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Groundwater Quality and Sustainability Evaluation for Irrigation Purposes: A Case Study in an Arid Region, Iraq

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ABSTRACT

Water resources are of great importance in the world's agriculture, especially regarding the scarcity of these resources. That calls for attention appropriate for analysis, study, and research in all issues and aspects that would contribute to the development and maintenance of those resources and achieve the maximum possible levels of quality and efficiency of use. The study was conducted during the fall season of 2020 to study groundwater quality (well water) in the city of Al-Qaim of Anbar Province to explain its suitability for agricultural exploitation in the region. The study included seven sites in Al-Qaim (Rtemi, Medicis, Eastern Akash, Okesha, Sawab, Albu-Hayat, and Al-Karah) to assess the validity of irrigation. The pH, Electrical conductivity (EC), positive ions (K^+, Na^+, Mg^{2+}, Ca^{2+}), and negative ions (HCO3, Cl-2, SO4) and CO3 were measured. The results showed that the studied well water is acceptable for irrigation purposes in terms of pH value, as for the electrical connection, it was six wells within the class (C2), which is adequate for irrigation for medium-salty crops, except for one well, which is a fine well within class C3 suitable for irrigation of high salinity crops. The total hardness values were low and did not pose any risk; as for the positive and negative ions, they were within the permissible limits within the specified classifications. By measuring the positive ions, the Sodium Adsorption Ratio (SAR) value was calculated and determined to be within the class S1, which means that the groundwater in the region is suitable for irrigation.

1. INTRODUCTION

Groundwater is the largest source of fresh water in the hydrological cycle and the largest of all surface lakes and rivers combined [1, 2]. More than half of the world's population withdraw freshwater from groundwater resources. Latent areas exist through groundwater shallow as well as deep aquifers [3, 4]. The water flows through the soil until it reaches where the groundwater accumulates. Due to the geological nature below the surface [5], groundwater wells are considered one of the water reserves that can be Use it for drinking, agriculture, and animal drinking. Water pollution is one of the most critical problems today [6, 7], the damages of which are reflected in human health, environmental systems, and civilized development [8]. As a result of bad practices by humans, the vast majority of water resources have become less suitable for human consumption, as it is contaminated with sewage residues, and various waste from chemicals, and toxic mineral elements, pesticides, in addition to oil pollution of seas and oceans [9]. The amount of groundwater used in the fields of irrigation and other uses is estimated at 4.2 billion cubic meters annually [10]. The geological environment plays a significant role in the distribution of underground reservoirs, as it is the main reservoir for water accumulation and its presence at different depths [11]. Agricultural expansion has imposed on the competent research authorities to focus their efforts on exploiting desert lands. Irrigation water varies significantly in the quantity and quality of salts, which come from melting some minerals and weathering rocks [12]. The study area in this research was located in the western Iraqi desert within Al Anbar Province in Al-Qaim district, as shown in Figure 1. It was characterized by a dry climate for long periods of days of the year. To provide a database for the quality of groundwater in the study area, the analyzes and laboratory tests that were conducted were to find out whether the water is suitable for irrigation of crops or not.

Water Management has faced many challenges in the Study Area [13]. The western Iraqi desert is an area covering nearly 32% of the total area of Iraq (437.072 km²) with a 1.5 million population [14]. It is classified as an arid region [15]. The central part of groundwater is renewable and recharged in limited flood areas in the desert only [16]. In the last two decades, Iraq has been suffering from insufficient water resources to meet population demands because of climate change and the dam's project in Syria and Turkey (Southeastern Anatolia Project – Turkey by constructing 22 dams on Tigris and Euphrates River). As well as the internal reasons are resulting from the absence of optimal utilization for water resources by creating a more sophisticated irrigation system [17, 18]. The above reasons make the water harvesting and implementation of modern irrigation systems is one of the essential Iraqi authority's priorities.

The groundwater resources are considered an adequate substitute for surface water, which increases the importance of investigating it [19, 20]. The current study affirmative that the groundwater resource in the western Iraqi desert determines its properties for irrigation or another usage [21]. Currently, investigating and utilizing water resources is one of Iraq's most critical problems. The destructive effect of the dams project in Turkey is briefly presented by surface water depleting: about 90% of the Euphrates River discharge will lose, which leads to increase desertification and pollution issues. 65% of Iraqi water demand for agriculture depends on Tigris and Euphrates. In addition, 80% of domestic use relies on both rivers. Statistically, about 20% of Iraqi territories have been deserted during the last few years. Moreover, 70% of crop-ping potential has been lost [22-24]. The above reasons will badly influence the Iraqi Western Desert because it will prevent any plans to invest in the region and use sophisticated irrigation systems. The surface water resources result from flash floods that rarely occur in the winter and spring seasons immediately after rapid short storms of rainfall [25, 26]. The region is rich with deposits of minerals area, such as iron, phosphate, pure sand for glass manufactures, and oases where people invest in agriculture and cattle grazing. After 2014, the region was considered as a conflict and military zone that made fieldwork difficult and, in some times, impossible to achieve. In addition, the difficulty of getting the appropriate data and reaching the studied area is time-consuming and leads to limiting the number of observation wells for investigation. The government is developing a plan for region inhabitation and expanding the use of groundwater for different purposes that make has a considerable interest intensive and need more detailed studies because it is the primary source of water in the region. Several studies dealt with water quality in other areas of the Anbar Province. Research [9] dealt with groundwater assessments for some wells in Al-Khafajia village west of Anbar Province. Research [27] also studied the improvement methods of groundwater quality in some areas of the Anbar Province. The present research aimed to evaluate the study area's water quality by looking at the physical, chemical properties and enriching studies related to groundwater in the Al-Qaim district.

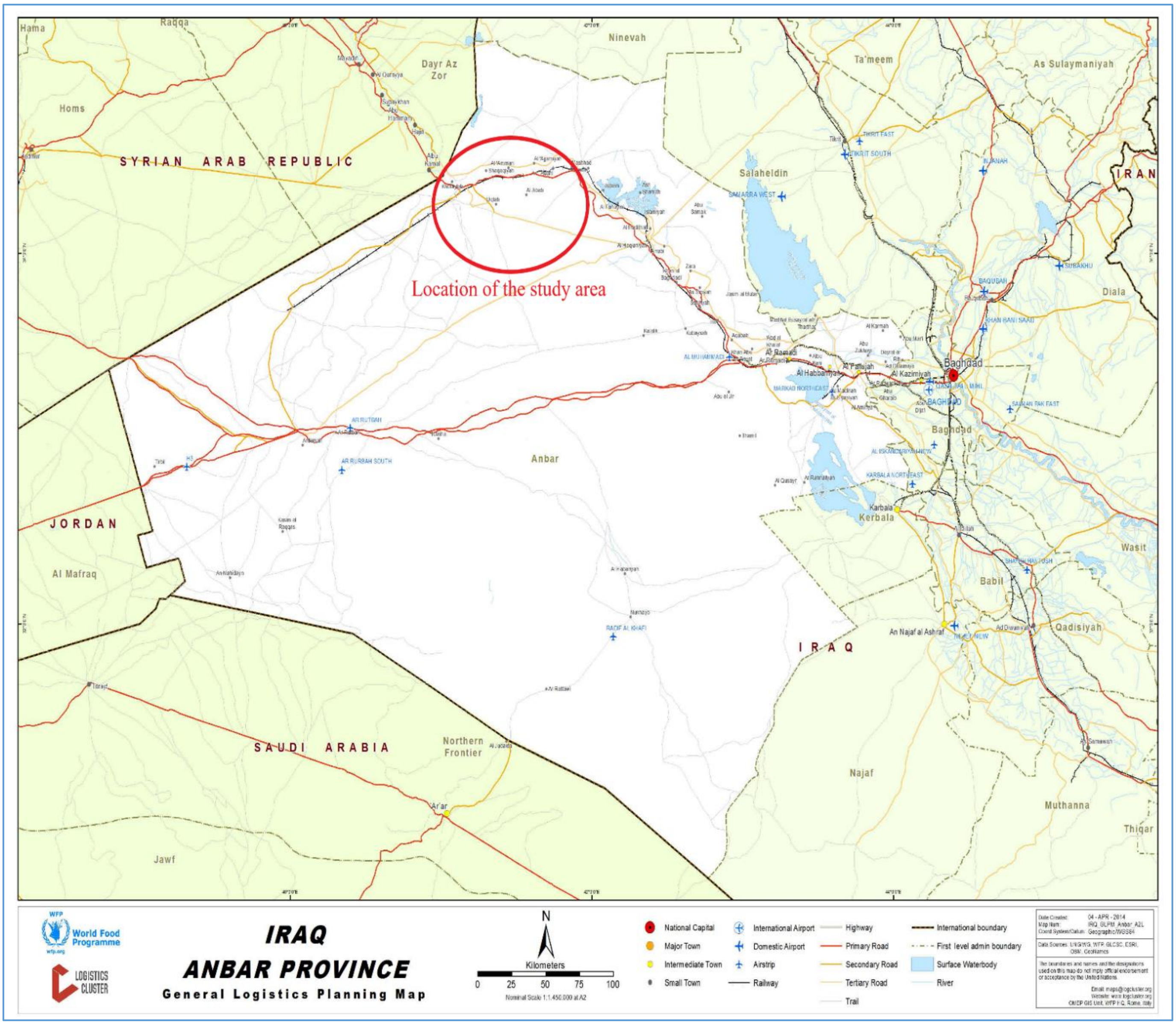

Figure 1. The study area

2. MATERIALS AND METHODS

Seven wells were selected to collect ten samples from each covered different season periods to evaluate water quality in Al-Qaim district within Al-Anbar Province, as shown in Figure 2. These wells were recently excavated by percussion drilling, and the people in this area are using them. The site has well water for agricultural purposes. One of the soil characteristics of this area it is a medium-dry desert (Aridisols) roughness is a quick-filtering lime.

The pH, Electrical conductivity (EC), positive ions (K^+, Na^+, Mg^{2+}, Ca^{2+}), and negative ions (HCO3, Cl^{-2}, SO4) and CO3 were measured. The SAR was valued for its importance and compared to the standard specifications for water suitable for agricultural purposes. As follows:

Acidic function (pH) and electrical conductivity (Ec) by using the EC-meter and the pH-meter [28]. Respectively and according to the method mentioned by Richards [29]. The Positive Sodium ions within samples were estimated using (flame photometer) according to the way mentioned by Richards [29]. The Calcium and magnesium Positive ions were evaluated by the correction method with Na^{2-}EDTA 0.01% standard according to the method mentioned by Richards [29]. Were determined using the process described in Source [30]. Negative ions included: Sulfates were determined by the deposition method of barium sulfate as calculated as mentioned in the source. v. As for carbonates and bicarbonates, they were estimated only Mentioned in the source [30]. The chloride was determined corrected with silver nitrate using the potassium chromate index, as reported by Jackson et al. [31]. The sodium adsorption ratio (SAR): was determined according to Eq. (1) because it is considered one of the most famous equations in determining Water fit for irrigation:

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

The total hardness was estimated using volume corrections to form complexes by direct scrubbing with a standard solution of EDTA in the presence of aero chrome black T as a guide at ideal conditions. Then the total hardness was calculated [32].

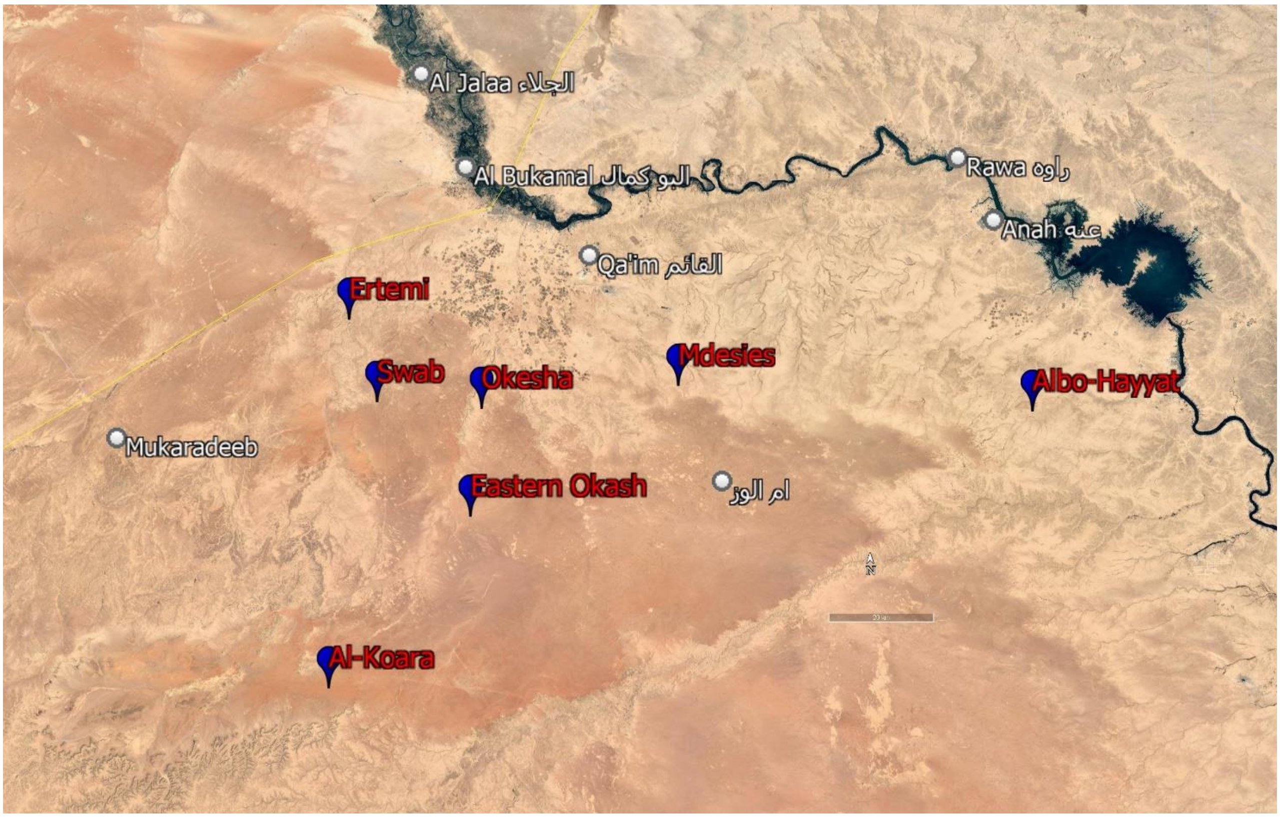

Figure 2. Location of the wells in the study area

3. RESULT AND DISCUSSION

In general, the water quality in the various wells is different. An analysis of water's physical and chemical properties from wells in the study area was done, as shown in Table 1. The evaluation of the water from the study wells was performed to determine its suitability for agricultural use, as follows:

3.1 Physical and chemical analyzes of water

Acidic function (pH) has a vital role in determining acidity and the base medium of the reaction for water. It expresses the activity and reactivity of the hydrogen ion, which results from the dilute acid and base balance as a result of different concentrations of dissolved compounds [33, 34]. The acidic function values of the well water ranged between (6.1-7.3). The results show that the water is suitable for irrigation purposes because it did not exceed the upper limits required to assess the quality of irrigation water, which is 8.4 according to Ayers and Westcot classification (1989). It is also noted that this water is suitable for drinking, and this is confirmed [9, 35].

Table 1 shows the electrical conductivity (EC) values of water wells in the study area, whose values ranged from (0.67-4), in which the electrical conductivity values exceeded 2.25 and according to the classification of the American salinity laboratory [36]. They can very well be used to irrigate crops that are very tolerant to salinity. The wells (1, 2, 5, 6, 7) fall within the category C2 (0.25-0.75), which means that they are suitable for medium tolerance to salinity crops. As for well No. 4, it falls within the class C3 (0.75-2.25) used for crops with high salinity tolerance and in well-drained soils and the presence of washing to prevent the accumulation of salts. The reason may be due to the increased solubility of ions and the nature of the geological components of the area surrounding the water [28].

Total hardness (TH) is the sum of the total salts of carbonates and bicarbonates, Sulfates, chlorides, and nitrates of calcium and magnesium. The percentage of study water has ranged between total hardness (4.5-20). It is within the range permitted by the World Health Organization, which is between (5-25). It is noted that well water is less cloudy than river water due to the depth of the water and the lower speed of its flow compared to the river water and its lack of direct connection with rainwater, and its low pollution with sewage [9].

Negative ions (CO32-, HCO-3) in the well's water come from the natural alkalinity sources such as limestone and dolomite rocks that generate carbonate and bicarbonate for sodium, calcium, and magnesium. The results show the absence of carbonates and the low bicarbonate concentration in all the irrigation water studied. The bicarbonate concentration reached 228, which is suitable for irrigation when comparing the results with the permissible limits in terms of bicarbonate risk of 610. We notice that some percentages are within normal limits, which may be attributed to the solubility of dolomite and limestone and its bicarbonate composition [37].

The sulfate (SO4) sources in the soil are due to oxidation Sulfides, which are derived from natural rocks (Pyrites). As well as from breaking down sulfide organic materials, Other Sulfates are natural groundwater [38]. The results showed that the studied irrigation water contained quantities of sulfates that ranged between (588-1100) mg.l^{-1}. When comparing these concentrations with the permissible concentrations of sulfates for agricultural uses, amounting to 1960 mg.l^{-1} according to the Ayers and Westcot classification [39]. We find that the water is suitable for irrigation.

When the Chloride (Cl)$^{-1}$ exceeds its limits due to the melting of rocks, Sedimentary and volcanic in the water become unfit for irrigation. The results showed chloride concentrations in the studied water, ranging between (528-1002) mg.l^{-1}. Therefore it is considered suitable for irrigation for not exceeding the permissible limits to evaluate the quality of irrigation water in terms of the severity of chloride 1050 mg.l^{-1} according to the classification of Ayers and Westcot [39].

Calcium (Ca^{+2}) is one of the essential cations in groundwater. It increases significantly when it is in contact with sedimentary rocks, represented by dolomite, consisting of calcium carbonate, magnesium, and sulfates such as gypsum. Calcium ion is one of the main components of the water hardness problem. The results show that the calcium concentration values ranged between 245-320, did not exceed the permissible limit of 800 as mentioned in the Ayers and Westcot classification, and therefore considered arable water.

Magnesium (Mg^{+2}) is another source of hardness and has one form in water; Mg^{+2} and magnesium are similar to calcium in several chemical properties and are necessary for plants. The results show that magnesium concentrations ranged between (186-301) mg.l^{-1} did exceed the permissible limit of 120 mg.l^{-1} as mentioned in the Ayers and Westcot classification [39] and therefore considered arable water. We note that it exceeded the permissible limit and the reason for the high magnesium concentration is the nature of the rocks and minerals containing magnesium [40].

Table 1. The physical and chemical analyzes of water wells in the study area

The name of the well	pH	TH mg.l-1	EC ds/m	Ca+2 mg\l	Mg+2 mg\l	SO4 mg\l	CL-2 mg\l	HCO3 mg\l	CO3 mg\l	SAR
Abu Hayat (1)	6.4	4.5	0.67	275	199	588	530	228	0.0	9.48
Swab (2)	6.1	18	0.7	290	200	690	980	350	0.0	8.94
Rtemi (3)	6.9	15	4	257	190	743	760	588	3.0	9.93
East okash (4)	6.1	13.5	1.7	320	301	1002	897	487	0.0	9.65
Okesha (5)	7.3	5.7	0.8	245	187	790	1002	593	0.0	8.36
Medicis (6)	6.9	12	0.55	286	199	997	528	477	0.0	9.24
Al-Karah (7)	6.7	20	0.7	320	186	865	897	410	0.0	9.87

Table 2. Comparison between measured and standard parameters of groundwater

No.	Water Quality Parameter	WHO International	Standards 2004	Range in Study Area
1	pH	6.5	8.5	6.1-7.3
2	EC ds/m	1400	-	0.55-1.7
3	TH Mg.l-1	100	-	4.5-20
4	Ca+2 Mg\l	75	500	245-320
5	Mg+2 Mg\l	50	200	186-301
6	Na+2 mg\l	-	150	123-170
7	CO3 mg\l	-	200	0-3
8	HCO3 mg\l	-	-	228-593
9	SO4 mg\l	200	400	588-1002
10	CL-2 mg\l	200	600	530-1002

Sodium (Na^{+2}) is the saltiest ion in abundance. The increase in sodium concentrations in irrigation water leads to an increase in its percentage in the soil to the level of toxicity. In the study, the results ranged between (238-458) mg.l^{-1}. It did not exceed the permissible upper limits for assessing the water quality in terms of sodium hazard, 920 mg.l^{-1} as mentioned in the [39].

Sodium adsorption ratio (SAR) is essential to determine the validity of water for irrigation [6]. Through the results, we note that the SAR values range between (8.36-9.93) according to the classification of the American Salinity Laboratory [36] that it falls within low-sodium (S1) water, so it is suitable for irrigation of most crops except for sodium-sensitive and used for all Variation of soils without damage. The variation in values is due to the difference in sodium, calcium, and magnesium values. We note that the studied water was within S1 class, and this water is one of the best qualities of water used for irrigation purposes. The variation in the values is due to the difference in sodium, calcium, and magnesium ratios. It is noticed that the sodium rises with the height of EC, and this height was within the permissible limits and does not cause soil problems when irrigation. Table 2 shows the comparison between the results in the present study with the standard parameters of groundwater.

3.2 Water suitability

Sodium percentage (Na%), sodium absorption ratio (SAR), and permeability index (PI), are the most critical Salinity indices that are considered for determining the suitability of groundwater for agriculture. Depending on Wilcox [41], Na% is a standard index used to estimate the usefulness of natural water for irrigation that can be obtained from the Eq. (2):

$$Na\% = Na^{+}\ 100 / \left[Ca^{2+} + Mg^{2+} + Na^{+} + K^{+} \right] \tag{2}$$

where: The ionic concentrations in mg/l. The Wilcox standards relating to Na% show that all the groundwater samples are in a suitable category, Table 3.

Table 3. Standard groundwater classification –Wilcox 1955

Water quality	Na (%)
Excellent	<20
Good	20-40
Permissible	40-60
Doubtful	60-80
Unsuitable	>80

Sodium adsorption ratio (SAR) is considered an indicator of the suitability of irrigation n water use in agriculture. The sodium concentration cause reduces the permeability of soil [42]. Alkali/sodium hazard is measured by SAR that influences crops. SAR is estimated by Eq. (3):

$$SAR = Na / [(Ca + Mg) / 2]^{0.5} \tag{3}$$

where: all terms are in mg/l. The value of SAR has a significant relationship with the ability of soil to absorb sodium. Irrigation with high SAR water requires soil treatment to avoid damage to soil resulting from displacing the calcium and magnesium in the soil by sodium that will lead to loss of soil structure and cause reduce the infiltration and soil permeability, which mean significant problems for crop production. The calculated values of SAR in the study area vary between 8.36 and 9.93 Table 4. The standard of groundwater depending on SAR is shown in Table 5. The SAR values for the study area are found within the range of excellent category, which is mean suitable for irrigation.

Table 4. SAR values in well water

Well no.	Na %	PI	Magnesium Ratio	SAR
1	23.55	25.98	41.98	9.48
2	22.22	25.19	40.81	8.94
3	24.87	28.95	42.5	9.93
4	21.49	24.28	48.47	9.65
5	22.16	26.55	43.29	8.36
6	22.89	26.37	41.03	9.24
7	23.68	26.73	36.76	9.87

Table 5. Groundwater standard depending on SAR (Todd 1959: Richards 1954)

Water quality	SAR values
Excellent	<10
Good	10-18
Doubtful	18-26
Unsuitable	>26

The water suitability classification for irrigation depending on permeability index (PI) that can be calculated by the following formula [43]:

$$PI = [Na + (HCO3)0.5]*100 / [Na + Ca + Mg] \tag{4}$$

where all terms in mg/l. The PI values in the study area vary from 24.28 to 28.95 Table 5. The World Health Organization has proposed a standard for estimating groundwater suitability for irrigation. The permeability index for the study area falls under the two (PI ranged between 25 and 75 %) except the well no. 4, which means the water is suitable for irrigation. Calcium and magnesium save a state of equilibrium that can be expressed with the index of magnesium hazard—this ratio or index developed by Paliwal [44]. The high magnesium hazard value causes relatively high alkaline with an adverse effect on the crop yield. The equation below used to estimate the magnesium ratio.

$$Magnesiumratio\$ = Mg^{2+} *100 / \left(Ca^{2+} + Mg^{2+} \right) \tag{5}$$

In the study area, the magnesium hazard values are between 36.76 and 48.47 % Table 5, which means it is suitable for irrigation. The hazard and adverse effect on the agricultural yield consider when the magnesium hazard is greater than 50%.

4. CONCLUSIONS

Based on the studied evaluation of the groundwater quality and sustainability, the following findings were observed: (i) the well water studied for irrigation under standard conditions according to the classification of the American Salinity Laboratory is considered suitable for irrigation where farmers can use the areas around the wells for agriculture. (ii) We recommend that well No. 4 be used only for irrigation of highly saline crops, as it falls under category C3. It is also recommended to modify the ionic composition by adding some chemicals to reduce the harmful effect of salts in well water, which helps to precipitate harmful components of carbonates and bicarbonates, and the relationship between Na/Mg/Ca cations must be modified.

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