



## A Fuzzy Logic Approach for Irrigation Water Quality Assessment: A Case Study of Karunya Watershed, India

Priya KL<sup>1\*</sup>

### Abstract

The water used for irrigation purposes remains unnoticed in a quality perspective. The ground water is a major source for irrigation in many arid and semi arid regions of India. The widely accepted standard for irrigation water is the United States Salinity Laboratory (USSL) classification system, which is based on Sodium Absorption Ratio (SAR) and Electrical Conductivity (EC). In the present study, a Fuzzy Inference System (FIS) has been developed to classify ground water for irrigation purposes. The membership functions were developed for four significant parameters such as SAR, EC, chlorides and sulphates and rules were fired to arrive at a Fuzzy Inference System for assessing irrigation water quality. The fuzzy model was validated using the ground water quality data collected from Karunya watershed. The FIS classes were initially developed based on the two parameters, such as SAR and EC and the results were observed to be consistent with the USSL classification system. The FIS was further improved by incorporating two more significant parameters namely chlorides and sulphates. The FIS classes thus obtained were different from that with two parameters for those samples having higher concentration of chlorides. Thus, the developed fuzzy model showed more reliable results for classifying ground water for irrigation purposes and avoids the uncertainty in the decision making.

### Keywords

Irrigation water quality; United States Salinity Laboratory; Fuzzy inference system; Coimbatore

### Introduction

The chemical, physical and bacterial characteristics of ground water determine its usefulness for municipal, commercial, industrial, agricultural, and domestic water supplies. In many arid and semi-arid regions, ground water is one of the alternative sources of water supplies, mainly for domestic and agricultural activities. The ground water contains more dissolved minerals compared to surface water and its suitability for irrigation purposes needs great attention, as the crop productivity depends on the quality of irrigation water. There are many standards for evaluation of irrigation water quality: USSL (United States Soil Laboratory) classification system (1954) [1]; Wilcox system (1955) [2]; BIS classification system (IS 11624:1986) [3].

\*Corresponding author: Priya KL, Assistant Professor, School of Civil Engineering, Karunya University, Coimbatore, Tamil Nadu, India, Tel: 0422 2614450; Fax: 0422 2615615; E-mail: [klpriyaram@gmail.com](mailto:klpriyaram@gmail.com)

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Even though different systems of classification have been attempted by many authors [4-10], uncertainties do pertain in the decision making with regard to the usefulness of the water. After having analysed the quality parameters, interpretation of the complex data have to be performed and it has to be presented in an understandable and useful way so that technical and policy makers and the public can be informed of the quality of water [11]. During modeling complex environmental problems, there exist a difficulty in making precise statements of inputs and outputs; at this point of view, fuzzy logic plays a significant role in converting complex input variables into simple output [12]. A few researches have made use of fuzzy logic to arrive at a simple output. Jowitt and Lumbers explored fuzzy logic for discharge standards of effluents into rivers [13]. Raman et al. developed a fuzzy inference system for assessing river water quality based on six parameters such as DO, BOD, COD, AN, SS and pH and arrived at a water quality index for drinking water [11]. Alavi et al. has made use of adaptive network-based fuzzy inference system for irrigation water quality [14]. Mirabbasi et al. developed a fuzzy inference system for assessing irrigation water quality based on SAR and EC. Studies exist for assessing river water quality for drinking purposes, but very few studies have concentrated on irrigation water quality [15]. Even though some of the studies look into the quality of water for irrigation, the classification technique is rough and imprecise. A simple output from the set of complex input variables is necessary. Thus, systems of classification, which can deal with uncertainty to produce simple results to tackle the situation, have to be emerged from a heuristic approach. Fuzzy logic is a mathematical tool that converts complicated statements into mathematical terms and again converts them into simple outputs [16].

All the studies pertaining to assess the quality of water for irrigation consider two parameters, namely Sodium Absorption Ratio (SAR) and Electrical conductivity (EC). Quantification of suitability for irrigation is a major limitation in these methods of classification. The Bureau of Indian standards provide the standards for irrigation water quality, in which permissible limits for SAR, EC, pH, chlorides and sulphates are specified (IS: 11624-1986) [3]. Chlorides and sulphates, even though essential at low concentrations, are toxic at higher concentrations and have an adverse impact on the crops. USSL classification system considers two parameters, namely SAR and EC. Hence, for assessing the quality of water for irrigation, it is proposed to improve the USSL classification system by the incorporation of two parameters, namely chlorides and sulphates. Uncertainties do arise when more parameters have to be dealt with for classification. Fuzzy Inference Systems (FIS) is a mathematical tool which helps in solving complicated set of linguistic variables and helps in decision making [15]. A Fuzzy Inference System (FIS) has been developed for classifying water suited for irrigation purposes. The developed fuzzy model was validated using ground water quality data of Karunya watershed and the ground water was classified for irrigation purposes.

### Methodology

#### Fuzzy modeling

Fuzzy sets are defined as sets whose members are vague objects. Fuzzy inference system is a method that interprets the values in the

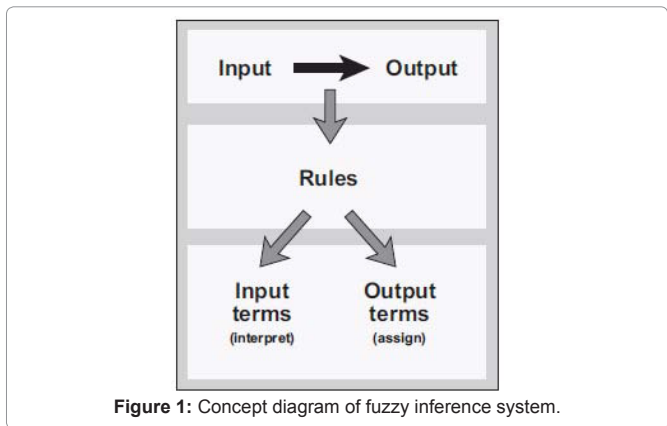


Figure 1: Concept diagram of fuzzy inference system.

input vector and based on some set of rules; assign values to the output vector (Figure 1) [17]. Two types of FIS such as Mamdani and Sugeno have been formulated in fuzzy logic toolbox of MATLAB software. The Mamdani method is used to describe a process by linguistic variables and the variables are used as inputs for a set of rules. The rules developed are utilized by the fuzzy inference engine to derive outputs from inputs. Defuzzification is done to map the fuzzy output variables and is the opposite of fuzzification. Thus an FIS model consists of two components: first being membership functions of input and output variables, which define the variables; and second is a rule base which is a collection of linguistic rules joined by if-then operator [17].

Uncertainties prevail in handling more number of variables and a large number of samples. Such uncertainties can be managed with the aid of fuzzy logic techniques. Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. It forms a powerful tool for dealing quickly and efficiently with imprecision and non linearity data. Fuzzy set theory and its derivatives may be used to directly introduce imprecise data into mathematical model with minimal input data requirements [18]. Since the data requirements for fuzzy modeling is minimal, it can be applied when the available data is sparse.

An FIS has been developed using the fuzzy logic toolbox of MATLAB software for classifying the water for irrigation purposes using Mamdani approach. The input variables for the FIS consisted of four water quality parameters, which are significant in assessing the quality of water to be used for irrigation purposes. The input variables include SAR, EC, chlorides and sulphates. Four different approaches for determining membership function include direct rating, set valued statistics, polling and reverse rating [19]. In addition to these, a number of approaches exist for automatic generation of membership function [20]. The membership functions for the present study were arrived at for the four significant parameters using direct rating based on USSL classification system for SAR and EC and Indian standards for chlorides and sulphates. For each of the parameters, three membership functions to define three classes such as ‘Excellent’, ‘Good’ and ‘Bad’ were developed. The classes of membership functions for each parameters were selected as per irrigation standards. Membership functions of SAR and EC were based on USSL classification system and that of chlorides and sulphates were based on IS 11624:1986 [3]. The membership functions were calibrated by trial and error method. Four classes for output membership function namely ‘Excellent’,

‘Good’, ‘Satisfactory’ and ‘Bad’ were developed. The membership functions for input and output parameters are given in Figure 2a to 2e. The four input membership functions were connected with the output membership function with  $3^4=81$  rules using the fuzzy AND operator. Figure 3 shows a sample of rules developed for the model. The rules (fuzzy if-then rules) were formulated for the classification of water quality for irrigation for the possible combinations of input parameters. As an example,

IF SAR is Excellent AND EC is Excellent AND Cl is Excellent AND Sulp is Good THEN Suitability Index is Excellent

IF SAR is Excellent AND EC is Good AND Cl is Excellent AND Sulp is Excellent THEN Suitability Index is Good

Higher weightage is given for SAR and EC than chlorides and sulphates due to the relative importance on irrigation water quality.

### Application site

Coimbatore is an important industrial city of India in the state of Tamil Nadu. It is located in between 10° 55’ and 11° 10’ N and 77° 10’ and 76° 50’E at an approximate altitude of 470 m. The study area includes Karunya Nagar, which is a village situated in the valley of Western Ghats and is 35 kms from Coimbatore city (Figure 4).

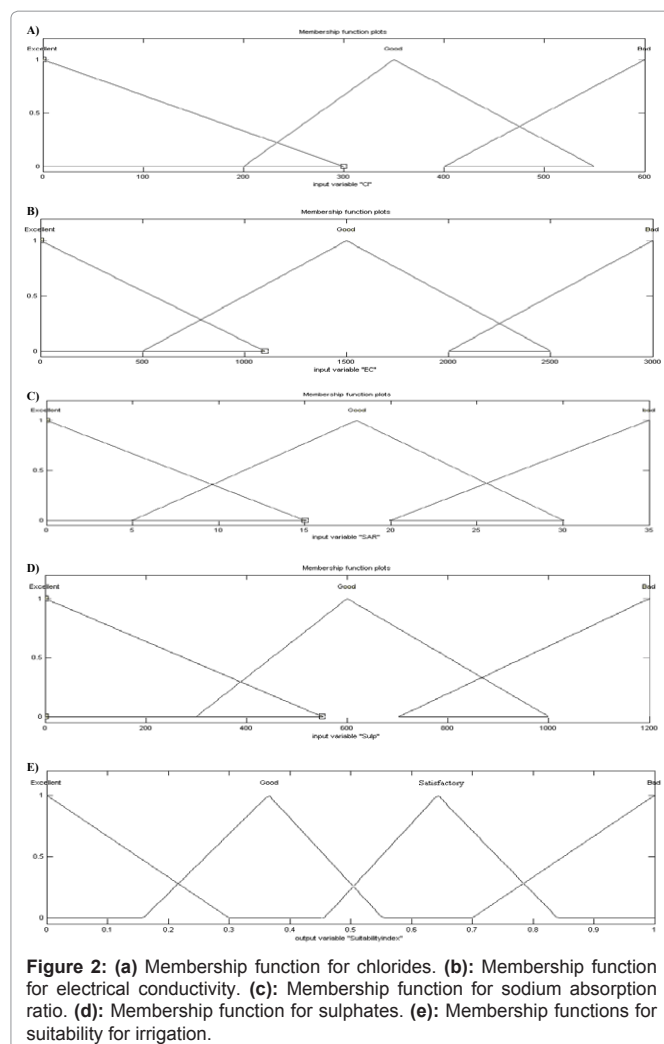


Figure 2: (a) Membership function for chlorides. (b): Membership function for electrical conductivity. (c): Membership function for sodium absorption ratio. (d): Membership function for sulphates. (e): Membership functions for suitability for irrigation.

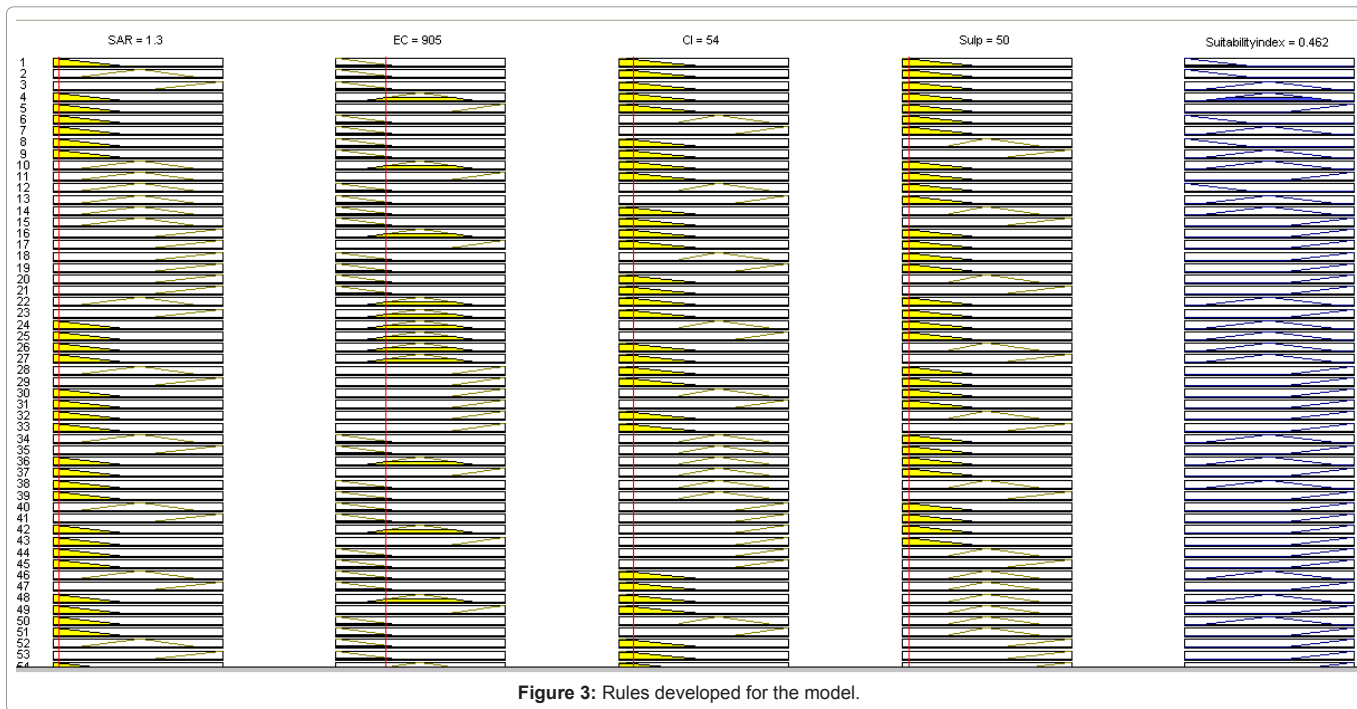


Figure 3: Rules developed for the model.

Rainfall is predominant in the months of August to November with an average annual rainfall of 1000 mm. The study area lies in the Noyal river basin, which forms a part of Cauvery river basin. The Noyal river emerges from the Velingiri hills and joins the Cauvery. The ground water table in the area has an average depth of 10.5 m. Agriculture is the main occupation of the residents of the place. The cultivations include coconuts, turmeric, sugarcane, rice, corn, cabbage etc. Fertilizers and animal waste are the main nutrient supplements used by farmers for the agricultural crops in this area. The study is concentrated in Karunya watershed of which a part of land is occupied by Karunya University campus and the rest is cultivable land for various crops and plantations. The ground water from Karunya watershed is extensively used for irrigation purposes. Bore wells play a major role for irrigation purposes because of the clayey soil strata which cannot hold the open wells for greater depth. Clayey soil is prominent for as long as 45 m. Noyal river is bordering the north face of the study area with its main tributaries running south and west. As a study on the evaluation of ground water quality for irrigation purposes does not exist in the study area, an attempt was made to evaluate the ground water quality of Karunya watershed.

### Analysis of water samples

Water samples collected in a pre-cleaned 1-l bottles from open wells, bore wells and Noyal river from different locations of the watershed were analyzed for the present study. The samples included ten open wells, four bore wells and three river water samples. Detailed sampling programmes were done on 6<sup>th</sup> October, 2010. Seventeen sample points were located which covers almost the entire watershed. The study area and the location of sampling stations are shown in Figure 4. During sample collection, geographical locations of the sampling stations were obtained using a hand-held GPS and the depth to water level was also obtained. The parameters analysed included: (1) general parameters (pH, EC, DO); (2) cations (Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup> and

Mg<sup>2+</sup>); and (3) anions (Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, PO<sub>4</sub><sup>3-</sup>, HCO<sub>3</sub><sup>-</sup>, CO<sub>3</sub><sup>2-</sup> and NO<sub>3</sub><sup>2-</sup>). The observations of pH, conductivity, temperature and dissolved oxygen were done at the site itself using a portable water quality analyser. Calcium (Ca<sup>2+</sup>), Magnesium (Mg<sup>2+</sup>), Chloride (Cl<sup>-</sup>), Carbonate (CO<sub>3</sub><sup>2-</sup>) and Bicarbonate (HCO<sub>3</sub><sup>-</sup>) were analysed by volumetric titration methods; Sulphates (SO<sub>4</sub><sup>2-</sup>) using spectrophotometry; while Sodium (Na<sup>+</sup>) and Potassium (K<sup>+</sup>) by Flame photometry. All the parameters were analysed as per APHA standard methods (18<sup>th</sup> edition 1992) [21]. SAR (Sodium Absorption Ratio) is an important parameter for determination of suitability of irrigation water. Sodium hazard of irrigation water can be well understood by knowing SAR. The sodium adsorption ratio (SAR) values of each water sample were calculated by using equation:

$$SAR = Na^+ / \sqrt{[(Ca^{2+} + Mg^{2+})/2]}$$

### Hydrochemical analysis

One method of comparing the results of chemical analyses of ground water is with a trilinear diagram. This diagram consists of two lower triangles that show the percentage distribution, on the milliequivalent basis, of the major cations (Mg<sup>2+</sup>, Ca<sup>2+</sup>, Na<sup>+</sup> and K<sup>+</sup>) and the major anions (Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and CO<sub>3</sub><sup>2-</sup> plus HCO<sub>3</sub><sup>-</sup>) and a diamond-shaped part above that summarizes the dominant cations and anions to indicate the final water type. These tri-linear diagrams are useful in bringing out chemical relationships among groundwater samples in more definite terms rather than with other possible plotting methods [22]. The hydrochemical pattern diagram helps in hydrogeochemical facies classification [23]. This classification system shows the anion and cation facies in terms of major-ion percentages. The hydro chemical facies were determined using the Piper's Trilinear diagram using the software Rockware AqQa [1.1.1]. The fluid and irrigational properties of the water samples including their water type were determined using the AqQa software.

## Results and Discussion

### Analysis of samples

The results of the qualitative analysis of the samples are given in Table 1. The Hill-Piper diagram was used to analyze the hydro-geochemical characteristics of the water samples. The cation and anion fields are combined to show a single point in a diamond-shaped field, from which hydro-geochemical characteristics of the water samples are drawn. The Piper diagram of the samples under study is given in Figure 5.

The DO of the samples was appreciable and there is no suspect of organic pollution of ground water. The pH ranged from 6.08 to 6.71 and the samples were slightly acidic. The EC ranged from 63.97  $\mu\text{S}/\text{cm}$  to 1595  $\mu\text{S}/\text{cm}$ . The higher value of EC is due to the presence

of dissolved solids in the water samples. The ground water exhibited more EC than surface water, because ground water dissolves minerals from soil and rock and has more amounts of dissolved solids than surface water. The major ions such as phosphates and nitrates are marginal indicating that there are no chances of nutrients leaching from agricultural field into ground water.

### Hydrochemical analysis

The piper hill diagram revealed the water type of the samples and it was found that samples S1, S7, S8, S9, S10, S14 and S15 fall under type of Mg-Cl. S3, S4, S6, S11, S12, S13, S16 and S17 exhibited Mg-HCO<sub>3</sub> type of water, S2 of Na<sub>2</sub>CO<sub>3</sub> and S5 of MgSO<sub>4</sub>. These are mainly due to the geological characteristics of the area concerned. The geological characteristics of the study area reflect on the water type of ground water.

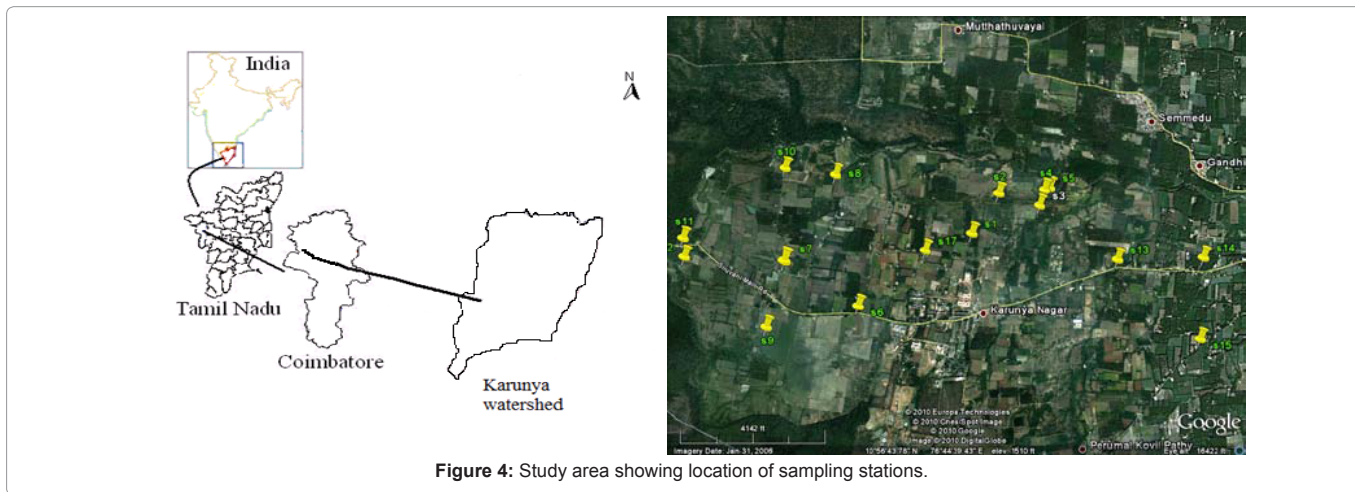


Figure 4: Study area showing location of sampling stations.

Table 1: Results of physiochemical analysis.

Sampling station	Details	Depth (m)	pH	EC ( $\mu\text{S}/\text{cm}$ )	TDS (mg/l)	DO (mg/l)	Na <sup>+</sup> (meq/l)	K <sup>+</sup> (meq/l)	Ca <sup>2+</sup> (meq/l)	Mg <sup>2+</sup> (meq/l)	Cl <sup>-</sup> (meq/l)	SO <sub>4</sub> <sup>2-</sup> (meq/l)	PO <sub>4</sub> <sup>3-</sup> (meq/l)	CO <sub>3</sub> <sup>2-</sup> (meq/l)	HCO <sub>3</sub> <sup>-</sup> (meq/l)	NO <sub>3</sub> <sup>-</sup> (meq/l)
S1	OW	2.28	6.22	1434	960.78	12.7	6.807	0.002491	4.641	20.74	3.869	0.3956	0.00307	ND	7.375	0.017174
S2	OW	3.2	6.69	1595	1068.65	11.7	12.59	0.002583	1.796	8.064	5.224	0.7495	0.003184	2.33	6.818	0.01451
S3	OW	2.74	6.34	590.6	395.702	10.4	3.871	0.001739	3.144	8.064	1.751	0.3748	0.002143	ND	3.753	0.007096
S4	OW	2.29	6.4	1302	872.34	8.1	9.678	0.01248	2.844	14.15	3.276	0.3956	0.01538	ND	7.703	0.01226
S5	R	0.45	6.48	78.25	52.4275	8.9	0.3784	0.001995	0.5489	1.234	0.4518	0.5621	0.002454	ND	0.2458	0.007903
S6	OW	2.74	6.57	573.3	384.111	10.4	3.415	0.001918	2.296	9.957	0.8189	0.3539	0.002363	ND	2.868	0.01226
S7	BW	47.19	6.31	947	634.49	9	5.437	0.008338	4.391	21.15	2.598	0.3123	0.01028	ND	5.081	0.01968
S8	BW	59.44	6.4	1126	754.42	9.8	6.481	0.007289	5.29	16.7	3.191	0.9161	0.008984	ND	5.539	0.01081
S9	R	0.73	6.59	263	176.21	9.3	0.8917	0.002276	2.944	3.374	13	0.2915	0.002742	ND	1.082	0.007257
S10	BW	150	6.08	1105	740.35	5	2.697	0.00266	4.541	12.26	1.694	0.229	0.003276	ND	3.278	0.01564
S11	R	0.6	6.77	63.97	42.8599	8.5	0.3393	0.001816	0.8982	1.481	0.5648	0.06246	0.002236	ND	0.4261	0.00758
S12	OW	4.5	6.49	505.4	338.618	8.6	1.074	0.001279	3.693	12.59	1.045	0.1249	0.001575	ND	2.917	0.007741
S13	R	9	6.31	276.1	184.987	8.5	1.027	0.001202	3.743	4.937	0.7342	0.1666	0.001481	ND	1.573	0.007096
S14	OW	3	6.3	2018	1352.06	8.3	9.765	0.001312	3.992	28.55	25.13	0.3748	0.01618	ND	6.162	0.01822
S15	OW	4.5	6.27	2126	1424.42	6.9	5.72	0.002532	1.392	33	16.94	0.812	0.003122	1.933	4.163	0.02048
S16	OW	3.9	6.77	481.8	322.806	9.6	1.836	0.002507	4.99	6.994	1.158	0.1666	0.003087	36	2.442	0.007419
S17	OW	10.5	6.51	904.7	606.149	9.5	4.458	0.001253	8.434	14.89	1.525	1.041	0.001544	40	4.589	0.01984

Note: OW – open well, BW – bore well, R- river, ND – Not Detectable

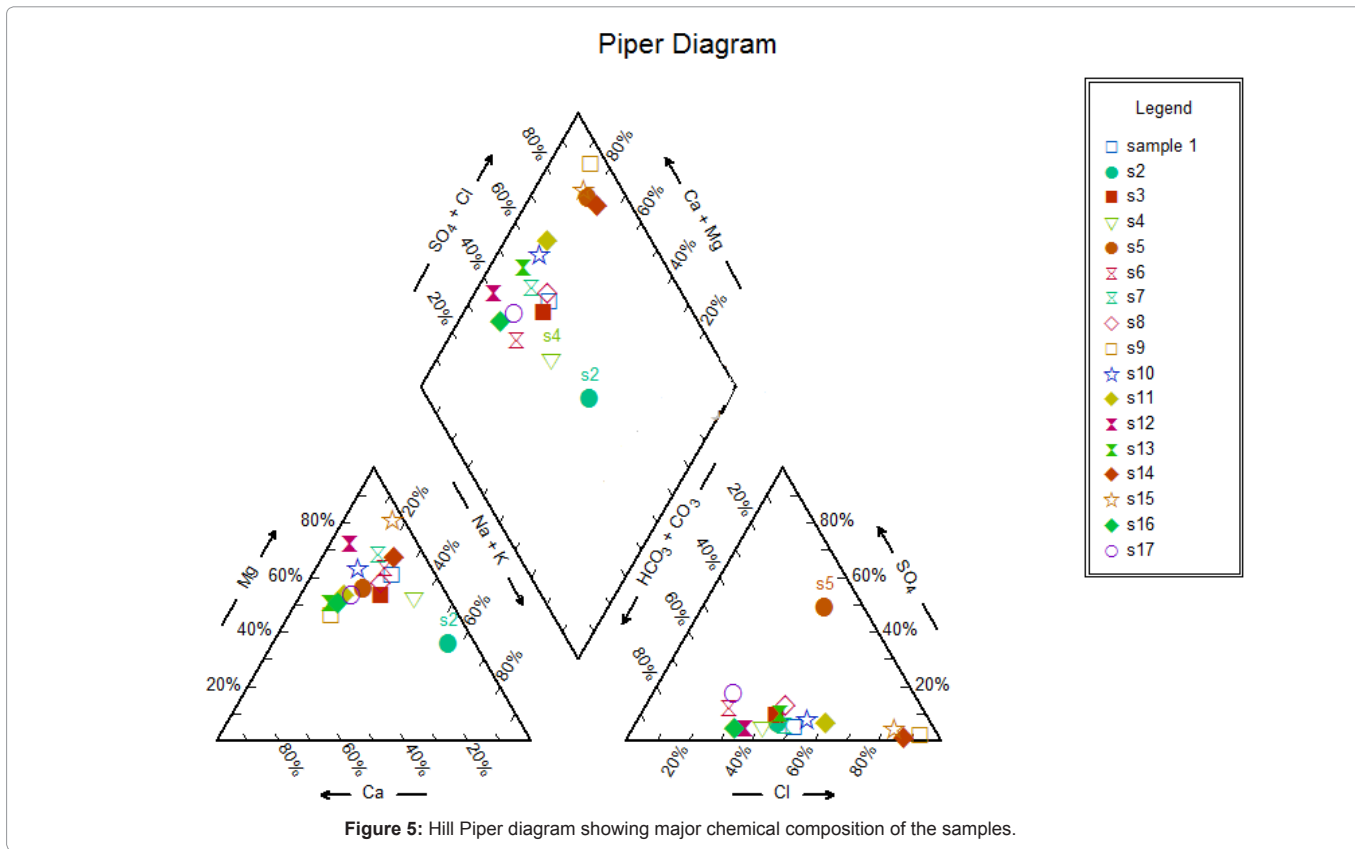


Table 2: USSL classes.

Sodium Absorption Ratio	USSL Class	Suitability	Electrical Conductivity ( $\mu\text{S}/\text{cm}$ )	USSL Class	Suitability
10	S1	Excellent	<250	C1	Excellent
10 – 18	S2	Good	250 – 750	C2	Good
18 – 26	S3	Satisfactory	750 – 2250	C3	Satisfactory
> 26	S4	Bad	> 2250	C4	Bad

### Fuzzy model application

The USSL classification system based on SAR and EC is furnished in Table 2. Four classes, namely ‘excellent’, ‘good’, ‘satisfactory’ and ‘bad’ were assigned based on the concentration of SAR and EC. The FIS scores were also classified into four: excellent, good, satisfactory and bad based on the FIS score as shown in Table 3. The FIS score is obtained as the output of defuzzification results for the samples. After defuzzification, the FIS score can be converted into the class, which decides on the suitability of water for irrigation. Uncertainties do prevail in the USSL system in the final suitability because it does not say anything about the suitability for a combination of USSL class. As an example, if for a sample, SAR is 13 and EC is 1250, the sample falling under S2 and C3, the class is ‘Good’ on the basis of SAR and ‘satisfactory’ based on EC. Uncertainty do exists as to select whether the suitability is good or satisfactory. This limitation can be overcome in FIS system, where the suitability class is decided based on a single FIS score.

The fuzzy model developed to classify the water for irrigation purposes was applied to the watershed. The samples were classified based on USSL system and FIS system. In order to find the

Table 3: FIS classes.

FIS score	FIS class
0 – 0.30	Excellent
0.25 – 0.55	Good
0.50 – 0.80	Satisfactory
0.70 – 1.0	Bad

applicability of the FIS, initially SAR and EC alone were selected and the membership functions of these two parameters were connected with  $3^2=9$  rules. The FIS classes, thus obtained were compared with the USSL classification system. The USSL classes and the FIS classes based on two parameters are shown in Table 4. It was observed that the FIS classes were consistent with USSL classes and further, FIS class, which was based on a single FIS score provide a single output with regard to the quality of water for irrigation.

Further, the FIS system has been improved by incorporating two more significant parameters, namely chlorides and sulphates. The membership functions of SAR, EC, chlorides and sulphates were connected with the output membership function, ie. Suitability index,

using 81 fuzzy rules. The FIS classes obtained by considering four parameters are given in Table 5.

On analyzing Table 4 and 5, it is evident that similar classes were scored by samples S5, S6, S7, S11, S12, S13, S16 and S17. Other samples having higher concentration of chlorides secured higher FIS scores. Thus, the incorporation of two more significant parameters resulted in more reliable results. More the number of parameters, higher will be the precision in the assessment of quality of water.

On examining the FIS class and the water type (Table 6), it seems that some relationship exists between the FIS class and water type. Most of the samples which exhibited MgCO<sub>3</sub> type were classified as 'Excellent' and that with MgCl type as 'Satisfactory'. However, the present study is not concentrated on establishing a relationship

between FIS class and water type, but can be dealt with in detail in future.

### Conclusion

The USSL classification system for irrigation water has been improved by the incorporation of two significant parameters such as chlorides and sulphates and based on which a FIS was proposed. The developed model has been validated with the ground water of Karunya watershed and it gave satisfactory results. The FIS system ranked higher than the USSL system for those samples having lesser concentration of chlorides and sulphates. Thus, the result of FIS is more relevant for the classification of irrigation water and it avoids the uncertainties associated in decision making. From the study, it can be ascertained that the fuzzy model has a worldwide application

**Table 4:** USSL classification system and FIS system for two significant parameters.

Samples	SAR	EC (µS/cm)	USSL class	Comments	FIS score	FIS class
S1	1.91	1434	S1C3	Excellent based on SAR Satisfactory based on EC	0.35	Good
S2	5.67	1595	S1C3	Excellent based on SAR Satisfactory based on EC	0.34	Good
S3	1.64	590.6	S1C2	Excellent based on SAR Good based on EC	0.167	Excellent
S4	3.36	1302	S1C3	Excellent based on SAR Satisfactory based on EC	0.35	Good
S5	0.401	78.25	S1C1	Excellent based on SAR Excellent based on EC	0.0972	Excellent
S6	1.38	573.3	S1C2	Excellent based on SAR Good based on EC	0.157	Excellent
S7	1.52	947	S1C3	Excellent based on SAR Satisfactory based on EC	0.309	Good
S8	1.95	1126	S1C3	Excellent based on SAR Satisfactory based on EC	0.35	Good
S9	0.502	263	S1C2	Excellent based on SAR Good based on EC	0.102	Excellent
S10	.93	1105	S1C3	Excellent based on SAR Satisfactory based on EC	0.349	Good
S11	0.311	63.97	S1C1	Excellent based on SAR Excellent based on EC	0.0971	Excellent
S12	0.377	505.4	S1C2	Excellent based on SAR Good based on EC	0.115	Excellent
S13	0.493	276	S1C2	Excellent based on SAR Good based on EC	0.102	Excellent
S14	2.42	2018	S1C3	Excellent based on SAR Satisfactory based on EC	0.362	Good
S15	1.38	2126	S1C3	Excellent based on SAR Satisfactory based on EC	0.43	Good
S16	.75	481.8	S1C2	Excellent based on SAR Good based on EC	0.11	Excellent
S17	1.31	904.7	S1C3	Excellent based on SAR Satisfactory based on EC	0.297	Good

**Table 5:** Fuzzy logic classification system based on four significant parameters.

Stations	SAR	EC (µS/cm)	Chlorides (mg/l)	Sulphates (mg/l)	FIS score	FIS class
S1	1.91	1434	137.35	18.99	0.5	Satisfactory
S2	5.67	1595	185.45	35.98	0.5	Satisfactory
S3	1.64	590.6	62.16	17.99	0.269	Good
S4	3.36	1302	116.30	18.99	0.5	Satisfactory
S5	0.401	78.25	16.04	26.98	0.131	Excellent
S6	1.38	573.3	29.07	16.99	0.25	Good
S7	1.52	947	92.23	14.99	0.473	Good
S8	1.95	1126	113.28	43.97	0.5	Satisfactory
S9	0.502	263	461.50	13.99	0.383	Good
S10	.93	1105	60.14	10.99	0.5	Satisfactory
S11	0.311	63.97	20.05	3.00	0.131	Excellent
S12	0.377	505.4	37.10	6.00	0.158	Excellent
S13	0.493	276	26.06	8.00	0.137	Excellent
S14	2.42	2018	892.12	17.99	0.597	Satisfactory
S15	1.38	2126	601.37	38.98	0.589	Satisfactory
S16	.75	481.8	41.11	8.00	0.148	Excellent
S17	1.31	904.7	54.14	49.97	0.462	Good

**Table 6:** Comparison of FIS with USSL system and water type.

Samples	Water type	USSL class	FIS class (two parameters)	FIS class (four parameters)
S1	MgCl	Excellent based on SAR Satisfactory based on EC	Good	Satisfactory
S2	Na <sub>2</sub> CO <sub>3</sub>	Excellent based on SAR Satisfactory based on EC	Good	Satisfactory
S3	MgHCO <sub>3</sub>	Excellent based on SAR Good based on EC	Excellent	Good
S4	MgHCO <sub>3</sub>	Excellent based on SAR Satisfactory based on EC	Good	Satisfactory
S5	MgSO <sub>4</sub>	Excellent based on SAR Excellent based on EC	Excellent	Excellent
S6	MgHCO <sub>3</sub>	Excellent based on SAR Good based on EC	Excellent	Good
S7	MgCl	Excellent based on SAR Satisfactory based on EC	Good	Good
S8	MgCl	Excellent based on SAR Satisfactory based on EC	Good	Satisfactory
S9	MgCl	Excellent based on SAR Good based on EC	Excellent	Good
S10	MgCl	Excellent based on SAR Satisfactory based on EC	Good	Satisfactory
S11	MgHCO <sub>3</sub>	Excellent based on SAR Excellent based on EC	Excellent	Excellent
S12	MgHCO <sub>3</sub>	Excellent based on SAR Good based on EC	Excellent	Excellent
S13	MgHCO <sub>3</sub>	Excellent based on SAR Good based on EC	Excellent	Excellent
S14	MgCl	Excellent based on SAR Satisfactory based on EC	Good	Satisfactory
S15	MgCl	Excellent based on SAR Satisfactory based on EC	Good	Satisfactory
S16	MgHCO <sub>3</sub>	Excellent based on SAR Good based on EC	Excellent	Excellent
S17	MgHCO <sub>3</sub>	Excellent based on SAR Satisfactory based on EC	Good	Good

in the field of irrigation water quality. The hydrochemical analysis of the samples gave an opening to new research: the relationship of water type with the FIS classes, which have to be dealt with in detail in the future.

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### Author Affiliation

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*<sup>1</sup>School of Civil Engineering, Karunya University, Coimbatore, Tamil Nadu, India*

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