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Ground Water Quality Evaluation for Irrigation Purpose: Case Study Al-Wafaa Area, Western Iraq

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ABSTRACT

This study was conducted during the summer season of 2023 to assess the groundwater quality in the Al-Wafaa region of Anbar Province western Iraq for irrigation purposes.18 water samples were collected from 18 wells Distributed in the study area. pH, EC, Total Dissolved Solid (TDS), main cations, and anions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, NO_3^-) were measured. The main cations were used to calculate the Percent Sodium (%Na) and Sodium Adsorption Ratio (SAR). Additionally, Wilcox and United States Salinity Laboratory (USSL) diagrams were employed to evaluate the suitability of the groundwater for irrigation. The study found that based on the EC values; all groundwater in the research area is classified as having very high salinity and is therefore not suitable for irrigation. Based on the Wilcox diagram, 83% of the well water samples in the Al-Wafaa region are classified as unsuitable for irrigation, and 17% fall within a doubtful to unsuitable category. According to the USSL diagram, 22% of groundwater samples are in the C4S3 category, indicating very high salinity with high sodium. Additionally, 61% of samples fall into the C4S2 category, suggesting very high salinity with medium sodium, and 17% of samples fall into the (C4S1) category, indicating very high salinity with low sodium. Overall, the findings indicate that the samples are not suitable for crop watering.

1. INTRODUCTION

In many countries of the world, groundwater is an important source for irrigation of agricultural lands, so groundwater quality evaluation has become a necessary task for managing groundwater quality in the future. In Iraq, the water of the Tigris and Euphrates rivers is considered an important source of drinking water, crop irrigation, and other purposes, but in recent years many problems have appeared that affected the river water quality such as the lack of rainfall and increased pollution. Therefore, it is necessary to search for other sources of water and hydrological evaluation of the well water location. Well water is taken into consideration the high-quality source for irrigating agricultural lands, it is possible to drink, and it is supposed to be dependable and free of contaminants, suspended substances, and sickness-causing microorganisms [1]. Several factors impact the willpower of the suitability charge of water for irrigation, together with water fine, climate, plant capacity to tolerate excessive salinity, soil type, and water drainage [2]. Modern innovations and techniques were utilized to evaluate and observe groundwater for irrigation. Some of these innovations used included irrigation water indicators like sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) [3]. The Water Quality Index (WQI) is a very suitable and powerful approach to evaluate the appropriateness of water best [4]. Many researchers have investigated the valuation of groundwater to irrigate crops and human utilization, specifically in Iraq and comparable arid regions in the world. Allawi et al. [5] presented research to evaluate groundwater quality within the Alnekheeb basin in western Iraq to perceive an extra applicable and sustainable water delivery. In this research, three groundwater water first-rate signs, hardness, SAR, and salinity, are forecast by employing two primarily based on artificial intelligence fashions, the Radial Basis Neural Network (RBF-NN) and the Probabilistic Neural Network (PNN). Furthermore, this study focused on the impact of enters parameters on the overall performance of the advised models. According to the evaluation results, adding greater information variables may once in a while enhance the efficacy of the advised models in forecasting accuracy. The outcomes indicate that the PNN model has an amazing overall performance in forecasting groundwater water exceptional matrices, outperforming the RBF-NN version. Khudair et al. [6] presented a study in 2021 to assess the quality of groundwater in the Al-Qaim metropolis, western Iraq, to irrigate crops within the research area. The research tested seven places in the study location to determine the effectiveness of irrigation. The pH, electric conductivity (EC), important cations, and anions (K, Na, Mg^2, Ca^2, HCO_3, Cl^-, SO_4), and CO_3 have been determined. The effects revealed that the examined water is suitable for crop watering regarding pH cost and EC. The total hardness values have been modest and did now not represent trouble, and the main cations and anions have been in the acceptable degrees for the indicated classes. The SAR was determined to be in magnificence S1, indicating that the groundwater in the research district is suitable for crop watering. Ghalib [7] conducted research to estimate the quality of groundwater satisfaction in Wasit province, Iraq. The physicochemical traits, consisting of total dissolved strong, important cation and anions, pH, and EC, have been utilized to estimate groundwater high-quality for human use and crop watering by comparing them to World Health Organization and Iraqi standards. TDS, sodium adsorption ratio, residual sodium bicarbonate, permeability index (PI), and magnesium ratio were used to determine irrigation appropriateness. The examined groundwater samples have been oversaturated with carbonate minerals and lacking evaporated minerals. The effects found that almost all of the groundwater samples were hazardous for drinking and irrigation because of salt and salinity risks. The present study has evaluated the quality of groundwater in a 5119 km^2 area in Babylon City, Iraq [8]. This research included well positions, maps, and data about the quality of groundwater provided by way of the special government. The WQI and IWQI were decided for groundwater samples using some characteristics such as EC, Cl-, HCO_3-, Na, and pH. Furthermore, groundwater suitability for watering is assessed by the use of some Indicators which include Kelly's Ratio (KR), SAR, and PI. Water Quality Indicator graphs were made using the Geographical Information System (GIS) surroundings. The findings show that the groundwater inside the research region needs particular treatments to be appropriate for use. Awad et al. [9] focused on studying the hydrogeochemical properties of groundwater, consisting of ion change, salinization, and hydrochemistry in the Green Belt area in northern Najaf province, Iraq. Also targeted the research on the evaluation of the pleasant of groundwater for crop watering based on the IWQI for thirteen parameters and groundwater quality indices such as TDS, EC, SAR, overall hardness (TH), PI, KR, and magnesium hazard ratio (MHR). The results indicate that groundwater inside the research district is incorrect for crop watering. To ensure the sustainability of groundwater applications, a continuous tracking program and appropriate control techniques. Al-Tameemi et al. [10] assessed the quality of groundwater in Kirkuk province, northern Iraq, for human uses, crop watering, leisure activities, and animal uses from 2017 to 2019, using the Canadian Water Quality Index (CWQI) and GIS. The groundwater quality was tested using Iraqi and World Health Organization (WHO) suggestions as well. The Iraqi standards were utilized for drinking water, whereas WHO standards were applied for watering, leisure activities, and animal purposes. Based on the CWQI, groundwater samples were classed as medium in 2017 and 2018, while there was unsafe drinking water detected in 2019. Al-Kubaisi et al. [11] presented an article to assess the groundwater for irrigation in the Al-Dabdaba aquifer in Karbala - Najaf Plateau in Iraq. The research blanketed mapping of the water quality index and the outcomes labeled the groundwater inside the Al-Dabdaba layer as having moderate. Soren et al. [12] used Wilcox and USSL schemes to evaluate groundwater first-class for irrigation and drinking functions in South 24-Parganas in West Bengal, India. The results confirmed that 46% of the samples had been categorized under the coolest to the permissible category and 37% were categorized below the permissible to questionable class. Sadashivaiah et al. [13] applied the technique of SAR, RSC, salinity hazards, and USSL chart to evaluate water for irrigation purposes in Tukur Taluk. The findings from USSL charts showed that the samples are classified as suitable for irrigation purposes and are classified in the suitable range for irrigation from SAR or RSC values. Hydrochemistry of groundwater in the Ain Azel plain, Algeria was used to evaluate groundwater for irrigation and the results showed that most of the samples are located in the area (C3-S1), meaning the risk of salinity is high and the risk of sodium is low [14]. The groundwater quality for irrigation purposes was evaluated in the city of Acarão Basin in Brazil by developing an IWQI depending on several parameters such as (EC, CL, HCO_3, Na) [15]. The study showed the risk of soil salinity and water venomousness in the crops. Siswoyo et al. [16] presented a study to evaluate groundwater to irrigate agricultural lands in the Jombang region, East Java, Indonesia. The study relied on IQWI techniques, and the results classified the groundwater quality between moderate restriction and low irrigation restriction. A study was presented to evaluate the groundwater quality for irrigation of agricultural lands in three villages in Iran using a combination of geographic information systems and the irrigation water quality index [17]. Ketata et al. [18] used IWQI as a device to manage groundwater nice within the El Khairat Deep aquifer inside the Tunisian Sahel. Nastos et al. [19] used artificial neural networks to forecast rainfall intensity for four months. The results simulations from the model showed decent forecasting of rainfall intensity values. Using artificial neural networks (ANN) for forecasting the water level of the Euphrates rivers in western Iraq and the result showed the artificial neural networks can valued water level (t+1) with a high grade accuracy [20]. Modeling approaches used in hydrological and hydraulic processes are required to provide accurate and sustainable water resource management [21].

Al-Waffa area is a semi-desert region with no surface water, so groundwater is essential to meet the water needs for irrigation and drinking purposes. This research aims to assess the groundwater quality for irrigation purposes.

2. STUDY AREA

Al-Wafaa is an area located in western Iraq, west of Anbar province, 50 km west of Ramadi. The study area is located between latitudes (33°23'51" N) and longitudes (42°51'11" E) The area is about 100 km^2 and has a population of about 8000 people. The Euphrates River flows east of the research region shown in Figure 1. The environment of the region is a very hot desert with and dehydrated summer with a high amount of evaporation and a cold season with a reduction in rainfall. It is characterized by simple slop and presence of the seasonal valleys such as Al-Asal Valley [22]. It is affected by the Abu Al-Jir area fault [23]. The area is also rich in bitumen and sulfates and the area is characterized by the presence of an unconfined aquifer consisting of sandstone with fine gravel and mudstone, covered with a layer of gypsum and sandy soil. Groundwater is extracted in this area by drilling wells [24].

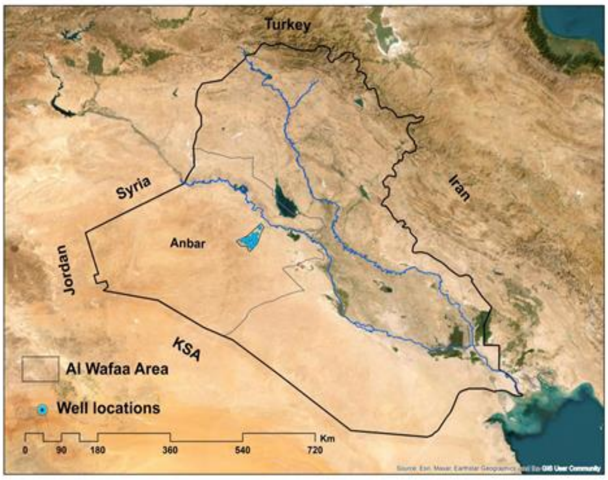

Figure 1. The map of the study area

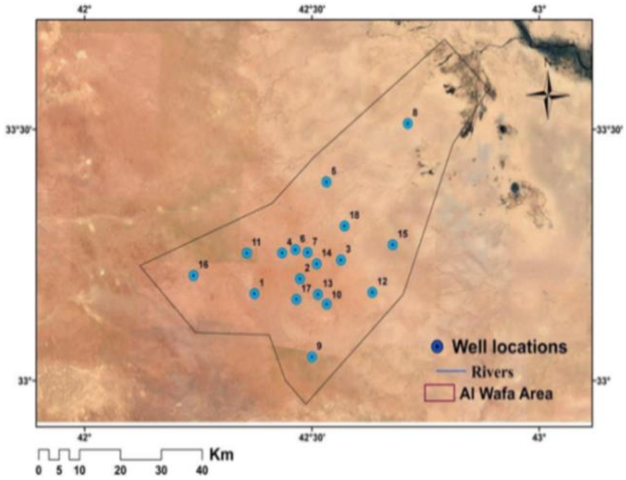

Figure 2. Location of the wells

3. METHODOLOGY

3.1 Collection of samples

Eighteen wells were selected in the study area shown in Figure 2. The wells' coordinates were determined via (GPS) and documented in Table 1. The samples were collected in August 2023 and kept in 2-liter clean and dry plastic bottles and transferred to the water quality control laboratory at the College of Engineering, Anbar University for the measurement of chemical parameters.

3.2 Lab analysis of samples

Water samples were analyzed for chemical parameters: pH, EC, TDS, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Sulphate (SO_4^{-2}), Chloride (Cl^{-1}) and Bicarbonate (HCO_3^{-1}). pH, EC, and TDS are important parameters for assessing groundwater for several purposes. All parameters were examined depending on the Standard Method for the Examination of water and wastewater following (APHA, 1998) American Public Health Association guidelines [25]. Conductivity and pH were measured by using a portable device pH/EC/ meter (HANNA HI9321). TDS, bicarbonate (HCO_3^{-}), chloride (Cl^{-}), magnesium (Mg^{2+}), and calcium (Ca^{2+}) were analyzed by titration methods; potassium (K^{+}) and sodium (Na+) were tested using the flame photometric method by flame photometer (Jenway PFP7); and sulfate (SO_4^{2-}) were analyzed by spectrophotometer (DR 5000 HACH).

Table 1. The coordinates of wells in the Al-Wafaa region

Wells No.	The Coordinates	Wells No.	The Coordinates
1	N 33° 17' 31.57" E 42° 37' 35.40"	10	N 33° 15' 22" E 42° 53' 23"
2	N 33° 20' 28" E 42° 47' 35"	11	N 33° 26' 10" E 42° 43' 24"
3	N 33° 23' 16" E 42° 50' 37"	12	N 33° 25' 42" E 42° 49' 43"
4	N 33° 25' 42" E 42° 43' 43"	13	N 33° 17' 18" E 42° 51' 30"
5	N 33° 25' 54" E 42° 49' 47"	14	N 33° 23' 25" E 42° 51' 03"
6	N 33° 26' 08" E 42° 46' 34"	15	N 33° 25' 19" E 42° 50' 06"
7	N 33° 25' 51" E 42° 49' 04"	16	N 33° 25' 35" E 42° 49' 48"
8	N 33° 23' 33" E 42° 51' 23"	17	N 33° 16' 18" E 42° 46' 56"
9	N 33° 15' 58" E 42° 53' 58"	18	N 33° 25' 20" E 42° 50' 01"

3.3 Calculation of water quality indices for irrigation

There are several key parameters to consider when evaluating the quality of irrigation water. These include pH, salinity levels, bicarbonate concentration (which is related to calcium and magnesium levels), and the presence of components such as sodium and chloride, which can be harmful to plants. To assess the suitability of groundwater for irrigation, water quality indices like the SAR and %Na are commonly used. In addition, graphical methods like the Wilcox diagram and USSL diagram are frequently employed to confirm the suitability of groundwater for irrigation purposes.

3.3.1 SAR

The Sodium Adsorption Ratio is considered an important factor to assess the groundwater quality and it was calculated using the equation given by Raghunath [26]. The ion concentration was measured in (meq/l).

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

3.3.2 %Na

%Na was calculated by the equation given by Todd and Mays [27]. The ion concentration was measured in (meq/l).

$$\%\mathrm{Na} = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100 \tag{2}$$

3.3.3 USSL diagram

Proposed chart for classification of groundwater quality for irrigation purposes. The classification depends on values of SAR and EC [28]. The irrigation water quality is classified as follows (Table 2).

3.3.4 Wilcox diagram

Proposed chart for classification of groundwater for irrigation purposes. The classification depends on values of %Na and EC [29]. The chart is classified into five categories such as: Excellent to Good, Good to permissible. Permissible to doubtful, Doubtful to unsuitable, and Unsuitable.

Table 2. Classification of groundwater for irrigation purposes

Classification of Groundwater for Irrigation Purposes	
EC (ms/cm)	**SAR (mg/l)**
C1 - low salinity risk	S1 - low sodium (alkali) risk
C2 - medium salinity risk	S2 - medium sodium (alkali) risk
C3 - high salinity risk	S3 - high sodium (alkali) risk
C4 It means very high salinity risk	S4 - very high sodium (alkali) risk

Table 3. Analysis results of water samples

Well No.	pH	EC (ms/cm)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	K^{+} (mg/l)	Na^{+} (mg/l)	HCO_3^{-1} (mg/l)	SO_4^{-2} (mg/l)	Cl^{-1} (mg/l)
1	7.19	4220	2734	320	161	29	430	510	674	636
2	7.25	5080	1600	191	121	12	684	164	592	305
3	7.21	5310	3440	216	146	16	708	435	1223	651
4	7.23	5210	3380	206	136	14	698	425	1211	641
5	7.18	5640	3661	387	168	30	533	332	1298	759
6	7.22	4100	2664	212	145	35	458	136	1033	602
7	7.19	5670	3682	389	170	33	535	336	1402	761
8	7.20	2470	3296	188	72	5	251	412	1200	627
9	7.14	6720	4370	429	283	128	495	543	1608	811
10	7.15	6660	4324	424	278	120	490	538	1602	806
11	7.16	5680	3690	389	170	36	535	336	1404	761
12	7.17	5620	3645	338	172	26	601	508	1237	711
13	7.26	2970	1925	185	127	9	270	212	555	540
14	7.20	2680	1740	179	110	7	255	223	530	408
15	7.15	5150	3344	199	129	10	691	420	1211	634
16	7.18	3830	2486	249	138	4	367	488	619	584
17	7.24	3360	2182	192	103	12	364	380	690	406
18	7.20	3240	2102	181	92	12	352	369	674	392
Maximum	7.26	6720	4370	429	283	128	708	543	1608	811
Minimum	7.14	2470	1600	179	72	4	251	136	530	305
Average	7.19	4645	3014.72	270.77	151.16	29.88	484.27	375.94	1042.38	613.05

4. RESULTS AND DISCUSSION

4.1 Water quality based on the absolute ions

The concentration of cations in the study region ranges from 179 to 429 mg/l for Ca^{2+}, 72 to 283 mg/l for Mg^{2+}, 251 to 708 mg/l for Na^{+}, and 4 to 128 mg/l for K^{+} (Table 3). The allowed levels for Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} in irrigation water are 80, 35, 200, and 30 mg/l, respectively [26]. Based on these acceptable levels, 0% of groundwater samples were suitable for Ca^{2+}, Mg^{2+}, and Na^{+}, while 72% were suitable for K^{+}, and 28% were not suitable.

The HCO_3^{-} and Cl^{-} levels in the groundwater samples ranged from 136 to 543 mg/L and 305 to 811 mg/L, respectively (Table 3). The acceptable limit for HCO_3^{-} and Cl^{-} in irrigation water is 250 mg/L [26]. Based on these acceptable levels, 0% of groundwater samples were suitable for HCO_3^{-}, 16% for Cl^{-}, and 84% were not suitable.

4.2 Irrigation water quality assessment depends on pH

The term pH refers to a solution that is either acidic or alkaline. The acidity or basicity of irrigation water is measured by its pH, with a pH below 7.0 being acidic and above 7.0 being basic. The impact of pH on hydraulic conductivity, regardless of SAR, has been proven [30]. Typically, irrigation water has a pH range of 6.5–8.4 [31, 32]. Water with a low pH can be corrosive, while water with a high pH may cause scaling [33]. The pH values of the samples ranged from 7.14 to 7.26, with an average value of 7.19, falling within the typical ranges for irrigation water.

4.3 Irrigation water quality assessment depending on EC values

EC measures the capacity of a material or solution to carry an electric current. The electrical conductivity of groundwater increases as temperature rises and fluctuates with TDS concentration. EC is a valuable indicator of the risk of salinity in agriculture, as it mirrors TDS levels in groundwater. When EC rises, plants have limited access to water [34].

The EC of samples ranges from 2470 µS/cm to 6720 µS/cm, with an average value of 4645 µS/cm as shown in Table 3. According to the results in Table 4, all groundwater samples are classified as very high salinity and cannot be used for watering.

Table 4. EC classification of groundwater [35]

EC ms/cm	Class Salinity	Well No.	% of Samples	Remarks
0-250	Low	Nil	Zero	Safety for irrigation.
250-750	Medium	Nil	Zero	Can be used for moderate leaching.
751-2250	High	Nil	Zero	Can be used for irrigation with proper management.
>2250	Very High	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17 and 18	100 %	Cannot be utilized for irrigation.

Table 5. Groundwater Classification based on TDS Carroll's (1962) classification

TDS (mg/l)	Classification	Well No.	% of Samples
0-1000	Fresh water	Nil	Zero
1000-10000	Brackish water	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17 and 18	100%
10000-100000	Salty water	Nil	Zero
> 100000	Brine	Nil	Zero

4.4 Irrigation water quality assessment depends on Total Dissolved Solid values

TDS refers to the solids remaining in a filtered water sample after evaporation. These solids include minerals, nutrients, and important ions such as Ca^{2+}, Mg^{2+}, K^+, Na^+, HCO_3-, SO_4^{2-}, Cl^-, etc., found in natural water. TDS levels below 450 mg/l are ideal for irrigation, while levels between 450 and 2000 mg/l are considered moderate. TDS concentrations over 2000 mg/l are not suitable for agricultural purposes [36]. In the study area, groundwater samples had TDS levels ranging from 1600 mg/l to 4370 mg/l, with an average of 3014.72 mg/l. According to Carroll's (1962) classification shown in Table 5, the groundwater in the research area is considered brackish water.

4.5 Irrigation water quality assessment depends on SAR

Table 6. Water quality indexes

Well No.	SAR (meq/l)	Na%
1	4.89	39.91
2	9.52	60.62
3	2.7	57.75
4	2.82	58.81
5	5.69	41.9
6	5.94	48
7	5.7	41.88
8	3.95	41.85
9	4.55	35.66
10	4.54	35.6
11	5.7	41.96
12	6.64	64.31
13	3.74	37.77
14	3.69	38.46
15	9.38	59.56
16	4.63	40.27
17	5.27	47.14
18	5.31	48.41

SAR is an important measure of groundwater quality for irrigation. High concentrations of sodium ions can reduce soil permeability, decrease water and air content, and disrupt soil structure by displacing calcium and magnesium ions. The SAR values of groundwater samples ranged from (2.7 to 9.52) meq/l as shown in Table 6. Based on the SAR classification in Table 7, all groundwater samples are classified as excellent and suitable for most crops and soil types, except those sensitive to sodium.

Table 7. Classification of groundwater samples based on sodium adsorption ratio SAR [37]

SAR (meq/l)	Class of Water	Well No.	Percentage of Sample in the Study Area
<10	Excellent	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17 and 18	100%
10 to 18	Good	Nil	Zero
10 to 26	Doubtful	Nil	Zero
>26	Unsuitable	Nil	Zero

4.6 Irrigation water quality assessment depends on %Na

Sodium is an essential ion for plant growth at low concentrations, but it can be toxic to crops at high concentrations. The recommended ranges for sodium ion concentration in irrigation water are as follows: below 20% (excellent), 20–40% (good), 40–60% (permissible), 60–80% (doubtful), and greater than 80% (unsuitable). In the present study, the percentage of sodium in the samples as shown in Table 6 ranged from 46.49% to 69.04%. According to Table 8, 28% of the groundwater samples are classified as good, while 61% are permissible, and 11% are doubtful.

Table 8. Classification of groundwater samples based on sodium adsorption ratio %Na [38]

%Na	Class of Water	Well No.	Percentage of Sample in the Study Area
<20	Excellent	Nil	Zero
20 to 40	Good	1, 9, 10, 13, 14	28%
40 to 60	Permissible	3, 4, 5, 6, 7, 8, 11, 15, 16, 17, 18	61%
60 to 80	Doubtful	2, 12	11%
>80	Unsuitable	Nil	Zero

4.7 Irrigation water quality assessment based on the Wilcox diagram

Based on the Wilcox diagram, 83% of water samples were classified as unsuitable for irrigation purposes, and 17% of water samples were classified as doubtful to unsuitable for crop irrigation as Figure 3.

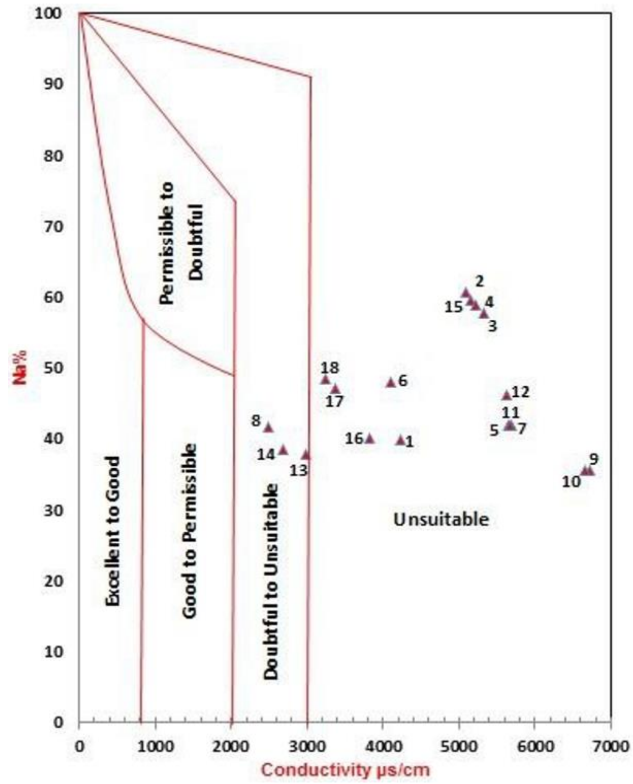

Figure 3. Wilcox diagram to classify ground water quality for irrigation

4.8 Irrigation water quality assessment based on the USSL diagram

Based on Figure 4, the results show that 4 of the samples belong to the (C4S3) class, indicating very high saltiness with high sodium content. Additionally, 11 of the samples from the study region belong to the (C4S2) class, suggesting very high saltiness with medium sodium content. Furthermore, 3 of the samples in the study region are categorized under the (C4S1) class, indicating very high salinity with low sodium content. This implies that the samples are unsuitable for irrigation purposes.

4.9 The potential impact of high salinity and sodium levels on crop yield and soil health

The quality of water is significantly affected by the type and amount of dissolved salts present. Elevated levels of salt in irrigation water can lead to salt deposition in the root region, causing salinity issues and reducing the amount of water available for root absorption [39]. If the soil isn't flushed with low-salt water, the excessive levels of salt in irrigation water can avert plant growth and cause wilting [31]. Salinity damage is a very important aspect in choosing the satisfactory water used for crop watering as a result of its influence on the osmotic strain of the soil [40]. Soil permeability is primarily prompted by the aid of soil salinity and the SAR [41]. High ranges of sodium in water, can impact soil shape and texture. Sodium can disrupt soil aggregates and disperse first-class particles, leading to the clogging of soil pores [41]. The presence of sure ions which include sodium and chloride in high concentrations in irrigation water can result in toxicity issues in vegetation, resulting in reduced boom and output. The quantity of toxicity relies upon the plant range and its rate of absorption.

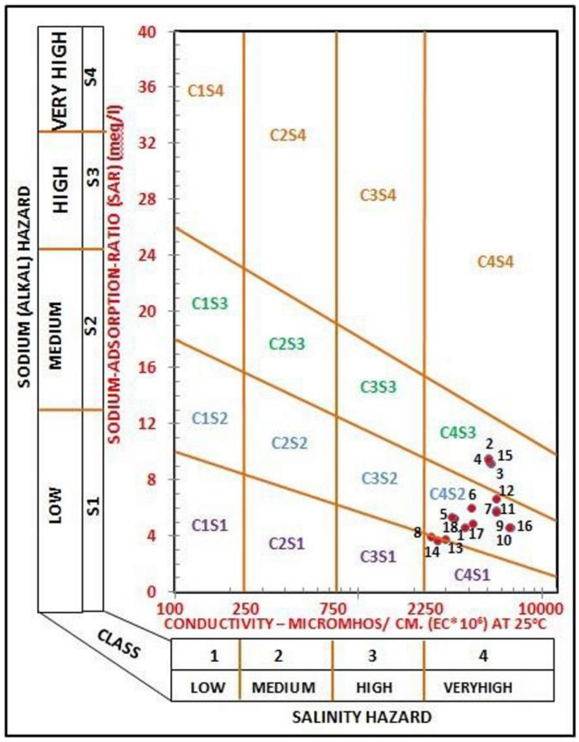

Figure 4. USSL diagram to classify Groundwater quality for irrigation

4.10 Comparison with similar studies

The permeability and water filtration in the soil are mainly influenced by salinity and SAR. In the study area, Table 3 shows a high EC value ranging between 2470-6720 µS/cm. These values are higher than those obtained by Hussain et al. [42] in their study of the groundwater of the Dammam aquifer in the western part of Iraq, which ranged between 1531-3460 µS/cm. The increased values EC is most likely owing to the study area's geological formations, which contain evaporated salts, gypsum, and dolomite. This deteriorates the water quality that travels through it. Table 6 reveals that SAR values in the research region were between (2.7-9.52) meq/l, which is consistent with the findings reported by Hussain et al. [42] in their investigation of groundwater in the Dammam aquifer in western Iraq, which ranged between (3.10 - 6.43) meq/l. These comparatively low results are the result of increased calcium and magnesium ion concentrations in the research region.

5. SPATIAL DISTRIBUTION MAPS

GIS is a specialized tool to generate spatial distribution maps that indicate acceptable and unsuitable zones based on water quality metrics [43]. This study created spatial distribution maps for EC, pH, TDS, SAR, and %Na.

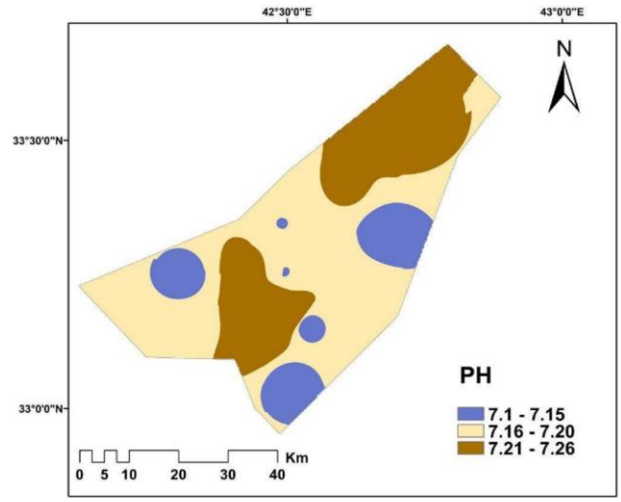

Figure 5. Spatial distribution map of pH

The spatial distribution map of pH shown in Figure 5 indicates that each study area falls within the permissible limits for irrigation. It also shows that the largest part of the study area has a pH ranging from 7.16-7.20.

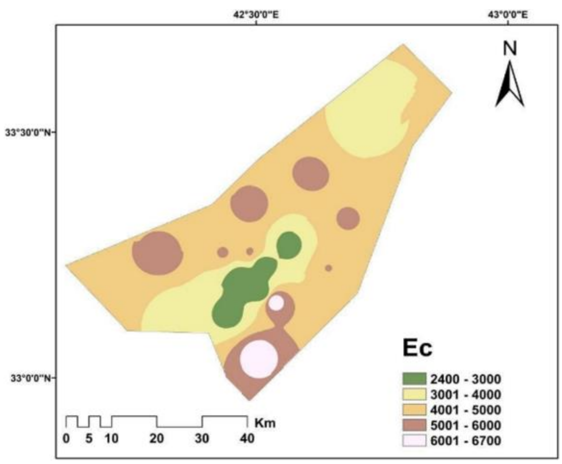

Figure 6. Spatial distribution map of EC

The spatial distribution map of EC is shown in Figure 6. This indicates that all study areas have high salinity. It also shows that the largest part of the study area has an EC ranging from 4001-5000 ms/cm.

The spatial distribution map shown in Figure 7 indicates that the TDS in the study area is very high. It also shows that the largest part of the study area has a TDS ranging from 2501-3000 mg/l, and the south part has a TDS ranging from 3501-4000 mg/l.

The spatial distribution map shown in Figure 8 indicates that the SAR in the study area is within the excellent zone. The values SAR ranges between (3.6–9.5) meq/l.

Figure 9 shows the geographical distribution map of %Na, which shows that the eastern half of the research region has very low %Na values when compared to the western sections of the study area.

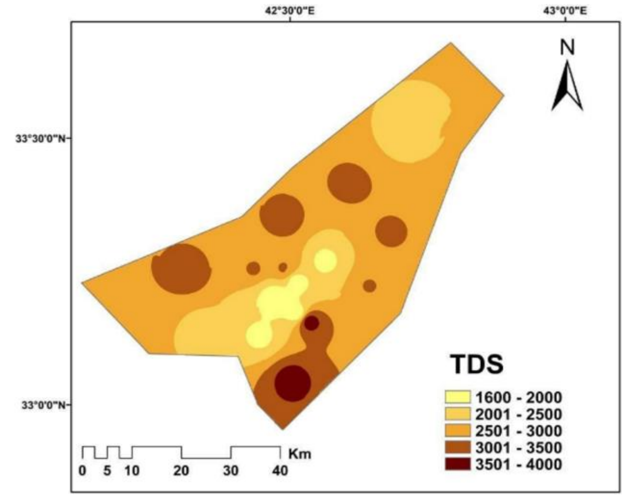

Figure 7. Spatial distribution map of TDS

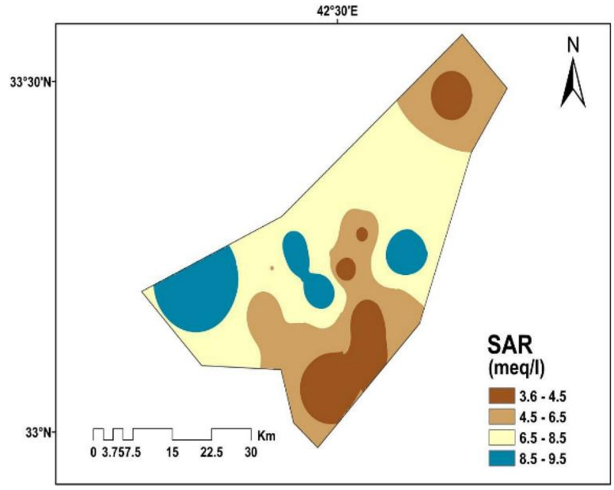

Figure 8. Spatial distribution map of SAR

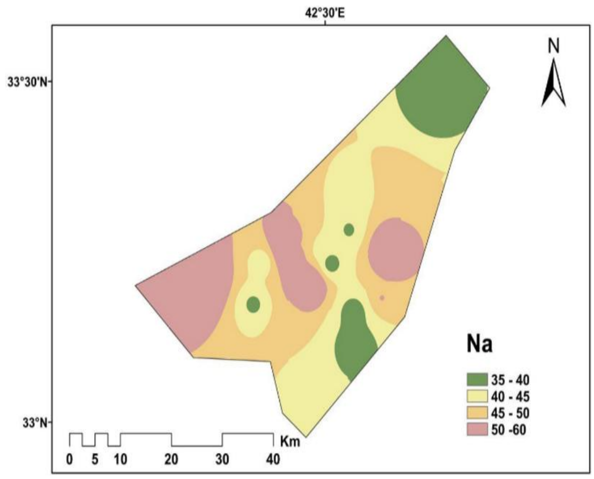

Figure 9. Spatial distribution map of %Na

6. CONCLUSIONS AND RECOMMENDATIONS

The use of groundwater is one of the strategic and main solutions in the desert and semi-desert regions such as the Western Desert in Iraq. The surface water quantities decrease significantly, particularly in times of water lack. The current study is a qualitative assessment of groundwater quality in the Al-Wafaa area in western Iraq. In this study, two diagrams were utilized to evaluate the quality of groundwater for irrigation. Below are the summary results of the assessment.

-The research found that most chemical standards exceeded permissible limits for irrigation. Na, Mg, Ca, and HCO_3 ions exceeded acceptable levels for irrigation, while the chloride ions showed low suitability.

-pH values of the groundwater samples are within the normal levels for irrigation water.

-EC of the groundwater is very high salt, ranging from 2470 to 6720 (ms/cm), with an average of 4645. This suggests that samples are improper for watering and pose a health hazard.

-The high salinity levels may be due to the significant dissolution of rock minerals or ion exchange processes, which introduce chloride (Cl), sodium (Na), and bicarbonate (HCO_3) ions into the groundwater in those specific areas. Further studies are required to evaluate the groundwater quality for different purposes.

-The water samples were classified as brackish water due to the values of TDS ranging from 1600 to 4370 mg/l, with a mean of 3014.72 mg/l.

-The Wilcox diagram indicates that most water samples are classified as unsuitable for irrigation, while few water samples are classified as doubtful to unsuitable.

-USSL diagram suggested that the groundwater samples belonged to C4S3, C4S2, and C4S1 categories, indicating high saltiness and high to medium to low sodium hazard. The findings show that the samples are not suitable for crop watering.

-This research recommends conducting multiple studies in the study area to assess the groundwater quality for drinking and domestic use.

-This research recommends conducting multiple studies in the research area to analyze heavy and toxic metals. It also suggests using geographic information systems and modeling techniques to rate the groundwater quality for watering.

-This research suggests growing salt-resistant plant species and utilizing modern scientific methods in irrigation operations.

-The findings of this study can assist policymakers in implementing measures to support sustainable agriculture in the research region.

-The proposed practical steps to address groundwater quality problems in the study area, especially high salinity and sodium levels, include the use of ion exchange filters and reverse osmosis filters. Additionally, chemicals such as sodium hydroxide or calcium hydroxide can be used to remove salts by reacting with them.

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REFERENCE

[1] Israil, M., Al-hadithi, M., Singhal, D.C., Kumar, B., Rao, M.S., Verma, S.K. (2006). Groundwater resources evaluation in the Piedmont zone of Himalaya, India, using Isotope and GIS techniques. Journal of Spatial Hydrology, 6(1): 34-48.

[2] Appelo, C.A.J., Postma, D. (2004). Geochemistry, Groundwater and Pollution. CRC Press.

[3] Al-Saffawi, A.Y.T., Abubakar, B.I., Abbass, L.Y., Monguno, A.K. (2020). Assessment of groundwater quality for irrigation using water quality index (IWQ Index) in Al-Kasik Subdistrict Northwestern, Iraq. Nigerian Journal of Technology, 39(2): 632-638. https://doi.org/10.4314/njt.v39i2.35

[4] Asadi, S.S., Vuppala, P., Reddy, M.A. (2007). Remote sensing and GIS techniques for evaluation of groundwater quality in municipal corporation of Hyderabad (Zone-V), India. International Journal of Environmental Research and Public Health, 4(1): 45-52. https://doi.org/10.3390/ijerph2007010008

[5] Allawi, M.F., Al-Ani, Y., Jalal, A., Ismael, Z.M., Sherif, M., El-Shafie, A. (2024). Groundwater quality parameters prediction based on data-driven models. Engineering Applications of Computational Fluid Mechanics, 18(1): 2364749. https://doi.org/10.1080/19942060.2024.2364749

[6] Khudair, M.Y., Kamel, A.H., Sulaiman, S.O., Al Ansari, N. (2021). Groundwater quality and sustainability evaluation for irrigation purposes: A case study in an arid region, Iraq. International Journal of Sustainable Development and Planning, 1(2): 413-419. https://doi.org/10.18280/ijsdp.170206

[7] Ghalib, H.B. (2017). Groundwater chemistry evaluation for drinking and irrigation utilities in east Wasit province, Central Iraq. Applied Water Science, 7: 3447-3467. https://doi.org/10.1007/s13201-017-0575-8

[8] Makki, Z.F., Zuhaira, A.A., Al-Jubouri, S.M., Al-Hamd, R.K.S., Cunningham, L.S. (2021). GIS-based assessment of groundwater quality for drinking and irrigation purposes in central Iraq. Environmental monitoring and assessment, 193(2): 107. https://doi.org/10.1007/s10661-021-08858-w

[9] Awad, E.S., Imran, N.S., Albayati, M.M., et al. (2022). Groundwater hydrogeochemical and quality appraisal for agriculture irrigation in greenbelt area, Iraq. Environments, 9(4): 43. https://doi.org/10.3390/environments9040043

[10] Al-Tameemi, I.M., Hasan, M.B., Al-Mussawy, H.A., Al-Madhhachi, A.T. (2020). Groundwater quality assessment using water quality index technique: A case study of Kirkuk governorate, Iraq. IOP Conference Series: Materials Science and Engineering, 881(1): 012185. https://doi.org/10.1088/1757-899X/881/1/012185

[11] Al-Kubaisi, Q.Y., Al-Abadi, A.M., Al-Ghanimy, M.A. (2018). Mapping groundwater quality Index for irrigation in the Dibdibba aquifer at Karbala Najaf plateau, central of Iraq. Iraqi Journal of Science, 59(3): 1636-1652. https://doi.org/10.24996/ijs.2018.59.3C.10

[12] Soren, D.D.L., Barman, J., Roy, K.C., Naskar, S.,

Biswas, B. (2023). Evaluation of groundwater quality of South Bengal, India. Journal of Earth System Science, 132(3): 130. https://doi.org/10.1007/s12040-023-02152-8
[13] Sadashivaiah, C.R.R.C., Ramakrishnaiah, C., Ranganna, G. (2008). Hydrochemical analysis and evaluation of groundwater quality in Tumkur Taluk, Karnataka State, India. International Journal of Environmental Research and Public Health, 5(3): 158-164. https://doi.org/10.3390/ijerph5030158
[14] Belkhiri, L., Boudoukha, A., Mouni, L. (2010). Groundwater quality and its suitability for drinking and agricultural use in Ain Azel plain, Algeria. Journal of Geography and Regional Planning, 3(6): 151-157.
[15] Meireles, A.C.M., Andrade, E.M.D., Chaves, L.C.G., Frischkorn, H., Crisostomo, L.A. (2010). A new proposal of the classification of irrigation water. Revista Ciência Agronômica, 41: 349-357. https://doi.org/10.1590/S1806-66902010000300005
[16] Siswoyo, H., Agung, I.G., Swantara, I.M.D. Sumiyati. (2016). Determination of groundwater quality index for irrigation and its suitability for agricultural crops in Jombang Regency, East Java, Indonesia. International Journal of Agronomy and Agricultural Research, 9(5): 62-67.
[17] Abbasnia, A., Radfard, M., Mahvi, A.H., Nabizadeh, R., Yousefi, M., Soleimani, H., Alimohammadi, M. (2018). Groundwater quality assessment for irrigation purposes based on irrigation water quality index and its zoning with GIS in the villages of Chabahar, Sistan and Baluchistan, Iran. Data in Brief, 19: 623-631. https://doi.org/10.1016/j.dib.2018.05.061
[18] Ketata, M., Gueddari, M., Bouhlila, R. (2012). Use of geographical information system and water quality index to assess groundwater quality in El Khairat deep aquifer (Enfidha, Central East Tunisia). Arabian Journal of Geosciences, 5: 1379-1390. https://doi.org/10.1007/s12517-011-0292-9
[19] Nastos, P.T., Moustris, K.P., Larissi, I.K., Paliatsos, A.G. (2013). Rain intensity forecast using artificial neural networks in Athens, Greece. Atmospheric Research, 119: 153-160. https://doi.org/10.1016/j.atmosres.2011.07.020
[20] Mohammed, A.S, Alboresha, R., Hatem, H. (2022). Forecasting the water level of the Euphrates river in western Iraq using artificial neural networks (ANN). International Journal of Design & Nature and Ecodynamics, 17(2): 303-309. https://doi.org/10.18280/ijdne.170218
[21] Almawla A.S., Kamel, A.H., Lateef, A.M. (2021). Modelling of flow patterns over spillway with CFD (Case study: Haditha Dam in Iraq). International Journal of Design & Nature and Ecodynamics, 16(4): 373-385. https://doi.org/10.18280/ijdne.160404
[22] Al Dulaymie, A.S., Hussien, B.M., Gharbi, M.A., Mekhlif, H.N. (2013). Balneological study based on the hydrogeochemical aspects of the sulfate springs water (Hit–Kubaiysa region), Iraq. Arabian Journal of Geosciences, 6: 801-816. 10.1007/s12517-011-0385-5
[23] Fouad, S.F. (2004). Contribution to the structure of Abu Jir fault zone, west Iraq. Iraqi Geological Journal, 32-33: 63-73.
[24] Awadh, S.M., Al-Ghani, S.A. (2014). Assessment of sulfurous springs in the west of Iraq for balneotherapy, drinking, irrigation and aquaculture purposes. Environmental Geochemistry and Health, 36: 359-373. 10.1007/s10653-013-9555-6
[25] American Public Health Association. (1926). Standard Methods for the Examination of Water and Wastewater (Vol. 6). American Public Health Association.
[26] Raghunath, H.M. (1987). Groundwater. Wiley Eastern Ltd. New Delhi, India.
[27] Todd, D.K., Mays, L.W. (2004). Groundwater Hydrology. John Wiley & Sons.
[28] Regional Salinity Laboratory (US). (1954). Diagnosis and improvement of saline and alkali soils (No. 60). US Department of Agriculture.
[29] Wilcox, L. (1955). Classification and Use of Irrigation Waters (No. 969). US Department of Agriculture.
[30] Suarez, D.L., Rhoades, J.D., Lavado, R., Grieve, C.M. (1984). Effect of pH on saturated hydraulic conductivity and soil dispersion. Soil Science Society of America Journal, 48(1): 50-55. https://doi.org/10.2136/sssaj1984.03615995004800010009x
[31] Ayers, R.S., Westcot, D.W. (1985). Water Quality for Agriculture. Rome: Food and Agriculture Organization of the United Nations.
[32] Wu, H., Chen, J., Qian, H., Zhang, X. (2015). Chemical characteristics and quality assessment of groundwater of exploited aquifers in Beijiao water source of Yinchuan, China: A case study for drinking, irrigation, and industrial purposes. Journal of Chemistry, 2015(1): https://doi.org/726340. 10.1155/2015/726340
[33] Tchobanoglus, G., Burton, F., Stensel, H.D. (2003). Wastewater engineering: treatment and reuse. American Water Works Association. Journal, 95(5): 201.
[34] Tank, D.K., Chandel, C.S. (2010). A hydrochemical elucidation of the groundwater composition under domestic and irrigated land in Jaipur City. Environmental Monitoring and Assessment, 166: 69-77. https://doi.org/10.1007/s10661-009-0985-7
[35] Handa, B.K. (1969). Description and classification of media for hydro-geochemical investigations. In: Symposium on Ground Water Studies in Arid and Semiarid Regions, Roorkee, p. 319.
[36] FAO (2006). Prospects for food, nutrition, agriculture and major commodity groups. World Agriculture: Towards.
[37] Bhat, M.A., Grewal, M.S., Rajpaul, R., Wani, S.A., Dar, E.A. (2016). Assessment of groundwater quality for irrigation purposes using chemical indices. Indian Journal of Ecology, 43(2): 574-579.
[38] Elsayed, S., Hussein, H., Moghanm, F. S., Khedher, K. M., Eid, E.M., Gad, M. (2020). Application of irrigation water quality indices and multivariate statistical techniques for surface water quality assessments in the Northern Nile Delta, Egypt. Water, 12(12): 3300. 10.3390/w12123300
[39] Bortolini, L., Maucieri, C., Borin, M. (2018). A tool for the evaluation of irrigation water quality in the arid and semi-arid regions. Agronomy, 8(2): 23-34.
[40] Simsek, C., Gunduz, O. (2007). IWQ index: A GIS-integrated technique to assess irrigation water quality. Environmental Monitoring and Assessment, 128: 277-300. https://doi.org/10.1007/s10661-006-9312-8
[41] Kahsay, G.H., Gebreyohannes, T., Tesema, F.W., Emabye, T.A.G. (2019). Evaluation of groundwater quality and suitability for drinking and irrigation

purposes using hydrochemical approach: The case of Raya Valley, Northern Ethiopia. Momona Ethiopian Journal of Science, 11(1): 70-89. https://doi.org/10.4314/mejs.v11i1.5
[42] Hussain, H.M., Al-Haidarey, M., Al-Ansari, N., Knutsson, S. (2014). Evaluation and mapping groundwater suitability for irrigation using GIS in Najaf Governorate, IRAQ. Journal of Environmental Hydrology, 22: 4.
[43] Sheikh, M.A., Azad, C., Mukherjee, S., Rina, K. (2017). An assessment of groundwater salinization in Haryana state in India using hydrochemical tools in association with GIS. Environmental Earth Sciences, 76: 465. https://doi.org/10.1007/s12665-017-6789-0

NOMENCLATURE

USSL	United state salinity laboratory diagram
EC	Electrical conductivity
WQI	Water quality index
SAR	Sodium adsorption ratio
RSC	Residual sodium carbonate
IQWI	Irrigation water quality index
ANN	Artificial neural networks
GPS	Global positioning global
%Na	Percent sodium
PNN	Probabilistic neural network
RBF-NN	Radial basis neural network
PI	Permeability index
KR	Kelley ratio
MHR	Magnesium hazard ratio
WHO	World health organization