$$\text{Accuracy} = \frac{n}{N} \times 100 \tag{5}$$

Where, n is number of samples correctly classified by fuzzy model and N is total number of samples considered for validation.

Table 4 depicted the results of the fuzzy model obtained for validation data set along with ions involved in the Water Type. Total 37 random samples have taken for validation of the data. Out of which,11 samples are not showing the change in the water quality as per Pipper's Diagram. As per the equation 5 the accuracy of Fuzzy Model is 70.3%[23].

Table 4. Comparison of developed fuzzy model and Pipper's groundwater Quality Classification

		Fuzzy Model prediction for water quality class					Total Prediction	%
	Classification	Temporary Hardness ($CaHCO_3$)	Saline (NaCl)	Mixing Class (No ion Effect)	Permanent Hardness (CaCl)	Alkali Carbonate ($NaHCO_3$)		
Piper's water Quality Class	Temporary Hardness ($CaHCO_3$)	**0**	9				9	0
	Saline(NaCl)		**18**				18	100
	Mixing Class (No ion effect)		1	**8**			9	88.88
	Permanent Hardness (CaCl)				**0**		0	00.00

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	Alkali Carbonate (($NaHCO_3$)		1			**0**	1	00.00
Total Observed		0	29	8	0	0	**26*/37**	
%		0	62.07	100	0	0		**70.3**

Concluding Remarks

Pipper's diagram is useful to understand the hydro geochemical regime of the study area in the graphical form which gives five water type classes, namely SO_4^{-2}-Cl^- and Na^+-K^+ (Saline), HCO_3^--$CO_3^-$and Na^+-K^+ (Alkali Carbonate),HCO_3^--$CO_3^-$and Ca^{+2}-Mg^{+2}(Temporary Hardness), SO_4^{-2}-Cl^- and Ca^{+2}-Mg^{+2} (Permanent Hardness), Mixing Zone(No Ion Effect). The dominant cations of the study area are in the order of mixed $Na^+ > Ca^{+2} > Mg^{+2} > K^+$ and anions shows SO_4^{-2} $^>Cl^- >$ HCO_3^-Dominant cations and anion are Na^+-K^+ and SO_4^{-2}-Cl^- indicate the seawater intrusion process by overexploitation followed by domestic wastewater, septic tank waste infiltration and ionic exchange process. Theresults of FRBS are more relevant for the classification of water type and it avoids the uncertainties associated in decision making. In this study, a new approach has been evaluated to established relations between Pipper's diagram and FRBS system for water type. Fuzzy model has a worldwide application in the field of water quality determination as it incorporates various input parameters as per the need of the study. Therelationships of water type with the FRBS classes are ready tool for the determination of water quality of the study area. Fuzzy Model is developed to overcome the limitations of the piper's Diagram.

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