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Mamdani-type fuzzy inference system for irrigational water quality

S. Ponsadai Lakshmi*, C. Gopi, P. Adwin Jose

Department of Science & Humanities, E.G.S. Pillay Engineering College, Nagapattinam, Tamil Nadu, India

Abstract

This paper aims to evaluate the quality of groundwater resources used for irrigation purposes using a Mamdani-type fuzzy inference system (MFIS). The MFIS is used to resolve ambiguities and uncertainties in economic, social, and natural systems and also facilitates the capture of expert knowledge in ways similar to human reasoning and thought processes. In this study, 20 groundwater samples were collected from various locations within the Mayiladuthurai district, Tamil Nadu, India, between January 2016 and December 2019. These samples underwent physical and chemical analyses to assess the suitability of the collected water resources for irrigation. The analysis utilizes the Mamdani Fuzzy Inference System, which combines values of Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR). Additionally, methods from the US Salinity Laboratory Staff were also employed. Ultimately, the groundwater quality in Mayiladuthurai is graded for irrigation use by this method. The results indicate that the MFIS reduces imprecision and uncertainty in data handling through the fuzzy membership function. The comparison of irrigation suitability results clearly demonstrates that the proposed MFIS method offers an improved assessment of the irrigation water quality level of the studied groundwater resources.

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Keywords: Mamdani fuzzy inference system, USSL diagram, irrigational water quality groundwater resources, Mayiladuthurai

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1. Introduction

The condition of the soil is worse because of the quality of water available in that area, which is also the reason for the poor quality of the crops in the ground [1, 2]. Usually, water quality depends on its salinity hazard, permeability hazard, sodium hazard, and specific ion harmfulness. Therefore, to evaluate the irrigational water quality, the above parameters should be considered [3].

The minerals dissolved in water determine the quality of water. These minerals vary according to the environment, movement, and groundwater sources. The type and concentration of minerals significantly impact water quality, particularly its suitability for drinking, industrial applications, irrigation, etc.

Keeping this in mind, Residual Sodium Carbonate (RSC), the guideline value, was recommended by Eaton [4] to assess the condition of irrigational water. After that, the USSL diagram [5] was suggested for classifying sodium hazard value and salinity hazard value in irrigational water. In addition to that, the classification diagram for irrigation, which is based on

*Corresponding Author Tel. No.: +91-944-349-3398;
Email address: lakshmiabinav@gmail.com (S. Ponsadai Lakshmi)

specific conductance value and sodium percent, was presented [6]. After several years of research and experience in the US Salinity Laboratory, "guidelines" were proposed by the committee of the University of California consultants [7]. Then, modification of guideline values was done by Ayers along with Wescot.

However, evaluating water quality based on individual guideline values alone is insufficient for irrigation because it does not consider the cumulative effect of all essential irrigation water quality parameters.

Development of an appropriate method is mandatory, which should explain the overall irrigational quality by including all the essential irrigational water quality parameters. To resolve this, a new GIS—GIS-integrated irrigation water Quality Index using the traditional water Quality Indexing system—was proposed by Simsek and Gunduz [3]. But, many researchers, including Silvert and Ocampo-Duque *et al.* [8, 9], addressed the limitations and ambiguities of that system. To rectify these limitations, the Fuzzy inference system (FIS) is utilized for addressing the multiple criteria decision-making in the environmental aspects problems in various manners [10–15]. Researchers evaluated the irrigation water quality using Fuzzy logic by including the combined outcome of Electrical Conductance and Sodium Adsorption Ratio. Therefore, this paper aims to use the Mamdani Fuzzy Inference System (MFIS) to assess the suitability of the irrigational water condition of the study area using Electrical Conductivity and Sodium Adsorption Ratio.

2. Materials and methods

2.1. Sketch about the analysis area

Mayiladuthurai, the 38th newly created district of Tamilnadu. It is positioned on the banks of the river Cauvery. It is the delta's main river, but most agricultural activities depend on groundwater, i.e., bore hole water sources. Because the river Cauvery is dried in the maximum days of the year. Figure 1 explains the pictorial locations of 20 water sampling sites, and the details of sample collected places are tabulated in Table 1. Three taluks, Mayiladuthurai, Kuttalam and Sirkazhi, come under the said district. These three areas, namely Mayiladuthurai, Kuttalam and Sirkazhi, have a population of more than two and a half lakh people according to 2011 census.Significant agricultural activity includes paddy cultivation, sugar cane cultivation, and cereals also practised in this region. The region has a typical Northeast monsoon climate with moderate rainfall, adequate heat, and average weather. The details of sampling sites include S-1 Kuttalam, the type of well is open well, and sampling sites from S2-S20 are bore wells. The sampling sites S-2 to S-7 are Sethrabalapuram, Arayapuram, Malliyam, Mahadhanapuram, Moovalur and Sitharkadu, respectively. Sampling sites S-8 to S10 are inMayiladuthurai, namely Pookadai Street, Koranadu and Mahadhana Street. The remaining sampling sites, S-11 to S-20, are from Thiruvazhandur, Mayiladuthurai Coconut Tree Street, Senthangudi, Nagangudi, Lakshmipuram, Uluthukuppai, S.S. Nallur, Thirunanriyur, KeezhaAthukudi and MelaAthukudi respectively.

2.2. Sample collection and analysis

Eighty water samples were collected from January 2016 to December 2019 and analysed. Calibrated digital equipments like conductivity meter HM digital COM-80 was used to measure the physical characteristics of water in the sampling sites. Experimental procedures were fixed as regular methods. The methods recommended by APHA and Sajeev *et al*. [16, 17] were used to analyse the chemical parameters in the water.

2.3. Mamdani-type Fuzzy inference system

Zadeh [18] suggested a Mamdani-type fuzzy inference system(MFIS). It is a nonlinear mapping method to the output element of the input data. The mapping is based on fuzzy logic. It is a tool for creating systems that use a specific present knowledge and understanding as information (known as an expert) [19].

Fuzzy Inference System (FIS) has emerged from artificial intelligence for multiple criteria decision-making. FIS provides principles of reasoning with fuzzy logic, which concludes assertions. The principles underlying fuzzy logic are primarily based on the theory of fuzzy sets. The system uses the entire continuum of real numbers, from zero (representing false) to one (meaning truth). It is used to progress reasoning as a basis for rules of interference. In place of two levels in classical mathematics (0,1), Fuzzy set theory conveys a multi-level process among [0,1] was conceived by Zadeh [18].

2.4. Principles of Fuzzy inference system

In FIS, three basic concepts are involved in decision-making: membership functions, fuzzy set operators and inference rules [20].

2.4.1. Membership functions

A membership function permits finer details to be revealed, such as the degree of membership a member has to have to be considered a fuzzy set. If X is a universe of discourse and its elements are denoted by x, then a fuzzy set A is defined as,

$$A \equiv \{\langle x, \mu_A(x)\rangle / x \in X\}, \tag{1}$$

Where $\mu_A(x)$ is a membership function for the set of all objects x in X. The membership function is an arbitrary curve. The membership function describes well the charting of every point in the input data to membership value between zero and one, whose shape is usually stated by trapezoidal, triangular, z form and s form. Their equations are displayed below. A trapezoidal membership function can be described as a piecewise linear function. The function is continuous and governed by four parameters a, b, c, d as seen in equation (2).

$$\mu_t rapezoidal(x;\ a, b, c, d) = \begin{cases} 0 & x \le a \\ \frac{x-a}{b-a} & a \le x \le b \\ 1 & b \le x \le c \\ \frac{d-x}{d-c} & c \le x \le d \\ 0 & x \ge d \end{cases} \tag{2}$$

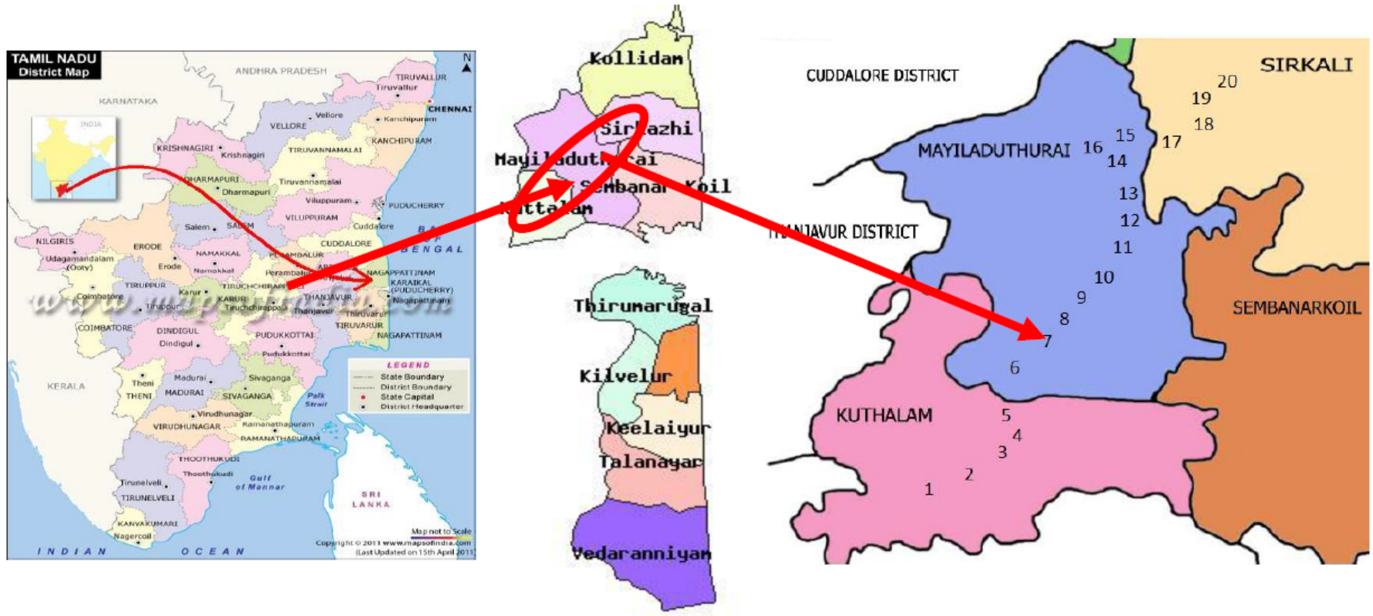

Figure 1. Map of the sample collecting sites.

The membership function, denoted by $\mu_A(x)$, represents the degree of membership of a value x in a given set A. The parameters $a \leq b \leq c \leq d$ act as four breakpoints that define the membership function. These breakpoints are labeled as follows: (a) left foot point, (b) left shoulder point, (c) right shoulder point, and (d) right foot point. The equations for other forms of membership function curves are given below:

$$\mu_{zform} = \begin{cases} 1, & x \leq c \\ \frac{c-x}{c-d}, & c \leq x \leq d \\ 0, & d \leq x \end{cases} \quad (3)$$

$$\mu_{triangular} = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0, & c \leq x \end{cases} \quad (4)$$

$$\mu_{sform} = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \end{cases} \quad (5)$$

where, $\mu_A(x)$ membership function, x –value observed, the parameters a ≤ b ≤ c ≤ d define four break points, here designated: (a) left foot point, (b)left shoulder point, (c) right shoulder point and (d) right foot point. In the case of a triangular function, (b) and (c) are equal and joined as peak points.

2.4.2. Fuzzy set operations

Fuzzy set procedures can generate a novel fuzzy set by combining existing sets. The functions that are involved in this context are specifically; (i) the union operation, also known as the OR operation, (ii) the intersection operation, sometimes referred to as the AND operation, and (iii) the additive complement operation, commonly known as the NOT operation. These fuzzy set operations accomplish the essence of fuzzy logic. The

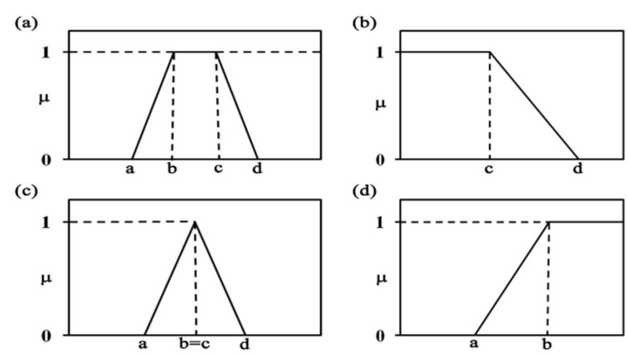

Figure 2. Illustration of membership function curves used in the FIS (a) trapezoidal, (b) form, (c) triangular and (d) form.

functions can be carried out for a given element x, where the sets, namely A and B, are termed on the Universe X.

Union, OR (Min)

$$\mu_{(A \cup B)}(x) = \ min\,\{\mu_A(x),\ \mu_B(x)\} \quad (6)$$

Intersection, AND (Max)

$$\mu_{(A \cap B)}(x) = max\,\{\mu_A(x),\ \mu_B(x)\} \quad (7)$$

Additive complement, NOT

$$\mu_{(\overline{A})}(x) = \ 1 - \mu_A(x) \quad (8)$$

2.4.3. Fuzzy Inference Rules (FIR)

The principles of reasoning provided by Fuzzy logic using judgment draw decisions from declarations known or expected to be true. A FIR has a well-known form: ‘IF – THEN’. IF ‘x is A’ THEN ‘y is B’, where x, y are linguistic variables and A, B are linguistic values. The linguistic variable ’x’ is antecedent,

Table 1. Comprehensive information regarding the groundwater sample stations within the designated study area.

S. No	Sampling stations	Source of water	GPS Coordinate
S-1	Kuttalam	Open well	11.0711° N, 79.5588° E
S-2	Sethrabalapuram	Bore Hole	11.0723° N, 79.5628° E
S-3	Arayapuram	Bore Hole	11.0757° N, 79.5814° E
S-4	Malliyam	Bore Hole	11.0836° N, 79.5976° E
S-5	Mahadhanapuram	Bore Hole	11.0836° N, 79.5976° E
S-6	Moovalur	Bore Hole	11.0850° N, 79.6095° E
S-7	Sitharkadu	Bore Hole	11.0922° N, 79.6215° E
S-8	MayiladuthuraiPookadai Street	Bore Hole	11.1018° N, 79.6526° E
S-9	MayiladuthuraiKoranadu	Bore Hole	11.1018° N, 79.6526° E
S-10	MayiladuthuraiMahadhana Street	Bore Hole	11.1018° N, 79.6526° E
S-11	Thiruvazhandur	Bore Hole	11.0470° N, 79.5852° E
S-12	Mayiladuthurai Coconut Tree Street	Bore Hole	11.1035° N, 79.6550° E
S-13	Senthangudi	Bore Hole	11.1096° N, 79.6588° E
S-14	Nagangudi	Bore Hole	11.1091° N, 79.6600° E
S-15	Lakshmipuram	Bore Hole	11.1091° N, 79.6600° E
S-16	Uluthukuppai	Bore Hole	10.7663° N, 79.7663° E
S-17	S.S. Nallur	Bore Hole	11.0968° N 7704041° E
S-18	Thirunanriyur	Bore Hole	11.1444° N 79.6986° E
S-19	KeezhaAthukudi	Bore Hole	11.1707° N 79.7074° E
S-20	MelaAthukudi	Bore Hole	11.1707° N 79.7074° E

and 'y' is consequent. Example of inference rule - IF the tomato is red, THEN it is ripe. The IF and THEN part of a rule can have many functions; in this sense, fuzzy set operations are applied for aggregation.

2.5. *Evaluating the Suitability of Water for Agricultural Irrigation*

To classify the irrigational water quality and its evaluation, Wilcox(1948) took many criteria into account. Hadeel *et al.* [1] presented the irrigational classification diagram centred on the specific conductivity of water and the percentage of sodium. The residual sodium carbonate contentwas recommended by Eaton [4] to test the water's suitability for irrigation. Quist-Jensen *et al.* [6] also classified irrigational water quality. He used two parameters, such as electrical conductivity and percentage of sodium, to classify water samples for irrigational water quality. Zaman *et al.* [5] also presented a plot. Zaman *et al.* [5] used the Electric Conductance parameter and Sodium Adsorption Ratioto categorize the suitability of irrigational quality.

Evaluating the quality of irrigation water holds significant importance as it enables the identification of detrimental salts and other undesirable sediment combinations present in the water [21]. This assessment is crucial for enhancing the growth and productivity of crops.The suitability of the water test provides us with the condition of the soil, hazards for growing crops, etc. [15]. The paramount parameters such as the nature of the ground, drainage level, the amount of water to be used and methods of irrigation are also important [22, 32, 33]. In addition to the above weather patterns of the region and the amount of rainfall received, nature also plays a vital role in the type of crop that must be grown in that area [15]. Generally, minerals that are present in water decide its irrigational suitability for the specific type of crop and soil. In addition to the parameters, in this study, sodium's electrical conductance and adsorption ratio have also been discussed because these two are very important for plant quality.

2.5.1. Evaluation of Water Quality using USSL Diagram for Irrigational purposes

In the classification of the quality of irrigational water, Zaman *et al*. [5] gives us information about the outcome of salinity hazard and sodium hazard. A scatter plot The graph in Figure 3 illustrates the relationship between salinity hazard (EC) values on the X-axis and sodium hazard (SAR) levels on the Y-axis. By default, the values of EC are graphed on a logarithmic scale. Concerning the capacity of conductivity, water is categorized into four classes and grouped into 16 categories. The classes are divided at 250, 750 and 2250 micro mhos per centimeter. The selection of class limitations for the electrical conductivity of irrigation water and soil saturation extract was based on the information provided in the link.

The following empirical equations are used to build the curves of Figure 3, Zaman *et al*. [5].

$$Upper curve: S = 43.75 - 8.87(\log C), \tag{9}$$

$$Middle curve: S = 31.31 - 6.66(\log C), \tag{10}$$

$$Lower curve: S = 18.87 - 4.44(\log C), \tag{11}$$

where abbreviations such as 'SAR' stands for Sodium Adsorption Ratio, 'EC' for Electric Conductivity in micro mhos per centimeter, and 'log C' for the logarithm to base 10, respectively. When 'log C' is used, the equations yield straight lines, which are plotted on rectangular coordinate paper using SAR and EC values as coordinates to locate the related points on the diagram.

The quality of irrigation water is classified based on the salinity hazard, which refers to the concentration of soluble salts expressed in terms of specific conductivity. Therefore, EC is used to classify irrigation water into four categories:

1. Low-salinity water (C1) is suitable for irrigating all crops, except in soils with low permeability.
2. Average-salinity water (C2) is suitable for soils with a medium rate of leaching. This water can also irrigate plants with moderate salt tolerance.
3. High-salinity water (C3) should not be used for soils with poor drainage. Instead, it is better suited for vegetation that can manage higher salt levels.

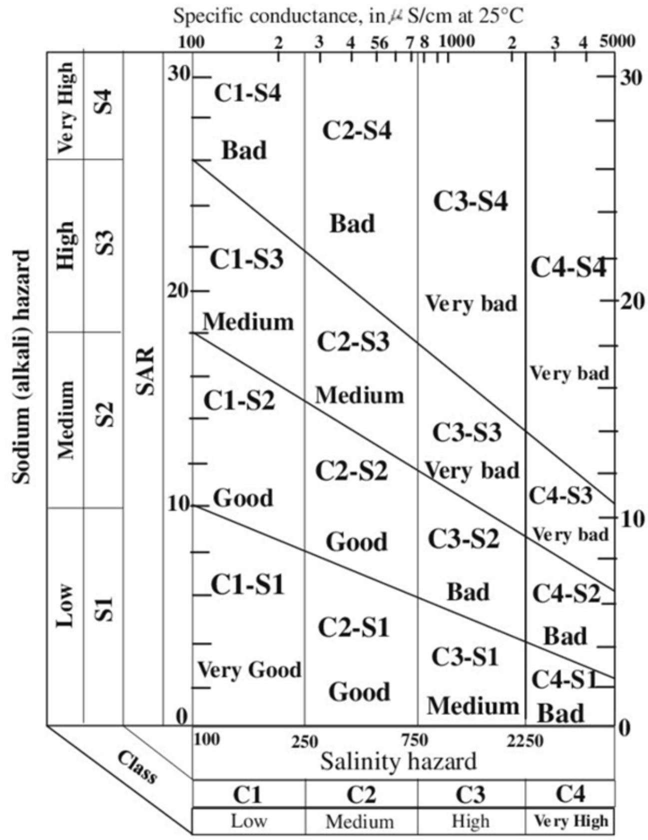

Figure 3. United States salinity laboratory diagram.

4. Very high-salinity water (C4) should only be used for soils that are permeable and have adequate drainage. In less ideal soils, this type of water should not be used for irrigation without applying surplus water to facilitate better leaching, and crops that tolerate very high salt levels should be selected.

The classification of water quality with respect to the Sodium Adsorption Ratio (SAR) depends on the impact of sodium on soil condition. However, plants sensitive to sodium may experience significant adverse effects. Salt accumulation contributes to soil quality deterioration. Important factors affecting water quality that impact the water's permeability and penetration capabilities include electrical conductivity, as well as the relative concentrations of sodium, magnesium, and calcium ions in the water.

The 'Sodium Adsorption Ratio (SAR)' is also used to describe this phenomenon. The calculation of SAR for irrigation water can be conducted according to the methodology outlined by the U.S. Salinity Laboratory in Zaman *et al.* [5] as shown in equation (12).

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}, \tag{12}$$

where SAR is reported in meq/l. Where all ion concentrations are stated in milli equivalents per litre, high salt content water will increase infiltration. The decrease in infiltration is caused by less salt content water or water having an elevated sodium-to-calcium ratio. Equally, both factors may function at the same time. When water contains high sodium, soil develops an elevated sodium surface. This reduces the structural construction of the ground [2]. Four categories of USSLdiagram based on-SAR: Small-sodium water(S1)is suitableforirrigation. Its suitability looks better fornearlyall types of soils except sodium-sensitive crops.

Water with medium-sodium content(S2)is suitable for good-surfaced soils with excellent cation-exchange ability with small oozing situations. It can be used for organic soils and soils with coarse texture because of the permeability of the ground. Water with high sodium content (S3) maybe able to exchange sodium in most soils, so it needs extra management and monitoring practices of the earth. Water with excessive sodium content(S4)is almost only suitable for irrigation if separate managing procedures are followed, such as adding gypsum to soil [23].

2.6. *Assessment of the quality of irrigational water suitability using the proposed model:*

A comparison of results obtained from the USSL diagram and MFIS is presented in Table 5. During the evaluation, it is important to get agreement between the expert's knowledge and Fuzzy Inference System outputs.That is, the system should give a suitable response to the different conditions that can be presented.

2.6.1. *Fuzzy Inference System (FIS)*

The fuzzy set theory and fuzzy inference system are helpful mathematical tools for understanding subjectivities, vagueness, and inaccuracies in socio-economic, human, and natural systems. These tools can address the vagueness and fuzzy ambiguity in assessing complex situations [24]. The methods facilitate decision-making through approximate reasoning and linguistic terms. The FIS, a nonlinear system, employs fuzzy rules to create models that explain the qualitative features of human knowledge without requiring precise quantitative analyses. Its flexibility and accurate estimations have made it a promising alternative modeling technique in recent years [25]. Generally, FIS is a potent tool for evaluating various categories of complex systems and assessment processes [26–29].

In the FIS model, the fuzzy inference engine converts the input data into linguistic variables. Specified rules then determine the outputs for the provided inputs. During the defuzzification process, output variables are converted into real-world variables. Subsequently, it is used to analyze real-world problems.

According to Nasibov [20], the FIS model incorporates professionals' viewpoints through language variables and fuzzy if-then rules. It comprises two types of components. The first component, a database, contains linguistic terms and practices. A rule base, the second component, consists of a collection of linguistic rules combined using an operative tool. In this research on water appraisal for irrigation, the fuzzy inference system in the fuzzy logic toolbox version 7.0 of MATLAB is utilized. In the FIS model, EC and SAR are inputs, and one output is the FIS benefit. Based on experts' judgment, 16 rules are designed for measuring irrigation water quality. In addition to the operations mentioned above, intersection, union, aggregation, implication, and defuzzification are also given due consideration. Specifically, MIN, MAX, SUM, PROD, and CENTROID operations are considered.

2.6.2. *Determining Membership Functions*

There are four kinds of approaches introduced by Turksen [30] to describe the attainment of membership functions. Several types of statistical methods are commonly used in research, including direct rating, set-valued statistics, polling, and reverse rating. Park *et al.* [31] thoroughly analyzed the various approaches employed in the natural creation of membership functions. This research paper utilized direct valuation based on United Salinity Staff Laboratory diagram limits to develop the membership functions. Using the trial and error method, the membership functions for Electrical Conductivity and Sodium Adsorption Ratio were determined. By comparing the results of the fuzzy system with the USSL diagram, the best membership function was selected. Figures 4, 5, and 6 represent the membership functions for Sodium Adsorption Ratio, Electrical Conductivity, and the appraisal output of irrigational water quality, respectively. The fuzzy rules are given in Table 2.

Fuzzy rule determination: The present study, 16 rules are designed for irrigation water quality assessment based on expert judgment. Some of the example rules are given below,

1. The quality is considered good if the specific absorption rate (SAR) is low and the Electrical Conductivity (EC) is moderate.
2. In the event that the SAR is high and the EC (Electrical Conductivity) is low, it can be inferred that the quality is of a moderate level.

3. Results and discussion

This research study employs fuzzy logic and a USSL diagram to assess the quality of groundwater samples for irrigation purposes. The analytical data for determining factors of irrigation water quality, such as Electrical Conductivity and Sodium Absorption Ratio, are presented in Table 3. With the help of the MATLAB 7 package, the membership functions and the bases of fuzzy rules were defined. Table 4 (the defuzzification table) shows the fuzzy score and the irrigation water excellence ranking.

The MFIS method is used to distinguish between samples of the same quality. In the MFIS method, a score ranging from 0 to 1 is assigned to each water sample for SAR and EC. A higher fuzzy score indicates better water quality, thereby suggesting improved irrigation quality. An analysis based on the USSL categorization was conducted on groundwater samples from several locations, namely Mahadhanapuram, Mayiladuthurai Koranadu, Mayiladuthurai Coconut Street, Uluthukuppai, S.S. Nallur, and Keezha Athukudi. These samples were all classified in the C3-S1 category (medium) in 2019. However, MFIS

Table 2. Fuzzy rules.

EC/SAR	Low	Mid	High	Very High
Low	Very Good	Good	Medium	Bad
Mid	Good	Good	Bad	Bad
High	Medium	Medium	Very Bad	Very Bad
Very High	Bad	Bad	Very Bad	Very Bad

Table 3. The analytical data of the irrigational water quality parameters such as EC and SAR.

		2016			2017			2018			2019		
S.No	Sampling station	EC	SAR	Class	EC	SAR	Class	EC	SAR	Class	EC	SAR	Class
1	Kuttalam	4.65	2600	C4-S2	6.23	1682	C3-S2	11.59	852	C3-S2	5.26	1329	C3-S2
2	Sethrabalapuram	3.87	2782	C4-S2	2.66	1250	C3-S1	8.12	2517	C4-S3	7.56	1985	C3-S2
3	Arayapuram	10.22	1852	C3-S3	13.6	2567	C4-S3	7.11	1577	C3-S2	5.95	908	C3-S2
4	Malliyam	12.97	912	C3-S3	1.95	2633	C4-S1	6.07	1785	C3-S2	4.38	2981	C4-S2
5	Mahadhanapuram	4.21	2420	C4-S2	7.22	1621	C3-S2	4.06	653	C2-S1	3.37	1372	C3-S1
6	Moovalur	6.57	1284	C3-S2	5.88	2357	C4-S2	2.46	1041	C3-S1	7.25	1934	C3-S2
7	Sitharkadu	7.05	917	C3-S2	4.48	2942	C4-S2	9.36	4795	C4-S3	7.51	2544	C4-S2
8	Mayiladuthurai Pookadai Street	5.95	1354	C3-S2	6.45	1225	C3-S2	4.78	1154	C3-S1	6.93	1810	C3-S2
9	Mayiladuthurai Koranadu	4.25	1285	C3-S1	5.14	1158	C3-S1	5.91	1211	C3-S2	5.27	1546	C3-S1
10	Mayiladuthurai Mahadhana Street	6.02	1755	C3-S2	6.45	1843	C3-S2	7.18	1874	C3-S2	6.91	1719	C3-S2
11	Thiruvazhandur	11.53	4125	C4-S4	10.79	4318	C4-S4	13.17	4263	C4-S4	15.82	4716	C4-S4
12	Mayiladuthurai Coconut Tree Street	4.71	1284	C3-S1	5.83	1325	C3-S2	5.61	1022	C3-S2	4.56	1225	C3-S1
13	Senthangudi	8.39	2617	C4-S2	10.32	2369	C4-S3	7.98	2182	C3-S2	9.51	2688	C4-S3
14	Nagangudi	6.81	2671	C4-S2	5.38	2319	C4-S2	6.37	2492	C4-S2	7.53	2578	C4-S2
15	Lakshmipuram	4.72	1524	C3-S1	5.48	1537	C3-S2	4.86	1783	C3-S1	3.97	2873	C4-S2
16	Uluthukuppai	5.08	1325	C3-S1	7.87	1524	C3-S2	5.69	1295	C3-S2	4.26	1198	C3-S1
17	S.S. Nallur	5.38	1785	C3-S2	2.48	1657	C3-S1	6.07	1638	C3-S2	5.95	1266	C3-S1
18	Thirunanriyur	6.53	1825	C3-S2	7.84	2215	C3-S2	8.26	1917	C3-S2	5.89	1983	C3-S2
19	KeezhaAthukudi	3.81	1437	C3-S1	5.89	1302	C3-S2	3.73	1394	C3-S1	3.64	1198	C3-S1
20	MelaAthukudi	6.78	2624	C4-S2	5.45	2303	C4-S2	7.26	2497	C4-S2	6.73	2482	C4-S2

Table 4. The fuzzy score and its irrigational water quality ranking (defuzzification table).

Sl. No.	Sampling Stations	2016	2017	2018	2019
1	Kuttalam	4.65	6.23	11.59	5.26
2	Sethrabalapuram	3.87	2.66	8.12	7.56
3	Arayapuram	10.22	13.6	7.11	5.95
4	Malliyam	12.97	1.95	6.07	4.38
5	Mahadhanapuram	4.21	7.22	4.06	3.37
6	Moovalur	6.57	5.88	2.46	7.25
7	Sitharkadu	7.05	4.48	9.36	7.51
8	Mayiladuthurai Pookadai Street	5.95	6.45	4.78	6.93
9	Mayiladuthurai Koranadu	4.25	5.14	5.91	5.27
10	Mayiladuthurai Mahadhana Street	6.02	6.45	7.18	6.91
11	Thiruvazhandur	11.53	10.79	13.17	15.82
12	Mayiladuthurai Coconut Tree Street	4.71	5.83	5.61	4.56
13	Senthangudi	8.39	10.32	7.98	9.51
14	Nagangudi	6.81	5.38	6.37	7.53
15	Lakshmipuram	4.72	5.48	4.86	3.97
16	Uluthukuppai	5.08	7.87	5.69	4.26
17	S.S. Nallur	5.38	2.48	6.07	5.95
18	Thirunanriyur	6.53	7.84	8.26	5.89
19	KeezhaAthukudi	3.81	5.89	3.73	3.64
20	MelaAthukudi	6.78	5.45	7.26	6.73

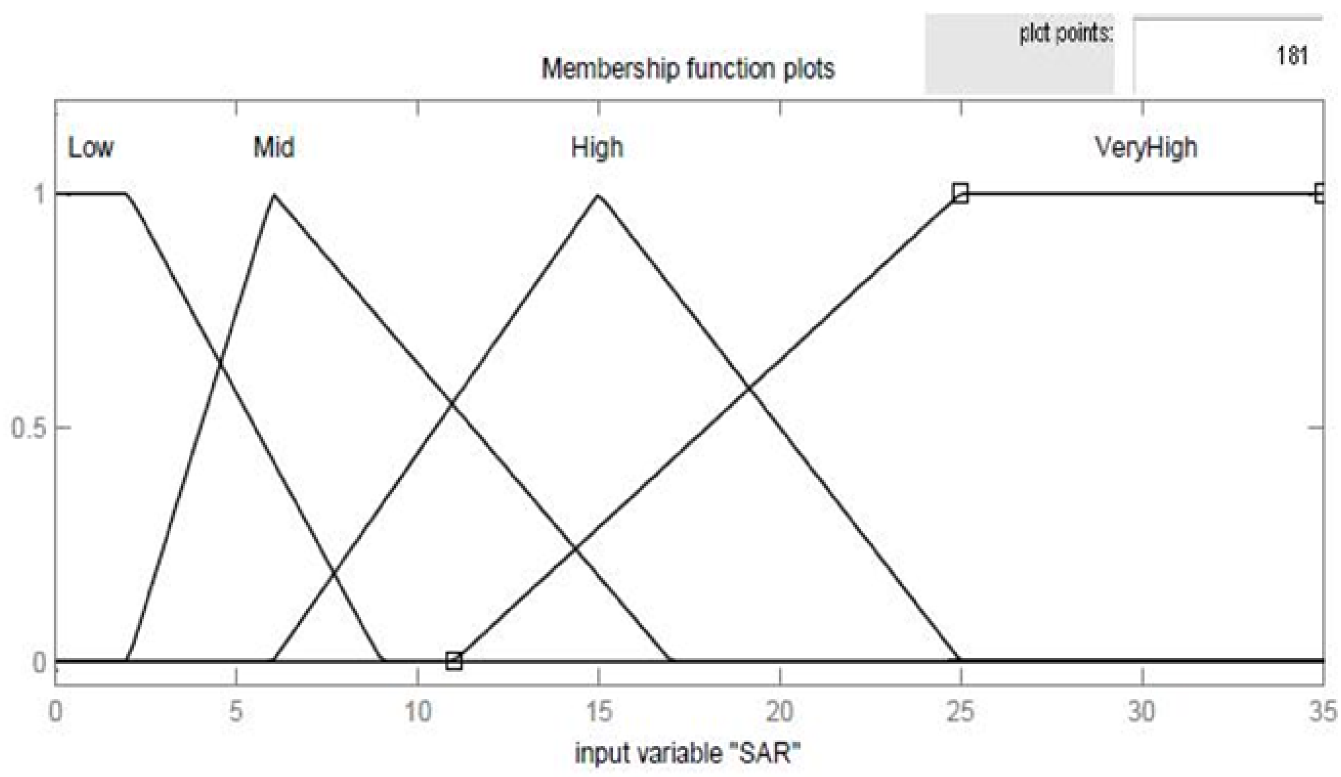

Figure 4. Sodium Adsorption Ratio membership functions.

assigns different ratings to these samples, which were categorized identically by USSL. According to the MFIS model, the scores were 100% for Mahadhanapuram, 75% for Mayiladuthurai Koranadu, 83% for Mayiladuthurai Coconut Street, 87% for Uluthukuppai, 68% for S.S. Nallur, and 97% for Keezha Athukudi. This indicates varying water quality across these samples. The sample from Mahadhanapuram was of the highest quality, while the one from S.S. Nallur was of the lowest. Addi-

Table 5. Comparison of results obtained from the USSL diagram.

Sl.NO	Sampling Stations		EC	USSL Class	Output	Fuzzy Evaluation	United Salinity Staff Laboratory Diagram Expert Evaluation	Percentage Agreement (%)
1	Kuttalam	4.65	2600	C_4-S_2	0.39	40% Bad and 60% Moderate	Bad	40
2	Kuttalam	6.23	1682	C_3-S_2	0.392	39% Bad and 61% Moderate	Bad	39
3	Kuttalam	11.59	852	C_3-S_2	0.32	87% Bad and 13% Moderate	Bad	87
4	Kuttalam	5.26	1329	C_3-S_2	0.413	25% Bad and 75% Moderate	Bad	25
5	Sethrabalapuram	3.87	2782	C_4-S_2	0.359	61% Bad and 39% Moderate	Bad	61
6	Sethrabalapuram	2.66	1250	C_3-S_1	0.475	100% Moderate	Moderate	100
7	Sethrabalapuram	8.12	2517	C_4-S_3	0.297	2% Very bad and 98% Bad	Very bad	2
8	Sethrabalapuram	7.56	1985	C_3-S_2	0.331	79% Bad and 21% Moderate	Bad	71
9	Arayapuram	10.22	1852	C_3-S_3	0.214	57% Very bad and 43% Bad	Very bad	57
10	Arayapuram	13.6	2567	C_4-S_3	0.172	85% Very bad and 15% Bad	Very bad	85
11	Arayapuram	7.11	1577	C_3-S_2	0.354	64% Bad and 36% Moderate	Bad	64
12	Arayapuram	5.95	908	C_3-S_2	0.402	32% Bad and 68% Moderate	Bad	32
13	Malliyam	12.97	912	C_3-S_3	0.171	86% Very bad and 14% Bad	Very bad	86
14	Malliyam	1.95	2633	C_4-S_1	0.384	44% Bad and 56% Moderate	Bad	44
15	Malliyam	6.07	1785	C_3-S_2	0.399	66% Bad and 34% Moderate	Bad	66
16	Malliyam	4.38	2981	C_4-S_2	0.307	96% Bad and 4% Moderate	Bad	96
17	Mahadhanapuram	4.21	2420	C_4-S_2	0.414	24% Bad and 76% Moderate	Bad	76
18	Mahadhanapuram	7.22	1621	C_3-S_2	0.348	68% Bad and 32% Moderate	Bad	68
19	Mahadhanapuram	4.06	653	C_2-S_1	0.585	77% Moderate and 23% Good	Good	23
20	Mahadhanapuram	3.37	1372	C_3-S_1	0.454	100% Moderate	Moderate	100
21	Moovalur	6.57	1284	C_3-S_2	0.378	48% Bad and 52% Moderate	Bad	48
22	Moovalur	5.88	2357	C_4-S_2	0.418	21% Bad and 79% Moderate	Bad	21
23	Moovalur	2.46	1041	C_3-S_1	0.482	100% Moderate	Moderate	100
24	Moovalur	7.25	1934	C_3-S_2	0.348	68% Bad and 32% Moderate	Bad	68
25	Sitharkadu	7.05	917	C_3-S_2	0.357	62% Bad and 38% Moderate	Bad	62
26	Sitharkadu	4.48	2942	C_4-S_2	0.32	87% Bad and 13% Moderate	Bad	87
27	Sitharkadu	9.36	4795	C_4-S_3	0.229	52% Very Bad and 48% Bad	Very bad	52
26	Sitharkadu	4.48	2942	C_4-S_2	0.32	87% Bad and 13% Moderate	Bad	87
27	Sitharkadu	9.36	4795	C_4-S_3	0.229	52% Very Bad and 48% Bad	Very bad	52
28	Sitharkadu	7.51	2544	C_4-S_2	0.335	77% in Bad and 23% in Moderate	Bad	77
29	Mayiladuthurai Pookadai Street	5.95	1354	C_3-S_2	0.402	32% Bad and 68% Moderate	Bad	32
30	Mayiladuthurai Pookadai Street	6.45	1225	C_3-S_2	0.383	45% Bad and 55% Moderate	Bad	45
31	Mayiladuthurai Pookadai Street	4.78	1154	C_3-S_1	0.421	19% Bad and 81% Moderate	Moderate	81
32	Mayiladuthurai Pookadai Street	6.93	1810	C_3-S_2	0.362	59% Bad and 41%Moderate	Bad	59
33	Mayiladuthurai Koranadu	4.25	1285	C_3-S_1	0.432	12% Bad and 88% Moderate	Moderate	88
34	Mayiladuthurai Koranadu	5.14	1158	C_3-S_1	0.415	23% Bad and 77% Moderate	Moderate	77
35	Mayiladuthurai Koranadu	5.91	1211	C_3-S_2	0.403	31% Bad and 69% Moderate	Bad	31
36	Mayiladuthurai Koranadu	5.27	1546	C_3-S_1	0.413	25% Bad and 75% Moderate	Medium	75

Sl.NO	Sampling Stations		EC	USSL Class	Output	Fuzzy Evaluation	United Salinity Staff Laboratory Diagram Expert Evaluation	Percentage Agreement (%)
37	Mayiladuthurai Mahadhana Street	6.02	1755	C_3-S_2	0.401	33% Bad and 67% Moderate	Bad	33
38	Mayiladuthurai Mahadhana Street	6.45	1843	C_3-S_2	0.384	44% Bad and 56% Moderate	Bad	44
39	Mayiladuthurai Mahadhana Street	7.18	1874	C_3-S_2	0.351	66% Bad and 34%Moderate	Bad	66
40	Mayiladuthurai Mahadhana Street	6.91	1719	C_3-S_2	0.363	58% Bad and 42% Moderate	Bad	58
41	Thiruvazhandur	11.53	4125	C_4-S_4	0.193	71% Very bad and 29% Bad	Very bad	71
42	Thiruvazhandur	10.79	4318	C_4-S_4	0.205	63% Very bad and 37% Bad	Very bad	63
43	Thiruvazhandur	13.17	4263	C_4-S_4	0.168	88% Very bad and 12% Bad	Very bad	88
44	Thiruvazhandur	15.82	4716	C_4-S_4	0.134	100% Very bad	Very bad	100
45	Mayiladuthurai Coconut Tree Street	4.71	1284	C_3-S_1	0.422	19% in Bad and 81% in Moderate	Moderate	81
46	Mayiladuthurai Coconut Tree Street	5.83	1325	C_3-S_2	0.404	31% Bad and 69%Moderate	Bad	31
47	Mayiladuthurai Coconut Tree Street	5.61	1022	C_3-S_2	0.407	29% Bad and 71% Moderate	Bad	29
48	Mayiladuthurai Coconut Tree Street	4.56	1225	C_3-S_1	0.425	17% Bad and 83% Moderate	Moderate	83
49	Senthangudi	8.39	2617	C_4-S_2	0.279	14% Very bad and 86% Bad	Bad	14
50	Senthangudi	10.32	2369	C_4-S_3	0.209	61% Very bad and 39% Bad	Very Bad	61
51	Senthangudi	7.98	2182	C_3-S_2	0.307	95% Bad and 5% Medium	Bad	95
52	Senthangudi	9.51	2688	C_4-S_3	0.226	49% Very bad and 51% Bad	Very bad	49
53	Nagangudi	6.81	2671	C_4-S_2	0.357	62% in Bad and 38% in Moderate	Bad	62
54	Nagangudi	5.38	2319	C_4-S_2	0.425	17% Bad and 83% Moderate	Bad	17
55	Nagangudi	6.37	2492	C_4-S_2	0.395	37% Bad and 63% Moderate	Bad	37
56	Nagangudi	7.53	2578	C_4-S_2	0.334	77% Bad and 23% Moderate	Bad	77
57	Lakshmipuram	4.72	1524	C_3-S_1	0.422	19% Bad and 81% Moderate	Moderate	81
58	Lakshmipuram	5.48	1537	C_3-S_2	0.409	27% Bad and 73% Moderate	Bad	27
59	Lakshmipuram	4.86	1783	C_3-S_1	0.42	20% Bad and 80% Moderate	Moderate	80
60	Lakshmipuram	3.97	2873	C_4-S_2	0.339	74% Bad and 26% Moderate	Bad	74
61	Uluthukuppai	5.08	1325	C_3-S_1	0.416	23% Bad and 77% Moderate	Moderate	77
62	Uluthukuppai	7.87	1524	C_3-S_2	0.313	91% Bad and 9% Moderate	Bad	91
63	Uluthukuppai	5.69	1295	C_3-S_2	0.406	29% Bad and 71% Moderate	Bad	29
64	Uluthukuppai	4.26	1198	C_3-S_1	0.431	13% Bad and 87% Moderate	Moderate	87
65	S. S. Nallur	5.38	1785	C_3-S_2	0.411	26% Bad and 74% Moderate	Bad	26
66	S. S. Nallur	2.48	1657	C_3-S_1	0.482	100% Moderate	Moderate	100
67	S. S. Nallur	6.07	1638	C_3-S_2	0.398	35% Bad and 65% Moderate	Bad	35
68	S.S. Nallur	5.95	1266	C_3-S_1	0.402	32% Bad and 68% Moderate	Moderate	68
69	Thirunanriyur	6.53	1825	C_3-S_2	0.381	46% Bad and 54% Moderate	Bad	46
70	Thirunanriyur	7.84	2215	C_3-S_2	0.316	89% Bad and 11% Moderate	Bad	89
71	Thirunanriyur	8.26	1917	C_3-S_2	0.288	8% Very bad and 92% Bad	Bad	92

Sl.NO	Sampling Stations		EC	USSL Class	Output	Fuzzy Evaluation	United Salinity Staff Laboratory Diagram Expert Evaluation	Percentage Agreement (%)
72	Thirunanriyur	5.89	1983	C_3-S_2	0.407	29% Bad and 71% in Moderate	Bad	29
73	Keezha Athukudi	3.81	1437	C_3-S_1	0.442	5% Bad and 95% Moderate	Moderate	95
74	Keezha Athukudi	5.89	1302	C_3-S_2	0.403	31% Bad and 69% Moderate	Bad	31
75	Keezha Athukudi	3.73	1394	C_3-S_1	0.444	4% Bad and 96% Medium	Moderate	96
76	Keezha Athukudi	3.64	1198	C_3-S_1	0.446	3% Bad and 97% in Moderate	Moderate	97
77	Mela Athukudi	6.78	2624	C_4-S_2	0.365	57% Bad and 43% Moderate	Bad	57
78	Mela Athukudi	5.45	2303	C_4-S_2	0.424	17% Bad and 83% Moderate	Bad	17
79	Mela Athukudi	7.26	2497	C_4-S_2	0.35	67% Bad and 33% Moderate	Bad	67
80	Mela Athukudi	6.73	2482	C_4-S_2	0.378	48% Bad and 52% Moderate	Bad	48

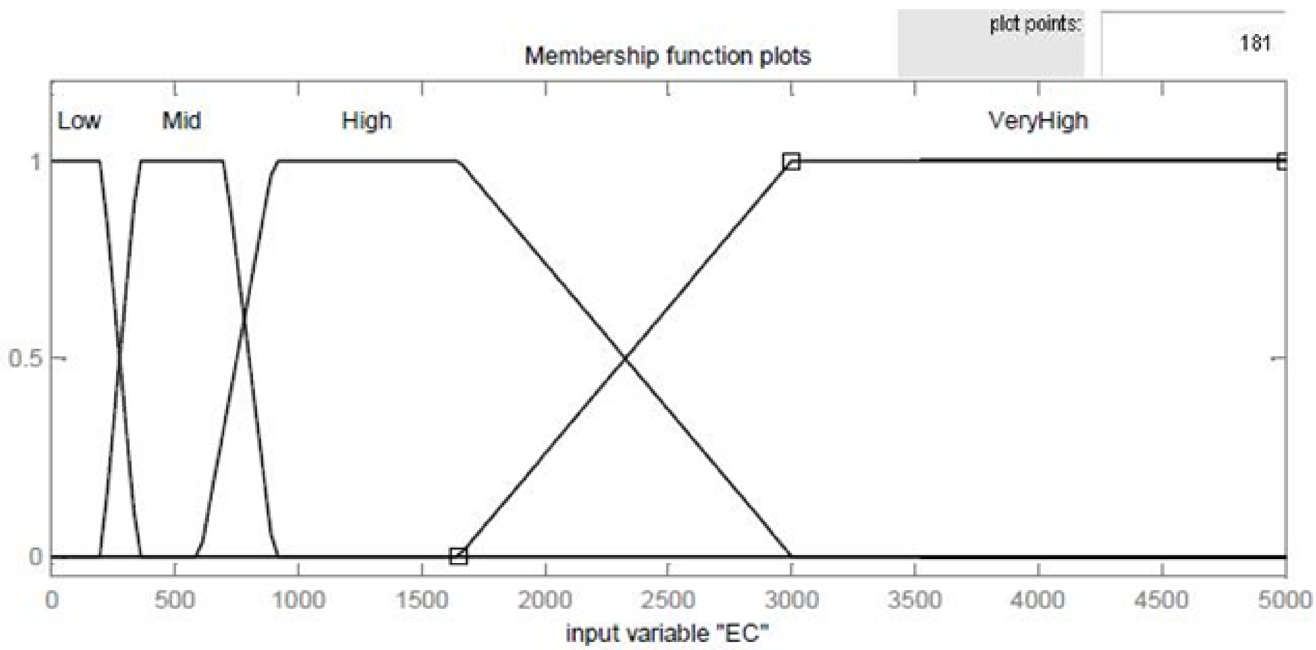

Figure 5. Electrical conductivity membership functions.

tionally, according to USSL, the samples from Mayiladuthurai Coconut Street fall into the C3-S2 category. However, MFIS ranks these samples differently for the studied period of 2016-2019. For Thiruvazhandur, USSL classifies the region as C4-S4, whereas MFIS shows better quality. Similarly, for Nagangudi and Mela Athukudi, USSL categorizes both as C4-S2, but MFIS indicates improved quality for these samples. The relationship between the two input variables and one output variable is visualized using a fuzzy surface in a graphical user interface. The fuzzy surface diagram, depicted in Figure 7, allows for the examination of potential clustering of input variables and the resulting output variable in a three-dimensional representation. Fuzzy surfaces are useful for understanding the relationship between input and output variables.

The plot representing the relationship between the fuzzy score of samples and time indicates the irrigation quality of groundwater samples. The outputs of the variables are utilized to obtain primary, secondary, and tertiary results, and these outputs are derived from the inputs and rules introduced into the system. According to the USSL diagram, the samples collected from Kuttalam (2017-2019), Arayapuram (2018-2019), Mayiladuthurai Pookadai Street (2016-2017), and Ulunthukupai (2017-2018) are categorized as C3-S2. However, the MFIS model produces different values for these samples, suggesting

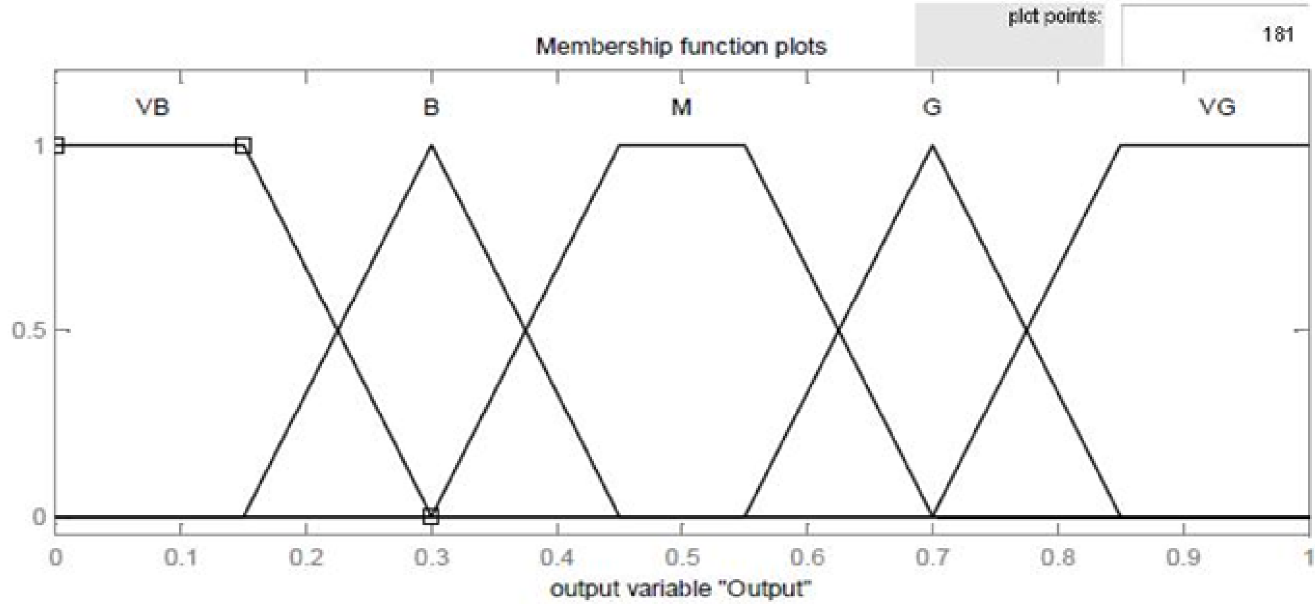

Figure 6. Irrigational water quality appraisal membership functions.

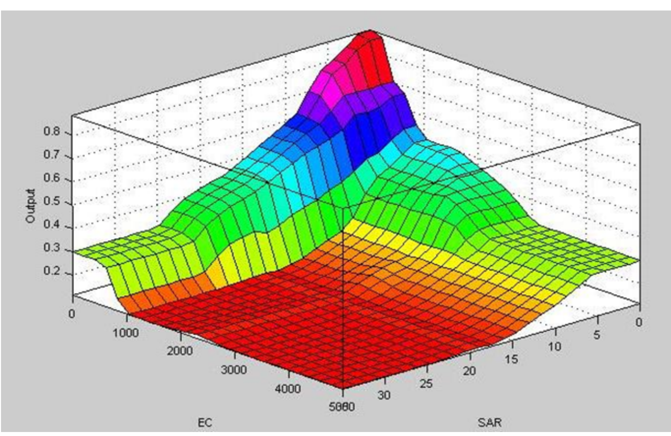

Figure 7. Fuzzy surface: SAR, EC and irrigational water quality assessment.

that the quality of groundwater varies periodically based on the presence of pollutants and rainfall. The effects of inherent inaccuracies caused by the classification differences in the United Salinity Staff Limited diagram have significantly enhanced the utility of the MFIS tool. Hydrochemical analysis and its errors can be corrected by this method, which substantially changes when water quality samples are near the margins of a class. Even a small percentage of error in chemical experiments can cause such samples to be misclassified. When the MFIS method is applied, the outcomes of experimental errors become negligible. This is reflected in the final evaluation of water quality for irrigation purposes. Furthermore, when the difference between two samples is minimal, the MFIS model plays a crucial role. Therefore, the MFIS method is considered more accurate than the USSL diagram in assessing boundary values between two classes.

4. Conclusion

In this work, the USSL diagram is used to assess the quality of groundwater samples. The proposed MFIS model integrates decisions and guideline values from the USSL diagram, combining the effects of key irrigation parameters such as EC and SAR. However, the USSL diagram has inherent imprecision between classes, which complicates the water quality evaluation and introduces significant ambiguities when stating water quality for specific practices, namely irrigation use. Additionally, uncertainties in the field data significantly affect the analysis. A groundwater quality diagram describes water quality in linguistic terms, while the MFIS provides different scores using fuzzy tools for various applications. The proposed MFIS model categorizes water quality as Very Good, Good, Medium, Bad, or Very Bad, assigning different fuzzy scores to each category. This model enhances the mitigation of potential errors, uncertainties, and hydrochemical analyses to improve their effects. The results obtained from the MFIS approach can distinguish, in terms of quality, between samples that belong to the same class in the USSL diagram. Furthermore, the MFIS assesses the quality of groundwater samples more accurately and offers a healthier water quality condition. The use of mathematical relations and linguistic terms yields better results in the MFIS model. The selection of membership functions, based on their shape and boundary, significantly influences the evaluation and classification of irrigation water samples. It more accurately classifies the original quality of the samples. Additionally, the MFIS model reduces the imprecision and uncertainty in data handling through the fuzzy membership function. The findings from the comparison of irrigation appropriateness indicate that the MFIS approach provides a more accurate depiction of the quality of irrigation water conditions.

References

[1] Hadeel A Al Saleh, Samir Saify & Nariman Y Othuman, "Spatial distribution of ground water quality parameters in Al-Najaf city using GIS and Geostatistics Techniques," IOP onf. Series: Earth and Environmental science **952** (2022) 012003. http://dx.doi.org/10.1088/1755-1315/952/1/012003.

[2] Mufeed Batarseh, Emad Imreizeeq, Seyda Tilev, Mohammad Al Alaween, Wael Suleiman, Abdulla Mohammed Al Remeithi, Mansoor Khamees Al Tamimi, & Majdy Al Alawneh, "Assessment of groundwater quality for irrigation in the arid regions using irrigation water quality index (IWQI) and GIS-Zoning maps: Case study from Abu Dhabi Emirate, UAE," Water quality for agriculture **14** (2021) 100611. https://doi.org/10.1016/j.gsd.2021.100611.

[3] . C.Simsek and O. Gunduz, "IWQ Index: A GIS-integrated technique to assess the irrigation water quality," Environ. Monit. Assess. **128** (2007) 277. https://doi.org/10.1007/s10661-006-9312-8.

[4] F. M. Eaton, "Significance of carbonate in irrigation water, Soil Science, fuzzy-based air quality index (FAQI) for air quality assessment," Atmospheric Environment **39** (1950) 123. https://doi.org/10.1097/00010694-195002000-00004.

[5] Mohammad Zaman, Shabbir A Shahid and Lee Heng, "Guideline for salinity assessment, Mitigation and Adaptation using nuclear and related techniques," Springer, Cham, **105** (2018) 113. http://dx.doi.org/10.1007/978-3-319-96190-3.

[6] C. A Quist-Jensen, F. Macedonio and E. Drioli, "Membrane technology for water production in agriculture: Desalination and waste water reuse," Desalination **364** (2015) 17. http://dx.doi.org/10.1016/j.desal.2015.03.001.

[7] R.S. Ayers, "Quality of water for irrigation," Journal of Irrigation and Drainage Div. ASCE **103**, (1977) 135. https://doi.org/10.1023/A:1005834807873.

[8] W. Silvert, "Fuzzy indices of environmental conditions" Ecological Modelling **130** (2000) 111. https://doi.org/10.1016/S0304-3800(00)00204-0

[9] W. Ocampo-Duque, N. Ferre-Huquet, J. L. Domingo, and M. Schuhmacher, "Assessing water quality in rivers with fuzzy inference systems: a case study," Environment International **32** (2006) 733. https://doi.org/10.1016/j.envint.2006.03.009.

[10] S. Lio and S. L. Lo, "A fuzzy index model for trophic status evaluation of reservoir waters," Water Research **96** (2004) 35. https://doi.org/10.1016/j.watres.2005.01.014..

[11] S. Dahiya, D. Datta and H. S. Kushwaha, "A fuzzy synthetic evaluation approach for assessment of physicochemical quality of groundwater for drinking purposes," Environmental Geology **8** (2005) 158. doi:10.1016/j.jhazmat.2007.01.119.

[12] W. O. Duque, N. F. Huguet, J. L. Domingo and M.Schuhmacher, "Assessing water quality in rivers with fuzzy inference systems: a case study," Environment International **32** (2006) 733. https://doi.org/10.1016/j.envint.2006.03.009.

[13] Y. Icaga, "Fuzzy evaluation of water quality classification," Ecological Indicators **7** (2007) 710. https://doi.org/10.1016/j.ecolind.2006.08.002.

[14] S. Ramesh, "An innovative approach of Drinking Water Quality Index–A case study from Southern Tamil Nadu, India," Ecological Indicators **10** (2010) 857. https://doi.org/10.1016/j.ecolind.2010.01.007.

[15] R. Mirabbas, S. M. Mazloumzadeh and M. B Rahnama, "Evaluation of irrigation water quality using fuzzy logic," Res. J. Environ. Sci., **2** (2008) 340. http://dx.doi.org/10.3923/rjes.2008.340.352.

[16] APHA (American Public Health Association), "Standard methods for the examination of water and wastewater" American Public Health Association, Washington DC, USA, 1995, pp. 1467 https://www.scirp.org/reference/ReferencesPapers?ReferenceID=1916575.

[17] Sruthy Sajeev, Selvam Sekar, Binoj Kumar, Venkataraman Senapathi, Sang Yang Chung and Gnanachandrasamy Gopalakrishnan, "Variations of water quality deterioration based on GIS techniques in surface and groundwater resources in and around Vembanad Lake,Kerala,India," Geochemistry **80** (2020), 125626. https://doi.org/10.1016/j.chemer.2020.125626.

[18] L. A. Zadeh, "Fuzzy sets," Inform. Control. **8** (1965) 338. https://doi.org/10.1016/S0019-9958(65)90241-X.

[19] H. Gharib, M. H Sowlat, A. H. Mahvi, H. Mathmoudzadeh, H. Arabalibeik, M. Keshavarz, N.Karimzadeh, G. Hassani, "Development of a dairy cattle drinking water quality index(DCWQI) based on fuzzy inference systems," Ecological Indicators **20** (2012) 228. https//:DOI:10.1016/j.ecolind.2012.02.015.

[20] E. N. Nasibov, "Aggregation of fuzzy information on the basis of decompositional representation," Cybernetics and system analysis **41** (2005) 309. https://doi.org/10.1007/s10559-005-0065-0.

[21] A. Y. Sangodoyin, and K. Ogedengbe, "Surface water quality and quantity from the standpoint of irrigation and livestock," Int. J. Environ. Stud. **38** (1991) 251. https://doi.org/10.1080/00207239108710670.

[22] S. Ponsadailakshmi, S. Ganapathy Sankari, S. Mythili Prasanna, G. Madhurambal, "Evaluation of water quality suitability for drinking using drinking water quality index in Nagapattinam district, Tamil Nadu in Southern India," Groundwater for sustainable development **6** (2018) 43. https://doi.org/10.1016/j.gsd.2017.10.005.

[23] D. J. Rooney, K. W. Brown and J. C. Thomas, "The effectiveness of capillary barriers to hydraulically isolate salt contaminated soils," Water, Air, and Soil Pollution **104** (1998) 403. https://doi.org/10.1023/A:1004966807950.

[24] M. H. Sowlat, H. Gharibi, M. Yunesian, M. Tayefeh Mahmoudi, S. Lotfi, "A novel, fuzzy-based air quality index (FAQI) for air quality assessment, Atmospheric Environment," **45** (2011) 2050. https://doi.org/10.1016/j.atmosenv.2011.01.060.

[25] H. Gharib, M. H. Sowlat, A. H. Mahvi, H. Mathmoudzadeh, H.Arabalibeik, M. Keshavarz, N.Karimzadeh, G. Hassani. "Development of a dairy cattle drinking water quality index(DCWQI) based on fuzzy inference systems," Ecological Indicators **20** (2012) 228. DOI:10.1016/j.ecolind.2012.02.015.

[26] E. Shekariana, A. A. Gholizadeh, "Application of adaptive network-based fuzzy inference system method in economic welfare," Knowledge-Based Systems **39** (2013) 151. https://doi.org/10.1016/j.procs.2016.09.435.

[27] D. Kumar, J. Singh, O. P. Singh and Seema "A fuzzy logic-based decision support system for evaluation of suppliers in supply chain management practices," Mathematical and Computer Modelling **57** (2013) 2945. DOI:10.1504/IJLSM.2020.10041107.

[28] F. Camastra, A. Ciaramella, V. Giovannelli, M. Lener, V. Rastelli, A. Staiano, G. Staiano and F. Starace, "A fuzzy decision system for genetically modified plant environmental riskassessment using Mamdani inference," Expert Systems with Applications **42** (2015) 1710. https://doi.org/10.1016/j.eswa.2014.09.041.

[29] E. Pourjavad, R. V. Mayorga, "A comparative study and measuring manufacturing system performance with Mamdani fuzzy inference system," Journal of Intelligence Manufacturing **30** (2017) 1085. https//:Doi:10.1007/s10845-017-1307-5.

[30] I. B. Turksen, "Measurement of membership functions and their acquisition," Fuzzy Sets Syst. **40** (1991) 5. https://doi.org/10.1016/0165-0114(91)90045-R.

[31] D. Park, A. Kandel and G. Langholz, "Genetic-based new fuzzy reasoning models with application to fuzzy control," IEEE Trans. Syst. ManCybem., **24** (1994) 39. https//:DOI:10.1109/21.259684.

[32] S. Ponsadai Lakshmi, R. Deepa , S. Ganapathy Sankari, and M. Jeyachandran, "Pollution Status of Groundwater Resources Through Hydrochemical Characteristics - A Case Study From Southern India," Journal of the Nigerian Society of Physical Sciences **4** (2022) 751. https//:DOI:10.46481/jnsps.2022.751.

[33] C. Gopi, A. Charles, C. Manivannan, S. Ponsadai Lakshmi, Adwin Jose and M. Muthiyan, "Physico-chemical and Trace metal Analysis in Ground water of Nagapattinam region in Nagapattinam district of Tamil Nadu state," Journal of the Nigerian Society of Physical Sciences **5** (2023) 1160. https://doi.org/10.46481/jnsps.2023.1160.