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Fuzzy system modelling to assess water quality for irrigation purposes

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Abstract: This study attempts to find a fuzzy logic system for assessing the quality of water in water treatment plants (WTPs) providing water for irrigation purposes in the Basrah Governorate (South of Iraq). Each month, samples are taken in each of six major WTPs to measure electrical conductivity (*EC*), and the content of sodium, magnesium and calcium. The calculated value which is the sodium adsorption ratio (*SAR*) is plotted with *EC* on the Richard diagram. *SAR* and *EC* values are combined together in a fuzzy inference system (FIS) to find out a quality number called the fuzzy irrigation water quality index number (*FIWQI*) which ranges from zero to one. The higher the value of the index, the better water quality. The Richard diagram, which helps to classify irrigation water, is used to adjust FIS components. Results show that the *FIWQI* for all WTPs changes depending on location and season. It ranges between 0.114–0.170, 0.120–0.190, 0.114–0.170, 0.114–0.202, 0.118–0.500 and 0.46–0.500 for Al-Bradhaia 1, Al-Jubaila 1, Shatt Al-Arab, Garmmah 1, Al-Rebat, and Old Shauaibah WTPs, respectively. The results indicate that WTPs effluent drawn from the Shatt Al-Arab River has poor water quality for irrigation purposes, except for an Old Shauaibah which receives water from another source called a sweet water canal. FIS results are compared with values obtained from the Richard diagram and 96% degree of compatibility between the two methods is attained. This indicates that FIS is an acceptable method for water quality classification.

Keywords: Fuzzy Inference System, irrigation water quality, Richard diagram, sodium adsorption ratio

INTRODUCTION

Irrigation does not depend only on a sufficient quantity of water, but also on its good quality which is a crucial factor regarding the yield and maintenance of soil productivity [Laze *et al.* 2016]. The Basrah Governorate (south of Iraq) lies mainly along the western bank of the Shatt Al Arab River (SAAR). In recent decades, the Basrah Governorate has had a problem with water quality (WQ), because it depends on the SAAR, the main source for most water treatment plants (WTPs) in the governorate. The increase in SAAR salinity started in the 1960s, then the situation of the river worsened in the 1970s onwards when regulators, dams and reservoirs were established on the Euphrates and Tigris Rivers [Ahmed, Dawood 2016].

Most major WTPs in the Basrah Governorate are located near the banks of the SAAR. Thus, it is the main source of water for the WTPs. Due to the rise of total dissolved solids (*TDS*) values to more than 2500 mg·dm^{-3} and the degree of pollution, another source of water was established in the 1990s. It is an excavated Sweet Water Canal (SWC) conveying water from the Garraf River (branch from Tigris) – Figure 1. The canal has a total dissolved solids (*TDS*) value of about 800 mg·dm^{-3} [Hamdan 2016b] which is considered suitable for drinking and domestic purposes, considering that Iraqi standards for drinking water specify the maximum acceptable limit for drinking water as 1000 mg·dm^{-3} [ICS: 13.060.20, IQS: 417].

This raw water is conveyed to a station called R-Zero, which receives water from the SWC and supplies most of the WTPs in Basrah with raw water [Almuktar *et al.* 2020].

The water discharged to Basrah-based WTPs replaces brackish water taken from the SAAR, but sometimes it is mixed with the SAAR when the R-Zero discharge is too little [Al Saad *et al.* 2020].

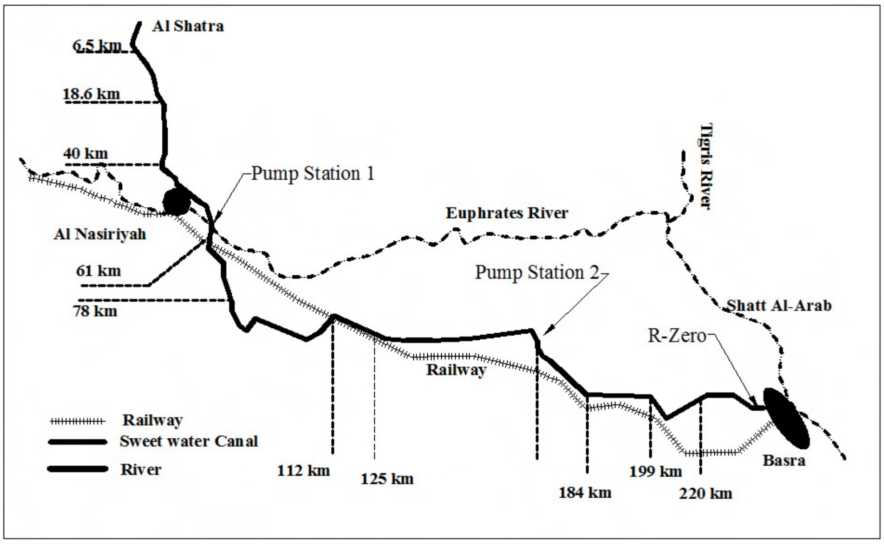

Fig. 1. The Sweet Water Canal route and R-Zero in Basrah Governorate; source: own study

The design capacity of the SWC is 13.1 $m^3 \cdot s^{-1}$, but it cannot carry more than 8 $m^3 \cdot s^{-1}$ to R-Zero due to some failures in the canal causing significant reduction of the canal capacity. The water demand of the Basrah Governorate reaches 15 $m^3 \cdot s^{-1}$ due to a high increase of its population. In 2020, it approached 5 mln people. Therefore, the SAAR is used as an additional source to overcome the shortage of water.

Most of WTPs in Basrah use coagulation, filtration and disinfection. Such treatment is reasonable only for fresh surface water because it does not decrease *TDS* values [HAMDAN 2016b]. A crisis occurred in the summer of 2018 due to a shortage of discharge to the Basrah Governorate either from the SWC or the SAAR. WTPs in Basrah decided to mix raw water received from the SWC with high quantity of raw water from the SAAR due to the deficiency of discharge from R-Zero. This caused an increase in *TDS* values, especially that the SAAR had high *TDS* levels. Laboratory tests in that period recorded tremendous increase in *TDS*s; some of physical, chemical and biological parameters were at a poisonous level for thousands of Basri people.

Generally, the quality of treated water in most of the WTPs of the Basrah Governorate is very poor and it is not suitable for domestic use. Nevertheless, it is sometimes suitable for irrigation. Hence, the people of Basrah usually buy drinking water from private suppliers.

Agricultural land, including domestic and public gardens, depend on tap water for irrigation, but due to the deterioration of WQ in recent years, agriculture has witnessed the worst conditions ever. This was especially true in the summer of 2018, when high *TDS* was recorded in different locations along the SAAR. The good WQ appropriate for irrigation depends on different factors, the most important of which are electrical conductivity (*EC*) and sodium concentration (*SAR*). The suitability of water for irrigation changes depending on crop type, soil permeability, and climate. Therefore, irrigation WQ criteria, developed by the US Salinity Laboratory (USSL), have been adopted in numerous countries [HAMDAN 2016b].

Shortage of water incoming to the SAAR from the Tigris River year by year deteriorates due to established dams, regulators, and reservoirs on the Tigris River in Iraq, and Turkey. This leads to seawater intrusion from the Arabian Gulf towards the SAAR and to *TDS* increase [HAMDAN 2016a]. Thus, *TDS* values increase as it approaches the estuary.

TDS values in the SAAR near the center of Basrah increased from 1,790 $mg \cdot dm^{-3}$ in the year 1997 to more than 20,000 $mg \cdot dm^{-3}$ in the summer of the year 2018. Furthermore, using the SAAR as a discharge point for sewage and agricultural drainage had further aggravated the WQ problem in the river [HAMDAN *et al.* 2019].

Most WTPs in the Basrah Governorate are old, have limited capacity, and need overall maintenance or comprehensive rehabilitation to produce reasonable WQ.

The US Salinity Laboratory Staff sets standards for irrigation water. WQ classification methods evaluate water applicability for different purposes. By making tests for required physical and chemical parameters and projecting parameters into a graph (such as US salinity diagram or Richard diagram), WQ could be classified. The process, however, may produce inaccurate results, as parameters which are near or far from the limit have equal importance for the assessment of concentration, or two samples lie in the same zone. Thus, it is not easy to determine which sample has the best WQ.

When the parameter is located near a class border, i.e. the separator boundary, WQ may not be identified, and thus, the sample can be assigned to an incorrect class. To overcome this limitation, FIS can be used, which provides a mathematical tool that can convert a complex set of linguistic assessment variables into an automatic assessment strategy. Fuzzy logic is a mathematical system based on the theory of the fuzzy set and expresses a multi-level process between 0 and 1 instead of two levels in classical mathematics [MIRABBASI *et al.* 2008].

Although, many studies have been provided to calculate WQ for groundwater and surface water in Iraq, few studies concentrated on water used for irrigation, especially in the Basrah Governorate. Some researchers resorted to the Fuzzy logic technique to calculate the quality of water used for irrigation.

MIRABBASI *et al.* [2008] used fuzzy logic to assess the quality of water used for irrigation in the Sirjan aquifer (Iran). They used the Richard diagram and FIS and got 84% agreement between their calculations. PRIYA [2013] used a fuzzy inference system (FIS) to assess the quality of water used for irrigation in the

Karunya Watershed, India. Initially, he used FIS depending on two parameters, *EC* and *SAR*. His results were compatible with the USSL classification system, then the FIS used four parameters, i.e. *SAR*, *EC*, chloride, and sulphate instead of two (*EC* and *SAR*). OSTOVARI *et al.* [2015] compared the FIS with the USSL methods (using Richard diagram), to classify groundwater used for irrigation in the Marvdasht aquifer. Then, they discovered the spatial distribution of irrigation groundwater quality using the FIS output. They sampled 49 agricultural wells and determined *EC* and *SAR*. Results of their comparison showed that the FIS technique was acceptable for assessing the irrigation water. HAMDAN [2016b] investigated the quality of treated water for irrigation purposes of major WTPs in the Basrah Governorate. In 2013, he tested twelve physical and chemical parameters and calculated the *SAR* and plotted *EC* and *SAR* on the Richard diagram. He also used the Piper diagram for water classification. His results showed that the Al-Maqil station had a reasonable WQ for irrigation. Since the station's location is in the north of the Basrah center, there is a slight effect of salinity wedge that comes from the Arabian Gulf. Other WTPs showed bad WQ. DAWOOD *et al.* [2018] examined five stations along the SAAR and tested twelve physicochemical parameters for each sample in the summer and winter of 2014 and calculated the *WQI*. The objective of their study was to evaluate the quality of water used for irrigation, drinking, and aquatic life. Results showed that the water was poor to unsuitable for drinking, irrigation, and support of aquatic life. YASEEN *et al.* [2019] selected two stations along the Garmat Ali River (tributary to SAAR in Basrah, Iraq) for testing some parameters, including pH, *EC*, *TDS*, Na, K, Ca, Mg, HCO_3, SO_4, Cl, and NO_3. The testing took place in January and March of 2019 and checked the suitability of water from the Garmat Ali River for irrigation. Results showed that the river water was unsuitable for irrigation.

The aims of this study are (1) develop a fuzzy irrigation water quality index (*FIWQI*) based on the Richard diagram to assess and classify water from Basrah-based water treatment plants and its use for irrigation, and (2) compare the FIS with the USSL method to evaluate the WTPs in the Basrah Governorate and the use of water for irrigation.

MATERIALS AND METHODS

STUDY AREA

In this study, six major WTPs that supply the Basrah Governorate with water were selected to study the quality of water used for irrigation (Fig. 2). Details of these WTPs are shown in Table 1. Figure 2 shows that most of the WTPs are built near to SAAR banks. The SAAR is considered to be the main fresh water source, but due to the deterioration of WQ, as determined at the R-Zero station which supply water from the SWC (Fig. 1), SAAR has become as a secondary source used only when the R-Zero station decreases its discharge [ALMUKTAR *et al.* 2020].

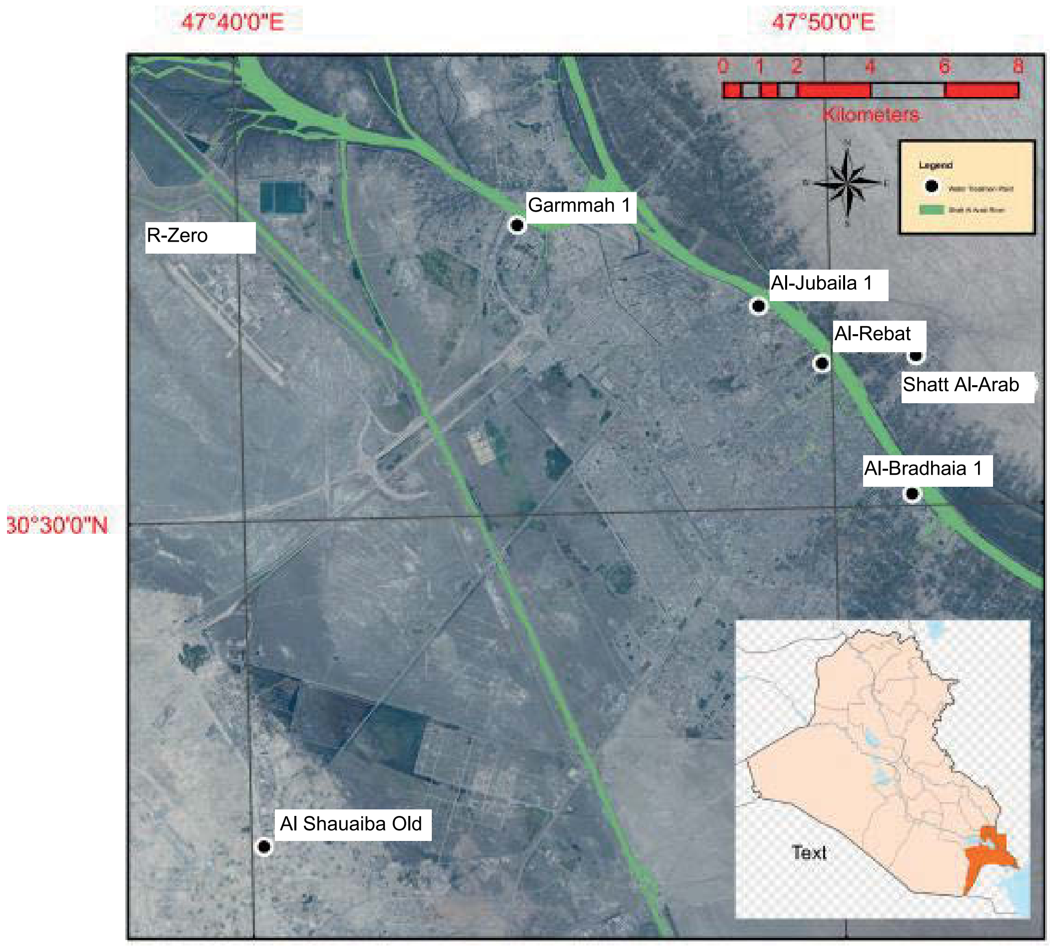

Fig. 2. The main water treatment plants in Basrah; source: own study

Table 1. Characteristics of water treatment plants in Basrah city

No.	Name	Longitude (E)	Latitude (N)	Year	Capacity ($m^3 \cdot s^{-1}$)	Water source
1	Al-Bradhaia 1	47.855	30.503	1958	0.231	SWC & SAA
2	Al-Jubaila 1	47.813	30.550	1986	0.231	SWC & SAA
3	Shatt Al-Arab	47.857	30.537	1976	0.231	SWC & SAA
4	Garmmah 1	47.746	30.571	1986	0.370	SWC & Garmat Ali
5	Al-Rebat	47.831	30.536	1986	0.139	SWC & SAA
6	Old Shauaibah	47.670	30.420	1968	0.185	SWC

Explanations: SWC = sweet water canal, SAA = Shatt Al-Arab.
Source: HAMDAN [2016b].

SAMPLING AND ANALYSIS

Monthly samples were taken from the effluent of each WTPs in 2018. Four parameters, namely electrical conductivity (*EC*), and content of sodium (Na^+), magnesium (Mg^{2+}), and calcium (Ca^{2+}), were tested using standard procedures, following guidelines from "Examination of water and wastewater" (APHA 2012) [CLESCERI *et al.* (eds.) 1989]. The collecting and testing of the samples were done by the water directorate in the Basrah Governorate.

USING THE RICHARD DIAGRAM FOR THE EVALUATION OF THE TREATED WATER USED FOR IRRIGATION

The quality of irrigation water was determined based on two important parameters, i.e. electrical conductivity (*EC*) (which represents salinity hazard) and the sodium adsorption ratio (*SAR*) (which represents sodicity hazard). The *SAR* is calculated using Equation (1) [AL-MAMOORI, AL-MALIKI 2016]:

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{++}+Mg^{++}}{2}}} \quad (1)$$

where: Na^+, Ca^{2+}, and Mg^{2+} are the concentrations ($meq \cdot dm^{-3}$), then the Richard diagram was used for evaluating the treated water.

The diagram suggested by the US Salinity Laboratory Staff for classifying irrigation water is called the USSL diagram or the Richard diagram, which is the most common method based on *SAR* and *EC* values ($\mu S \cdot cm^{-1}$) to classify the quality of water used for irrigation (Tab. 2). Four types of *EC* and *SAR* were used for water classification with grading of excellent, good, satisfactory, and bad. Figure 3 is the Richard diagram which shows the combined effect of the *EC* (salinity hazard) in the *x*-axis and *SAR* (sodium hazard) in the *y*-axis [AYERS, WESTCOT 1985]. The diagram was grouped into sixteen zones that were used to evaluate water with regards to the rise in salinity and undesirable ion-exchange effects in the soil structure [NISHANTHINY *et al.* 2010]. Table 3 clarifies the water sample classification based on the USSL diagram.

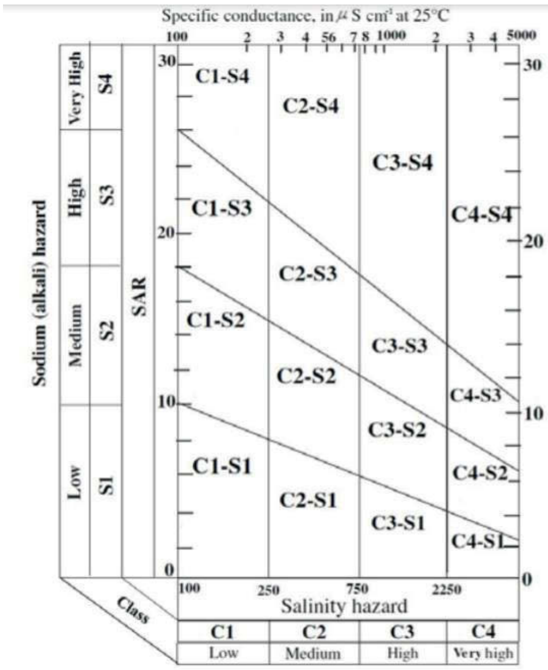

Fig. 3. Richard diagram for classification of irrigation water; source: VADIATI *et al.* [2019]

Table 2. US Salinity Laboratory Staff (USSL) classification for sodium adsorption ratio (*SAR*) and electrical conductivity (*EC*)

SAR	USSL class	Suitability	*EC* ($\mu S \cdot cm^{-1}$)	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

Source: JEON *et al.* [2020].

Table 3. Irrigation water classification according to the Richard diagram

Index	Water class	Index	Water class
C1S1	excellent	C3S1	admissible
C1S2	good	C3S2	marginal
C1S3	admissible	C3S3	marginal
C1S4	poor	C3S4	poor
C2S1	good	C4S1	poor
C2S2	good	C4S2	poor
C2S3	marginal	C4S3	very poor

Source: HAMDAN [2016b].

THE FUZZY INTERFACE SYSTEM (FIS)

The FIS was used to obtain a fuzzy irrigation water quality index (*FIWQI*). The index ranges from zero to one, with WQ being the best when the number is close to one [MIRABBASI *et al.* 2008]. The FIS is formulated using Matlab software, the model inputs were the *EC* and *SAR* and the output was *FIWQI*. Matlab software contains two types of FIS which were Mamdani and Sugeno, Mamdani fuzzy interface system (MFIS). Based on the research, it describes the process states by linguistic variables and uses these variables as inputs to control rules [ABDULLAH *et al.* 2008]. From Figure 4, it can be shown the FIS block diagram that transmits input data (crisp non-fuzzy) into linguistic variables and the limits of these data form fuzzy datasets. It is a connection between real parameters and the fuzzy system, and it transforms the output set to a non-fuzzy (crisp) one. The FIS uses defined rules and develops fuzzy outputs from the inputs. The defuzzifier processes fuzzy output variables into real-world variables that can be used to control a real-world application. The defuzzification process is a reverse of fuzzification [OSTOVARI *et al.* 2015].

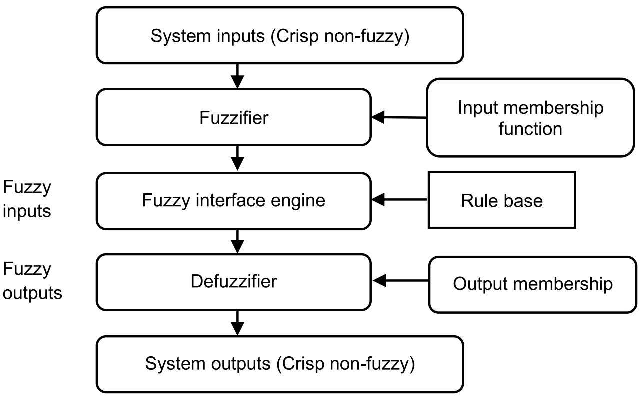

Fig. 4. Block diagram of the fuzzy interface system; source: PRIYA [2013]

MEMBERSHIP FUNCTION (MF)

The MF is a curve that determines the validity of a given statement for a given input value. It defines how each point in the input space is set to a membership value (or membership degree) from zero and one (Math Works, Applications of Fuzzy Logic in Control Design).

The Richard diagram was used to justify the MF by comparing its results with fuzzy inputs to get the best MF. Based on Figure 3, MFs were specified to two variable inputs (*EC* and *SAR*) as shown in Figure 5, and Figure 6. Figure 5 shows the MF of the *EC* (input No. 1), where MF's with low (0–350), medium (200–900), high (600–3000) and very high (1650–30000) values. Figure 6 shows the MF of the *SAR* (input No. 2), with MF low (0–9), medium (2–17), high (6–25) and very high (11–40) values. The output MFs, shown in Figure 7, were chosen for WQ assessment. The figure shows the *FIWQI* (output) and MF's with very bad (0–0.30), bad (0.15–0.45), medium (0.30–0.70), good (0.55–0.85) and very good (0.70–1.00) water quality.

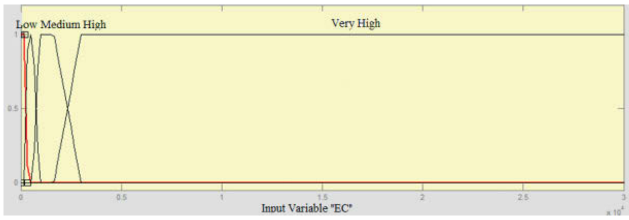

Fig. 5. Graph of the electrical conductivity (*EC*) membership functions; source: own study

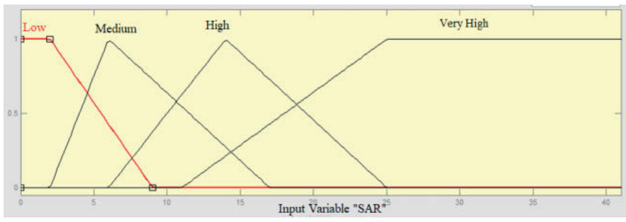

Fig. 6. Graph of the sodium adsorption ratio (*SAR*) membership functions; source: own study

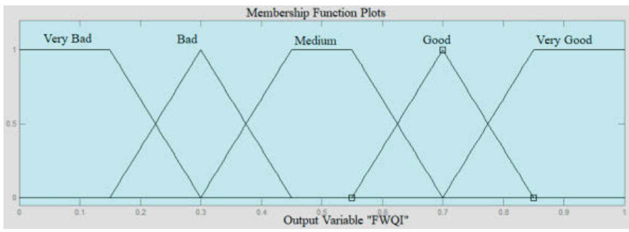

Fig. 7. Graph of the irrigation water quality membership functions; source: own study

FUZZY RULES DETERMINATION

Specialists have classified WQ according to specific rules [HAMDAN 2016b]. Based on the MF, inputs (*EC*, and *SAR*) were justified by the Richard diagram and 16 rules used in the study. These are shown in Table 4.

RESULTS AND DISCUSSION

Six major WTPs in Basrah were chosen for the assessment, including station 1 (Al-Bradhaia 1), station 2 (Al-Jubaila 1), station 3 (Shatt Al-Arab), station 4 (Garmmah 1), station 5 (Al-Rebat), and station 6 (Old Shauaibah). The samples of treated water were taken once per month from each of WTPs in 2018. The samples were analysed for *EC*, Na^{+}, Mg^{2+} and Ca^{2+}. Then,

Table 4. Fuzzy rules development

Electrical conductivity	Sodium adsorption ratio			
	low	**medium**	**high**	**very high**
Low	very good	good	medium	bad
Medium	good	good	bad	bad
High	medium	medium	very bad	very bad
Very high	bad	bad	very bad	very bad

Source: MIRABBASI *et al*. [2008].

the mean value of these parameters was calculated for each season. The values of Na^+, Ca^{2+}, and Mg^{2+} were used to calculate the *SAR* according to Equation (1).

A comparison of the mean values with other WTPs for each season are shown in Figures 8–11.

Figures 8–11 show that the maximum values of Na^+, Ca^{2+}, Mg^{2+} and *EC* in all seasons of 2018 were in station 1. It was due to the effect of salinity intrusion from the Arabian Gulf [HAMDAN *et al*. 2020] and because of contamination from sewage and the drainage of agricultural land [HAMDAN *et al*. 2018] in the vicinity of the station, a station which is the closest to the estuary. Station 6 showed minimum values of Na^+, Ca^{2+}, Mg^{2+} and *EC*, except for autumn. This revealed a convergence of station 6 and 5, since the source for station 6 is the SWC.

Na^+ and *EC* values show a high variability between the stations, but Ca^{2+}, Mg^{2+} show convergent values between the stations.

The Grapher software was used to draw the relation between salinity hazard (*EC*) and sodium hazard (*SAR*) in the Richard diagram for each season in 2018. Then, the quality of irrigation water could be classified depending on the location of the point in the diagram. The assessment of water can be determined according to Table 3 (Fig. 12).

Figure 12 shows that stations 1, 2 and 3 are located in the C4S4 zone. During all seasons, water there had very bad water quality. Station 4 was located in the C4S3 zone in spring and C4S4 in other seasons, which represented very bad water quality. Station 5 was located in the C4S2 zone in winter, C4S4 in spring, C3S1 in summer and autumn, which represented bad, very bad, and medium water quality, respectively. Station 6 was located in the C3S1 zone, which represented medium water quality in all seasons.

Calculated values for each season were used in the FIS to determine the *FIWQI* using a Simulink library of MATLAB (R2012a).

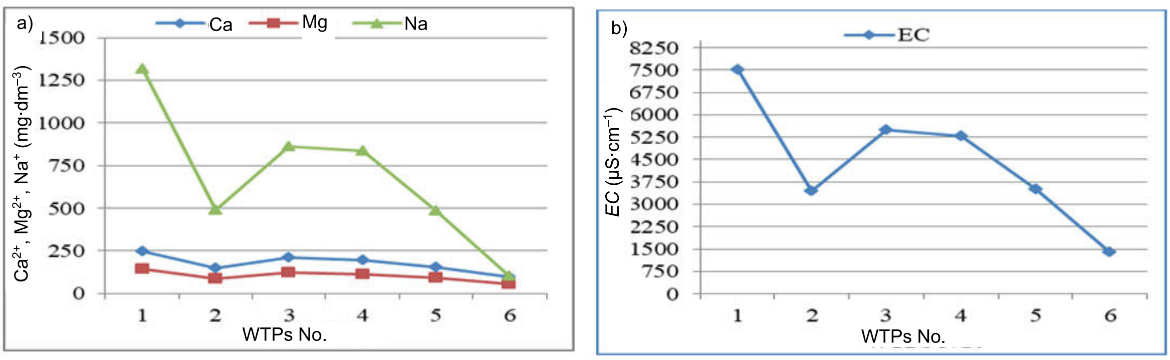

Fig. 8. Mean values of chosen parameters for the considered wastewater treatment plants (WTPs) in summer 2018: a) Ca^{2+}, Mg^{2+}, and Na^+, b) electrical conductivity (*EC*); source: own study

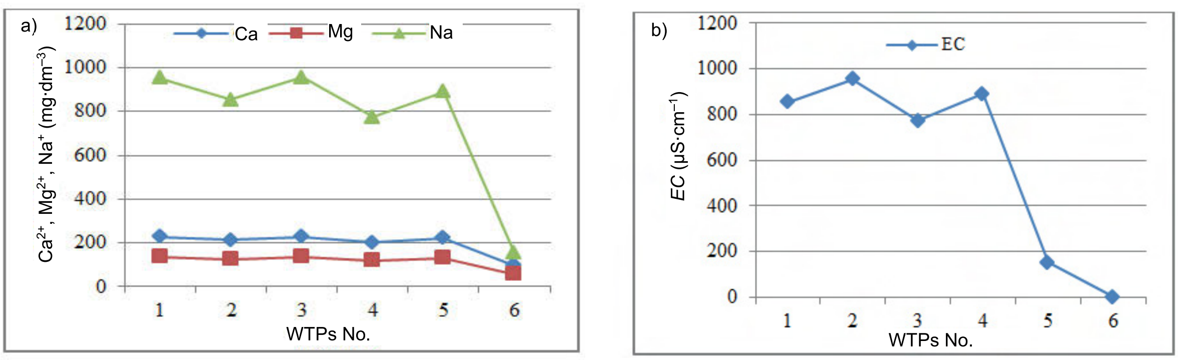

Fig. 9. Mean values of chosen parameters for the considered wastewater treatment plants (WTPs) in spring 2018: a) Ca^{2+}, Mg^{2+}, and Na^+, b) electrical conductivity (*EC*); source: own study

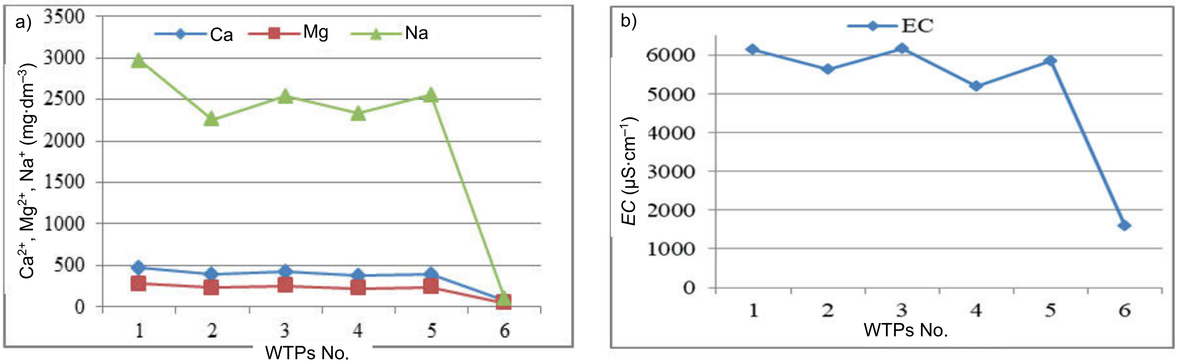

Fig. 10. Mean values of chosen parameters for the considered wastewater treatment plants (WTPs) in summer 2018: a) Ca^{2+}, Mg^{2+}, and Na^{+}, b) electrical conductivity (*EC*); source: own study

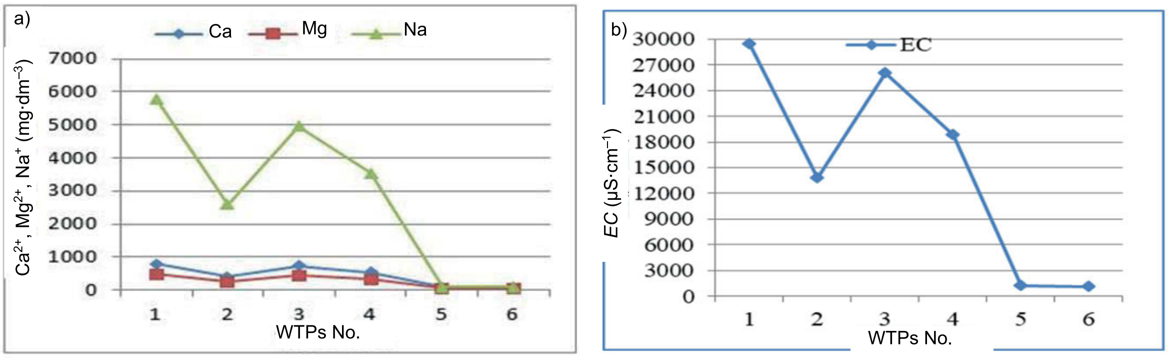

Fig. 11. Mean values of chosen parameters for the considered wastewater treatment plants (WTPs) in autumn 2018: a) Ca^{2+}, Mg^{2+}, and Na^{+}, b) electrical conductivity (*EC*); source: own study

The MFs block and fuzzy logic controller with rule viewer were used from a fuzzy logic toolbox along with the Mux block from commonly used blocks and a display sink to visualize results.

Al-Bradhaia 1 (Station No. 1) is shown in the Simulink workspace, rule viewer, and surface viewer for winter 2018 in Figures 13, 14, and 15, respectively.

Figure 16 shows *FIWQI* results for the six WTPs during four seasons of 2018. Their ranges changed between 0.114–0.170, 0.120–0.190, 0.114–0.170, 0.114–0.202, 0.118–0.500, and 0.462–0.500 for station 1 (Al-Bradhaia 1), station 2 (Al-Jubaila 1), station 3 (Shatt Al-Arab), station 4 (Garmmah 1), station 5 (Al-Rebat), and station 6 (Old Shauaibah), respectively.

From Table 5, it can be noted that each station has a special value of the *FIWQI*. It indicates the actual water quality for irrigation purposes at a specified season, while the assessment results in the Richard diagram (acc. to RICHARDS (ed.) [1954]) gives further general description for water quality. Results of the comparison indicate that the Richard diagram classification does not give an accurate distinction of water quality between stations and does not show how the quality of water varies between seasons.

Using the FIS method, according to *SAR* and *EC* of each water sample, a score is assigned between 0 and 1. Whenever the fuzzy score of the sample become increases, the quality for irrigation is better. For example, Table 5 shows the sample from the effluent of the water treatment plant at Garmmah 1 in winter and spring. The water is C4S4 class (very bad), but the difference between the sample and all of other samples is not clear based on the Richard diagram. Nevertheless, the FIS goes further and provides values between 100 and 66% for the very bad class, i.e. there is a difference between the two samples using the FIS method. In the winter season, WQ is reads 100% at Garmma 1 in very bad water quality, whereas in spring it is 66% in the very bad class and 34% in bad class. Thus, the system enables to grade the results.

In general, WQ seems to be the worst in summer in all WTPs in comparison with the other seasons, except for station 6 (Old Shauaibah) which has a medium WQ. The causes of medium WQ at this station is the feeding from R-zero station with water from the SWC that has better water quality. However, the other stations which abstracted raw water from the SAAR encountered high salinity.

Al-Rebat 1 had to some extent better WQ in winter and autumn as compared with other stations that took raw water from the SAAR. The reason might be its location is in the northern side of the Basrah center and the fact that salinity intrusion from the Arabian Gulf vanished especially in winter and autumn when high flow rate occurs in the river.

In general, stations 1–4 had very bad water properties in all seasons as shown in Table 5.

Al-Bradhaia 1 (station No. 1), Al-Jubaila 1 (station No. 2) and Shatt Al-Arab (station No. 3) had bad WQ because of salinity intrusion from the Arabian Gulf and pollution from wastewater discharged to the SAAR from tributary creeks. Additionally, Garmmah 1 (station No. 4) had bad WQ because of its location on the right bank of the Garmmah River, which is considered a contaminated river with a high level of *TDS*.

The comparison between results in the Richard diagram and FIS in Table 5 reveals the degree of matching between treated water using the Richard diagram and FIS. This degree was

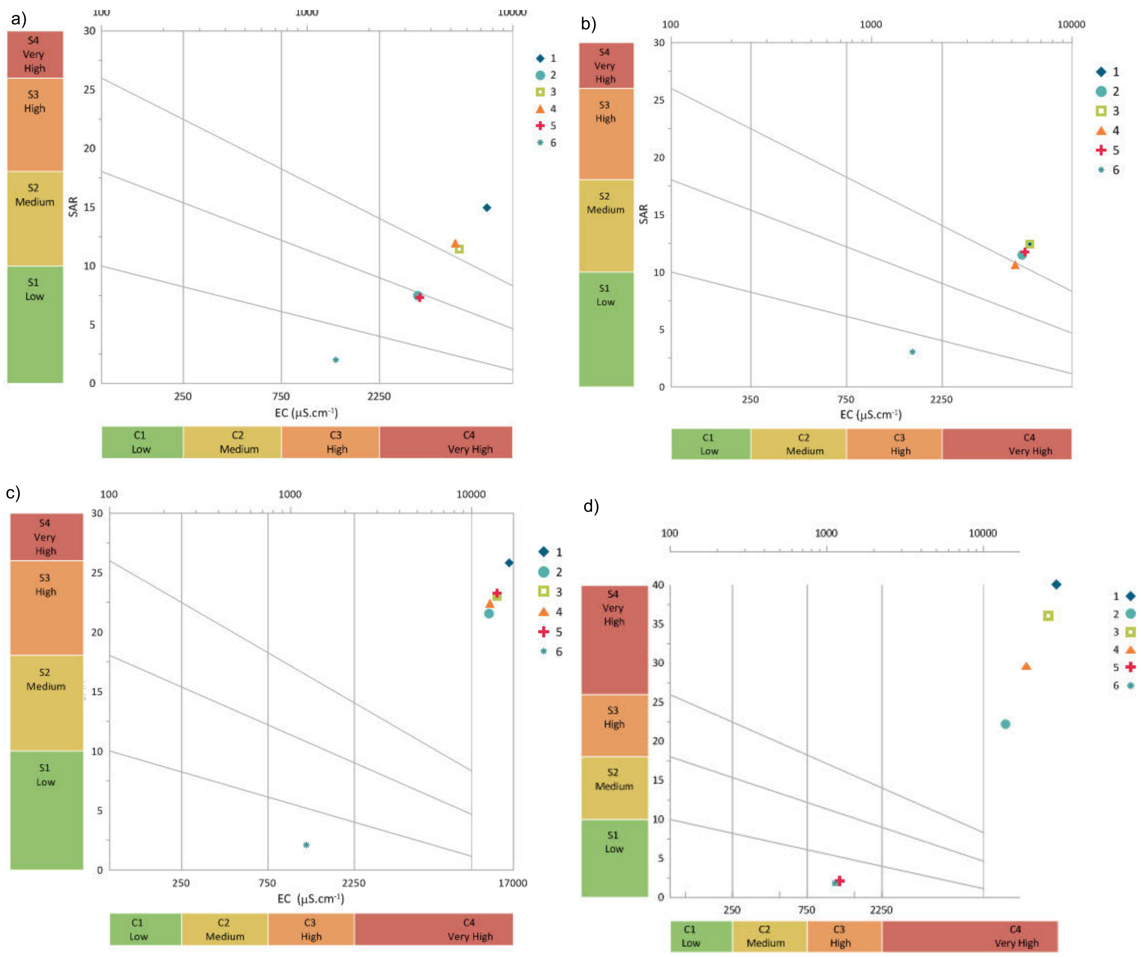

Fig. 12. Classification of salinity (expressed by electrical conductivity – *EC*) and sodium (expressed by sodium adsorption ratio – *SAR*) hazard for the six wastewater treatment plants (WTPs) samples for irrigation according to the Richard diagram in each season of 2018: a) winter, b) spring, c) summer, d) autumn; sodium alkali hazard: S1 = low, S2 = medium, S3 = high, S4 = very high, salinity hazard: C1 = low, C2 = medium, C3 = high, C4 = very high; source: own study

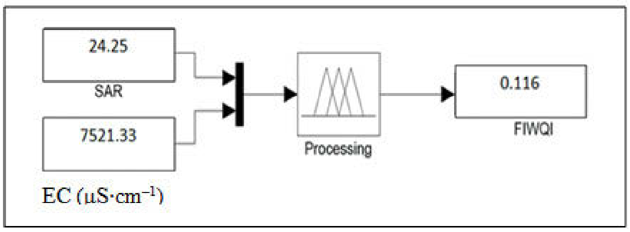

Fig. 13. Simulink sketch for Al-Bradhaia (Station No. 1) during the winter of 2018; *EC* = electrical conductivity; *FIWQI* = fuzzy irrigation water quality index; source: own study

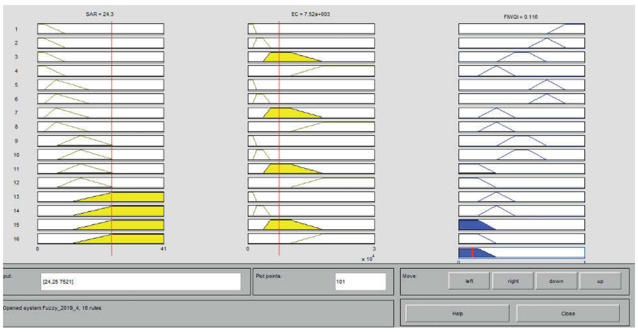

Fig. 14. Rule viewer for Al-Bradhaia1 (station No. 1) during the winter of 2018; *EC* = electrical conductivity, *SAR* = sodium adsorption ratio, *FIWQI* = fuzzy irrigation water quality index; source: own study

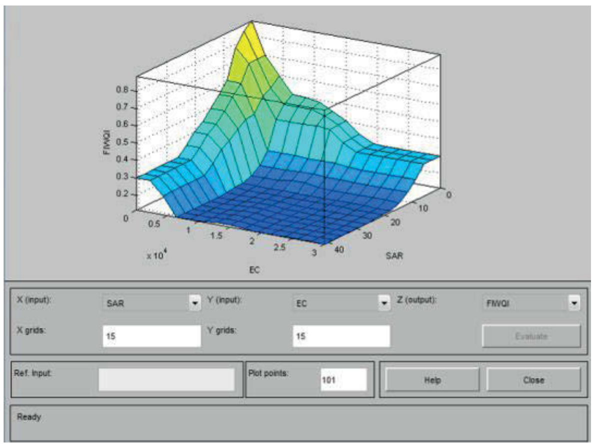

Fig. 15. The surface viewer of fuzzy irrigation water quality index (*FIWQI*) in Al-Bradhaia 1 (station No. 1) during the winter of 2018; source: own study

obtained by projecting the *FIWQI* value (column 5) on its MF (Fig. 7) and calculated fuzzy assessment (column 6), and then comparing results obtained with the Richard diagram (column 7). The degree of matching is calculated for each station and season (column 9), and then the average of column 9 is calculated; the average degree of matching was about 96%.

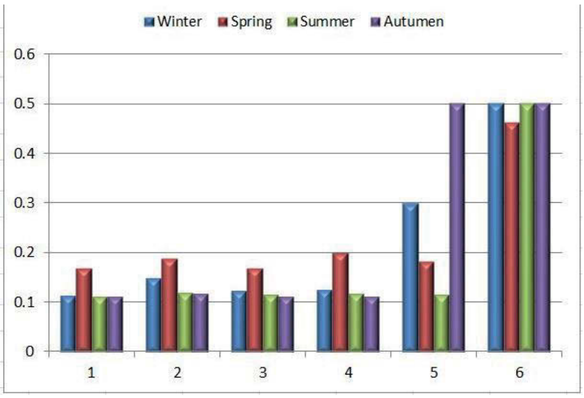

Fig. 16. Fuzzy irrigation water quality index (*FIWQI*) for water treated in the six stations; source: own study

CONCLUSIONS

1. A new method using the fuzzy inference system (FIS) has been used to assess and classify the effluent of main wastewater treatment plants (WTPs) in Basrah used for irrigation purposes.

2. The effluent water of the main WTP's in Basrah has been assessed using the Richard diagram and FIS method. Results show that the assessment using the FIS is more accurate than the Richard diagram, and it provides a good representation of the water quality status.

3. Results of the Richard diagram and FIS approach indicate a matching of about 96% between them.

Table 5. Assessment results of the fuzzy irrigation water quality index (*FIWQI*) and US Salinity Laboratory (USSL) diagram for the water treatment plant (WTPs)

Date	WTP No.	*SAR*	*EC*	*FIWQI*	Fuzzy assessment (Fig. 7)	USSL class	USSL assessment	USSL-FIS degree of matching (%)
Winter 2018	Al-Bradhaia 1	24.25	7521.33	0.116	100% in very bad	C4-S4	very bad	100
	Al-Jubaila 1	14.07	3458.67	0.150	100% in very bad	C4-S4	very bad	100
	Shatt Al-Arab	19.92	5504.00	0.125	100% in very bad	C4-S4	very bad	100
	Garmmah 1	16.68	5279.00	0.127	100% in very bad	C4-S4	very bad	100
	Al-Rebat	4.68	3517.67	0.300	100% in very bad	C4-S2	bad	100
	Old Shauaibah	2.06	1386.33	0.500	100% in very bad	C3-S1	medium	100
Spring 2018	Al-Bradhaia 1	12.39	6137.33	0.170	77% in very bad and 23% in bad	C4-S4	very bad	77
	Al-Jubaila 1	11.46	5637.33	0.190	72% in very bad and 28% in bad	C4-S4	very bad	72
	Shatt Al-Arab	12.41	6182.33	0.170	77% in very bad and 23% in bad	C4-S4	very bad	77
	Garmmah 1	10.60	5188.67	0.202	66% in very bad and 34% in bad	C4-S3	very bad	66
	Al-Rebat	11.75	5854.67	0.184	75% in very bad and 25% in bad	C4-S4	very bad	75
	Old Shauaibah	3.07	1597.33	0.462	100% in medium	C3-S1	medium	100
Summer 2018	Al-Bradhaia 1	25.79	16032.00	0.114	100% in very bad	C4-S4	very bad	100
	Al-Jubaila 1	21.51	12487.67	0.121	100% in very bad	C4-S4	very bad	100
	Shatt Al-Arab	23.02	13891.33	0.118	100% in very bad	C4-S4	very bad	100
	Garmmah 1	22.37	12608.67	0.120	100% in very bad	C4-S4	very bad	100
	Al-Rebat	23.22	13850.67	0.118	100% in very bad	C4-S4	very bad	100
	Old Shauaibah	2.13	1226.67	0.500	100% in medium	C3-S1	medium	100
Autumn 2018	Al-Bradhaia 1	40.14	29403.33	0.114	100% in very bad	C4-S4	very bad	100
	Al-Jubaila 1	22.28	13835.67	0.120	100% in very bad	C4-S4	very bad	100
	Shatt Al-Arab	36.09	26042.33	0.114	100% in very bad	C4-S4	very bad	100
	Garmmah 1	29.72	18836.67	0.114	100% in very bad	C4-S4	very bad	100
	Al-Rebat	2.12	1200.67	0.500	100% in medium	C3-S1	medium	100
	Old Shauaibah	1.79	1132.33	0.500	100% in medium	C3-S1	medium	100

Explanations: *SAR* = sodium adsorption ratio; *EC* = electrical conductivity, *FIWQI* = fuzzy irrigation water quality index.
Source: own study.

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