Suitability of Groundwater in Al-Qaim Area / West of Iraq for different life uses

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Abstract

A total of twenty wells were studied in Al-Qaim region in the western part of Iraq. The main purpose of the present study was to investigate, evaluate and specify adequacy of the hydrochemistry properties of groundwater and its suitability for different uses. The studied area is located between latitude (34° 16 52.5-34° 21 56) north and longitude (41° 1 15 -41° 8 16.5) east. The obtained results are gain through a constant procedure started from field tours as a first step and ending with recorded results from laboratory analysis. The results explained the changing between dry and wet periods which provide a noticeable increasing for dry analysis comparing with wet one. Physical properties which include pH, Temperature, Electrical Conductivity and TDS were computed to show increasing in dry period by (12.78, 5.01, 7.34 and 14.27) % for T, pH, TDS and EC respectively. On the other hand, chemical properties which include cations (Ca²⁺, Na⁺, Mg²⁺ and K⁺) and anions (Cl⁻, SO₄²⁻ and HCO₃⁻) were calculated to show increasing in dry period by (6.40, 7.87, 13.03 and 16.32) % for (Ca²⁺, Na⁺, Mg²⁺ and K⁺) respectively and (5.30, 4.28 and 5.74) for (Cl⁻, SO₄²⁻ and HCO₃⁻) respectively. From obtained results, it is worth mentioning that the groundwater in the studied area is adequate for livestock, building, agricultural and irrigation purposes and not adequate for drinking and industrial purposes.

Keywords: Hydrochemistry, Groundwater, Suitability of groundwater, Al-Qaim area.

1. Introduction

Water quality is as important as its quantity, therefore, groundwater hydrochemistry represent an indicator for evaluating the quality of groundwater for different uses, its assessment and monitoring gained substantial importance nowadays. It is necessary to be ensure that the water resources sustainability and their equitable allocation and efficient to enable an acceptable level of social welfare and economic. Recently, consumption of water has raised suddenly with the increase in demand for developing industrial, building, agriculture, drinking, live stoke and irrigation. It is worth mentioning that in the present time, drinking water directly from the source without proper treatment is a hard task The quality status of groundwater assessment is important for socio-economic development and growth[¹]. Groundwater consists of a much larger freshwater volume than surface water and it is important for water security in many countries and areas, but many aquifers are subject to levels of unsustainable abstraction and pollution[²][³].
Study area

The study area is located in the western part of Iraq, in Al-Anbar Governorate; the area is located on the right side of the Euphrates River, where the river enters the Iraqi territory. The studied area located between latitude (34° 16' 52.5-34° 21' 56") north and longitude (41° 11' 15" -41° 8' 16.5") east (Fig. 1). Elevations of the area are ranged between (184-225) m.a.s.l. Tectonically and structurally, the area is located within Rutba-Jezira subzone which belongs to the Stable Shelf zone, and characterized by the absence of surface folds and low dipping beds of less than 1° toward northeast with a gradient of 10-20 m per km from Iraqi-Jordan-Saudi Arabia borders to the Euphrates river [4]. Although, the Euphrates river cross nearby the studied area, most of human uses depending on groundwater as main water resource. In the study area, there is no any further source of water except the groundwater. Euphrates aquifer represents the most upper groundwater aquifer in the studied area [5]. Therefore, Al-Qaim area is considered a mixture of urban and rural area.

Fig.1: Location map of the studied area

2. Materials and methods

Twenty groundwater samples were collected from the wells in two field tours to investigate physical and chemical properties for the water in each well. Temperature, hydrogen number, electric conductivity and total dissolved solids were measured in the situ. Other properties were measured in the Central Laboratory of Western Desert. After chemical analysis, each parameter was calculated for ion equilibrium to test the accuracy. The accuracy of the obtained results of water samples were calculated by using the equation developed by [6][7][8]. The equation of accuracy (U) states the difference between total concentration of cations and anions (with epm units), as shown in the relation below:

\[
U = \frac{r \sum \text{cations} - r \sum \text{anions}}{r \sum \text{cations} + r \sum \text{anions}} * 100 \text{………………………….}(1)
\]

\[
\text{A\%} = 100 - U \text{………………………….}(2)
\]

Where:
U: Uncertainty (reaction error)

r: cpm

A: accuracy

If the accuracy was greater than 10%, interpretation of these parameters would not be out feasible (Table 1).

3. Results and Discussions

Accuracy

The calculation of accuracy values showed that all the analysis results of the groundwater samples of the studied area were certain except well No. 19 (dry period) and well No. 20 (wet period) were probable certain (Table 2).

Table 1: Accuracy classification and relative difference

| U%   | A     | Acceptability |
|------|-------|---------------|
| U ≤ 5% | A% ≥ 95 | Certain       |
| 5% ≤ U ≤ 10% | 90% ≤ A% ≤ 95% | Probable certain |
| U > 10% | A% < 90% | Uncertain     |

Table 2: the accuracy of groundwater samples results for dry and wet period

| Well No. | Dry period | Wet period |         |         |
|----------|------------|------------|---------|---------|
|          | U%         | T%         | U%     | T%     |
| W-1      | 2.0        | 98         | 0.513  | 99.487 |
| W-2      | 2.32       | 97.68      | 3.72   | 96.28  |
| W-3      | 0.95       | 99.05      | 0.39   | 99.61  |
| W-4      | 4.38       | 95.62      | 3.13   | 96.87  |
| W-5      | 2.05       | 97.95      | 0.74   | 99.26  |
| W-6      | 3.33       | 96.67      | 0.02   | 99.98  |
| W-7      | 3.62       | 96.38      | 3.90   | 96.10  |
| W-8      | 1.95       | 98.05      | 2.44   | 97.56  |
| W-9      | 3.03       | 96.97      | 1.50   | 98.50  |
| W-10     | 2.37       | 97.63      | 0.04   | 99.96  |
| W-11     | 3.36       | 96.64      | 1.94   | 98.06  |
| W-12     | 1.98       | 98.02      | 0.59   | 99.41  |
| W-13     | 2.39       | 97.61      | 0.69   | 99.31  |
| W-14     | 4.64       | 95.36      | 3.90   | 96.1   |
| W-15     | 2.99       | 97.01      | 1.93   | 98.07  |
| W-16     | 2.17       | 97.83      | 0.31   | 99.69  |
| W-17     | 1.40       | 98.60      | 0.80   | 99.20  |
| W-18     | 4.12       | 95.88      | 0.32   | 99.68  |
| W-19     | 5.39       | 94.61      | 3.21   | 96.79  |
| W-20     | 0.13       | 99.87      | 6.77   | 93.23  |
Physical analysis

Physical analysis carried on the groundwater samples (Table 3), showed that the value of groundwater temperature ranged between 24.5 and 28.1 °C with an average of 26.6 °C during dry period (September of 2020) and 23.2 to 21 °C with an average 25.6 °C during wet period (April, 2021). pH values are ranged between (7.2-8.1) with an average (7.58) in dry period, and ranged between (7.2-7.9) with an average (7.47) for the wet period. TDS values are ranged between (678-2124) ppm with an average of (1206.75) ppm in dry period, while in wet period it ranged between (633-1990) ppm with an average of (1118.1) ppm. EC values ranged between (955-3032 μS/cm) with an average of (1733 μS/cm) while for the wet period it ranged between (845.1-2558.9) μS/cm with an average of (1145.17) μS/cm.

Table 3: The physical parameters of the groundwater samples in both dry and wet periods.

| Parameter | T | pH | TDS | EC | TH |
|-----------|---|----|-----|----|----|
|           | Unit | C° | pH  | ppm | μS/cm | ppm |
| period    | Dry | wet | dry | wet | dry | wet | dry | wet |
| W-1       | 26  | 22  | 7.5 | 7.4 | 1020 | 1000 | 1452 | 1312.5 | 441.6 | 401 |
| W-2       | 28  | 25  | 7.3 | 7.3 | 2124 | 1990 | 3032 | 2558.9 | 924.9 | 850.3 |
| W-3       | 27.5| 24  | 7.4 | 7.3 | 774  | 712  | 1088 | 949.6  | 330.1 | 299.4 |
| W-4       | 26.3| 21.5| 7.5 | 7.3 | 1136 | 1013 | 1641 | 1327.9 | 501.4 | 453.8 |
| W-5       | 28  | 25  | 7.6 | 7.4 | 1448 | 1302 | 2079 | 1691  | 633.8 | 590.5 |
| W-6       | 25.2| 21.5| 8   | 7.8 | 1730 | 1530 | 2481 | 1979.3 | 757.7 | 685  |
| W-7       | 24.5| 21  | 7.3 | 7.2 | 1560 | 1440 | 2248 | 1866.9 | 686.7 | 600  |
| W-8       | 25.2| 21.3| 8.1 | 7.9 | 1286 | 1235 | 1854 | 1607.6 | 565.5 | 520.4 |
| W-9       | 25.3| 21.9| 7.4 | 7.4 | 884  | 834  | 1275 | 1102.3 | 388.6 | 365.2 |
| W-10      | 26.2| 22  | 7.2 | 7.2 | 900  | 780  | 1294 | 1035.3 | 391.4 | 302  |
| W-11      | 26.3| 22.7| 7.6 | 7.5 | 1704 | 1553 | 2457 | 2008.3 | 748  | 650.4 |
| W-12      | 27.2| 25  | 7.5 | 7.4 | 1238 | 1200 | 1779 | 1562  | 541.9 | 480  |
| W-13      | 26.5| 23.1| 7.4 | 7.3 | 940  | 901  | 1337 | 1181.8 | 406.7 | 367  |
| W-14      | 27.6| 24.1| 7.5 | 7.5 | 906  | 844  | 1318 | 1110  | 401.1 | 355  |
| W-15      | 26.2| 24  | 7.6 | 7.4 | 780  | 694  | 1119 | 920.9 | 338.5 | 310  |
| W-16      | 26.2| 23.8| 7.7 | 7.5 | 678  | 633  | 955  | 845.1 | 288.3 | 247  |
| W-17      | 27.7| 24.2| 7.6 | 7.5 | 1168 | 1097 | 1684 | 1420.6 | 512.6 | 460  |
| W-18      | 26.6| 22  | 7.8 | 7.7 | 1050 | 1019 | 1501 | 1305  | 456.9 | 370.2 |
| W-19      | 27.9| 25  | 7.9 | 7.8 | 1598 | 1380 | 2306 | 1820  | 704.8 | 595.5 |
Chemical analysis

The chemical analysis carried on the groundwater samples both in the dry period (Table 4) and in the wet period (Table 5). The results showed that the Ca$^{2+}$ ion values have been ranged between (87-278) ppm with an average (260.7) ppm in dry period, while in wet period it ranged between (75-276) ppm with an average (160.4) ppm. Mg$^{2+}$ values were ranged between (11-36) ppm with an average of (21.1) ppm in the dry period, while in the wet period it ranged between (10-34) ppm with an average of (18.35) ppm. The values of Na$^{+}$ concentrations for groundwater samples ranged between (84-250) ppm with an average of (192.9) ppm for the dry period and in the wet period it ranged between (7-50) ppm with an average of (18.3) ppm. The values of Cl$^{-}$ concentration in groundwater samples ranged between (95-362) ppm with an average of (192.9) ppm for the dry period, while for the wet period it ranged between (67-278) ppm with an average of (173.3) ppm. K$^{+}$ concentration values for groundwater samples ranged between (6.4-19) ppm with an average of (12.3) ppm in the dry period, while in wet period it ranged between (5-17) ppm with an average of (10.30) ppm. Cl$^{-}$ concentration in groundwater samples were ranged between (95-362) ppm with an average of (192.9) ppm for the dry period, while for the wet period it ranged between (87-336) ppm with an average of (182). SO$_4^{2-}$ concentration in groundwater samples ranged between (47.2-415.3) ppm with an average of (190.2) ppm in dry period, while in wet period it ranged between (40-395.3) ppm with an average of (182.06) ppm. HCO$_3^{-}$ concentration in groundwater samples ranged between (235.4-488) ppm with an average of (363.8) ppm in dry period, while in wet period it ranged between (212-471) ppm with an average of (342.75) ppm.

Table 4: Results of hydrochemical analysis of groundwater samples for the dry period
(September,2020)

| Well No. | Ca$^{2+}$ | Mg$^{2+}$ | Na$^+$ | K$^+$ | Cl$^{-}$ | SO$_4^{2-}$ | HCO$_3^{-}$ |
|----------|-----------|-----------|--------|-------|----------|-------------|-------------|
|          | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm | ppm |
| W-1      | 133  | 6.63 | 17   | 1.39 | 122     | 5.30 | 10   | 0.25 | 170  | 4.80 | 115.2 | 2.39 | 307  | 5.85 |
| W-2      | 278  | 13.7 | 36   | 2.95 | 250     | 10.86| 18   | 0.46 | 362  | 10.22| 415.3 | 8.64 | 488  | 8    |
| W-3      | 99   | 4.94 | 36   | 1.06 | 100     | 4.34 | 7.4  | 0.18 | 95   | 2.68 | 125.3 | 2.60 | 308.1| 5.05 |
| W-4      | 150  | 7.48 | 20   | 1.63 | 137     | 5.95 | 11.5 | 0.29 | 142  | 4.01 | 209   | 4.35 | 349  | 5.72 |
| W-5      | 190  | 9.48 | 25   | 2.04 | 170     | 7.39 | 15   | 0.38 | 183  | 5.16 | 295.8 | 6.15 | 439  | 7.19 |
| W-6      | 227  | 11.32| 30   | 2.45 | 207     | 9    | 18   | 0.46 | 220  | 6.21 | 394   | 8.20 | 447  | 7.32 |
| W-7      | 206  | 10.27| 27   | 2.21 | 192     | 8.34 | 15   | 0.38 | 267  | 7.54 | 274   | 5.70 | 396  | 6.49 |
| W-8      | 170  | 8.48 | 22   | 1.80 | 150     | 6.52 | 12   | 0.30 | 220  | 6.21 | 185   | 3.85 | 390  | 6.39 |
| W-9      | 117  | 5.83 | 15   | 1.22 | 112     | 4.86 | 9.3  | 0.23 | 152  | 4.29 | 47.24 | 0.98 | 377  | 6.18 |
| W-10     | 118  | 5.88 | 15   | 1.22 | 115     | 5    | 9.7  | 0.24 | 156  | 4.40 | 109   | 2.27 | 312  | 5.11 |
| W-11     | 225  | 11.2 | 29   | 2.3  | 215     | 9.34 | 18   | 0.46 | 288  | 8.13 | 281.1 | 5.85 | 482  | 7.90 |
| W-12     | 163  | 8.13 | 21   | 1.72 | 162     | 7.04 | 14   | 0.35 | 207  | 5.84 | 227.5 | 4.73 | 366  | 6    |
| W-13     | 122  | 6.08 | 16   | 1.31 | 118     | 5.13 | 8    | 0.20 | 160  | 4.51 | 136   | 2.83 | 292  | 4.78 |
| W-14     | 120  | 5.88 | 16   | 1.31 | 109     | 4.73 | 8.2  | 0.20 | 152  | 4.29 | 98.18 | 2.04 | 294.2| 4.82 |
| W-15     | 102  | 5.08 | 13   | 1.06 | 93      | 4.04 | 7.8  | 0.19 | 132  | 3.72 | 65.23 | 1.35 | 287  | 4.70 |
|   | W-16 | W-17 | W-18 | W-19 | W-20 |
|---|------|------|------|------|------|
| **Max.** | 154  | 37   | 211  | 205  | 278  |
| **Min.** | 87   | 6.68 | 137  | 211  | 205  |
| **Ave.** | 160.7 | 4.34 | 3.74 | 10.25 | 36.65 |

| Well No. | Ca$^{2+}$ | Mg$^{2+}$ | Na$^+$ | K$^+$ | Cl$^-$ | SO$_4^{2-}$ | HCO$_3^-$ |
|----------|-----------|-----------|--------|-------|--------|------------|----------|
| W-1      | 128       | 6.38      | 15     | 1.22  | 113    | 4.91       | 8        |
| W-2      | 276       | 13.77     | 34     | 2.78  | 239    | 10.39      | 17       |
| W-3      | 75        | 3.74      | 10     | 0.81  | 97     | 4.21       | 6        |
| W-4      | 145       | 7.23      | 18     | 1.47  | 119    | 5.17       | 10       |
| W-5      | 183       | 9.13      | 23     | 1.88  | 147    | 6.39       | 10       |
| W-6      | 215       | 10.72     | 25     | 2.04  | 200    | 8.69       | 15       |
| W-7      | 199       | 9.93      | 22     | 1.80  | 185    | 8.04       | 14       |
| W-8      | 169       | 8.43      | 20     | 1.63  | 148    | 6.43       | 10       |
| W-9      | 109       | 5.43      | 14     | 1.14  | 99     | 4.30       | 8.1      |
| W-10     | 92        | 4.59      | 11     | 0.90  | 101    | 4.39       | 5        |
| W-11     | 210       | 10.47     | 28     | 2.29  | 197    | 8.56       | 15       |
| W-12     | 153       | 7.63      | 20     | 1.63  | 110    | 6.52       | 13       |
| W-13     | 112       | 5.58      | 13     | 1.06  | 110    | 4.78       | 7        |
| W-14     | 141       | 5.68      | 12     | 0.98  | 100    | 4.34       | 6        |
| W-15     | 94        | 4.69      | 11     | 0.90  | 86     | 3.73       | 6        |
| W-16     | 79        | 3.94      | 10     | 0.81  | 72     | 3.13       | 6        |
| W-17     | 150       | 7.48      | 16     | 1.31  | 139    | 6.04       | 10       |
| W-18     | 124       | 6.18      | 14     | 1.14  | 112    | 4.86       | 9        |
| W-19     | 193       | 9.63      | 22     | 1.80  | 176    | 7.65       | 14       |
| W-20     | 188       | 9.38      | 29     | 2.37  | 149    | 6.47       | 17       |

| **Min.** | 75 | 10 | 72 | 5 | 87 |

| **Ave.** | 160.7 | 4.34 | 3.74 | 10.25 | 36.65 |
Table 5: Results of hydrochemical analysis of groundwater samples for the wet period (April, 2021)

| Parameter | Average of dry period concentrations | Average of wet period concentrations | WHO 2011 | IQS 2009 |
|-----------|--------------------------------------|--------------------------------------|----------|----------|
| PH        | 7.58                                 | 7.47                                 | 6.5-8.5  | 6.5-8.5  |
| EC        | 1733                                 | 1145.7                               | 1500     | 1500     |
| TDS       | 1206.7                               | 1118.1                               | 1000     | 1000     |
| TH        | 535.8                                | 478.6                                | 500      | 500      |
| Ca²⁺      | 160.7                                | 150.4                                | 50       | 75       |
| Mg²⁺      | 21.1                                 | 18.35                                | 50       | 125      |
| Na⁺       | 148.6                                | 136.95                               | 200      | 200      |
| K         | 12.3                                 | 10                                   | 12       | 12       |
| Cl        | 192.9                                | 182                                  | 250      | 250      |
| SO₄²⁻     | 190.2                                | 182.06                               | 250      | 250      |
| HCO₃⁻     | 363.8                                | 342.95                               | 200      | 200      |
| NO₃       | -                                    | -                                    | 50       | 50       |
| PO₄        | -                                    | -                                    | -        | -        |
| Fe        | -                                    | -                                    | 0.3      | 0.3      |
| Ni        | -                                    | -                                    | 0.02     | 0.02     |
| Cd        | -                                    | -                                    | 0.005    | 0.005    |
| As        | -                                    | -                                    | 0.1      | 0.1      |
| Pb        | -                                    | -                                    | 0.05     | 0.05     |

Hints:
- Red values represent to the exceeded values
- All units are in ppm except EC in µS/cm and pH without unit

Groundwater suitability for human drinking purposes

Drinking water may be described as sanitary non-defective water when it does not cause any diseases or health issues [9]. Groundwater suitability depends on several parameters (major and minor elements, inorganic, organic chemicals and biological constituents). For the purpose of assessing groundwater suitability for humans, Table (6) shows physical and chemical properties of groundwater and suitability for drinking water in the study area as compared with the standards of [11][12]. As a result, the groundwater in the study area was generally unsuitable for human drinking purposes for most parameters, which effect on human life. However, there are some parameters lies within guideline, which had no human affection.

Table 6: Physicochemical properties of groundwater and its suitability for human drinking compared with the standards of [11][12]

| Parameters | Average of dry period concentrations | Average of wet period concentrations | WHO 2011 | IQS 2009 |
|------------|--------------------------------------|--------------------------------------|----------|----------|
|            |                                      |                                      | 6.5-8.5  | 6.5-8.5  |
|            |                                      |                                      | 1500     | 1500     |
|            |                                      |                                      | 1000     | 1000     |
|            |                                      |                                      | 500      | 500      |
|            |                                      |                                      | 50       | 75       |
|            |                                      |                                      | 50       | 125      |
|            |                                      |                                      | 200      | 200      |
|            |                                      |                                      | 12       | 12       |
|            |                                      |                                      | 250      | 250      |
|            |                                      |                                      | 250      | 250      |
|            |                                      |                                      | 200      | 200      |
|            |                                      |                                      | 50       | 50       |
|            |                                      |                                      | -        | -        |
|            |                                      |                                      | 0.3      | 0.3      |
|            |                                      |                                      | 0.02     | 0.02     |
|            |                                      |                                      | 0.005    | 0.005    |
|            |                                      |                                      | 0.1      | 0.1      |
|            |                                      |                                      | 0.05     | 0.05     |

Ground waters suitability for livestock
The groundwater had been evaluated for livestock uses depending on the classification proposed by [13]. This classification based on the major cations, anions, and TDS. Based on Altoviski classification in 1962, the results of the analyzed groundwater samples of the study area for both the dry and wet periods in (ppm) unit (Table 7), showed that all the samples were of very good type.

Table 7: Comparison of water quality standards with the selected parameters for groundwater samples in the study area for livestock purposes according to Altoviski (1962).

| Elements and Parameters | Very good | Good | Acceptable | Can be used | Maximum limits | Average concentrations of dry period | Average concentrations of wet period |
|------------------------|-----------|------|------------|-------------|----------------|-------------------------------------|-------------------------------------|
| Na⁺                   | 800       | 1500 | 200        | 2500        | 4000           | 148.6                               | 136.95                              |
| Ca²⁺                  | 350       | 700  | 80         | 900         | 100            | 160.7                               | 150.4                               |
| Mg²⁺                  | 150       | 350  | 500        | 600         | 700            | 21.1                                | 18.35                               |
| Cl⁻                   | 900       | 2000 | 3000       | 4000        | 6000           | 192.9                               | 182                                 |
| SO₄²⁻                 | 1000      | 2500 | 3000       | 4000        | 6000           | 190.2                               | 182.06                              |
| TDS                   | 3000      | 5000 | 7000       | 10000       | 15000          | 1206.75                             | 1118.1                              |
| TH                    | 1500      | 3200 | 4000       | 4700        | 5400           | 535.8                               | 478.6                               |

Groundwater suitability for building purposes

Altoviski(1962) [13] has suggested a classification for water quality used in building. This classification based on the major cations, and anions average concentrations of groundwater samples by (ppm) unit (Table 8). It is clear that all water samples in the study area are acceptable for building purposes when compared to the Altoviski (1962) standard.

Table 8: The suitability of groundwater in the study area for building purposes according to Altoviski (1962).

| Ions | Permissible Limit | Average concentrations |
|------|-------------------|------------------------|
|      |                   | Dry period | Wet period    |
| Na   | 1160              | 148.6      | 136.95        |
| Ca   | 437               | 160.7      | 150.4         |
| Mg   | 271               | 21.1       | 18.35         |
| Cl   | 2187              | 192.9      | 182           |
| SO₄²⁻| 1460              | 190.2      | 182.6         |
| HCO₃⁻| 350               | 363.8      | 342.95        |

Groundwater suitability for industrial purposes

The use of water for industrial purposes needs different requirement in terms of specifications and qualities specifications for each industry [14]. Three parameters that are generally important for industrial water are salinity, silica and hardness [15]. The comparison of the groundwater samples, with the standards suggested by Hem (1991) (Table 9) showed that the groundwater in the study area is unacceptable for all industrial purposes mentioned in the table below.
Table 9: Water Quality Standards for Industrial Uses according to [16]

| Parameters | Textile | Chemical pulp and paper | Wood chemicals | Synthetic rubber | Petroleum products | Canned, dried, frozen fruits and vegetables | Soft-drinks bottling | Leather tanning | Hydraulic cement manufacture |
|------------|---------|--------------------------|----------------|-----------------|-------------------|-----------------------------------------------|---------------------|----------------|----------------------------------|
| Ca²⁺       | -       | 20                       | 100            | 80              | 75                | --                                            | 100                 | --             | --                               |
| Mg²⁺       | 0       | 12                       | 12             | 50              | 36                | 30                                            | --                  | --             | --                               |
| HCO₃⁻       | 0       | --                       | --             | 250             | --                | --                                            | --                  | --             | --                               |
| Cl⁻        | 0       | 200                      | 200            | 500             | --                | 300                                           | 250                 | 500            | 250                              |
| SO₄²⁻      | 0       | --                       | --             | 100             | --                | 250                                           | 500                 | 250            | 250                              |
| NO₃⁻       | 0       | --                       | --             | 5               | --                | 10                                            | --                  | --             | --                               |
| Zn         | -       | --                       | --             | --              | --                | --                                            | --                  | --             | --                               |
| TH         | 25      | 100                      | 100            | 900             | 350               | 350                                           | 250                 | soft           | --                               |
| TDS        | 100     | --                       | --             | 1000            | --                | 1000                                          | 500                 | --             | 600                              |
| pH         | 2.5-10.5| 6-10                     | 6-10           | 6.5-8           | 6.5-8.3           | 6.9                                           | 6.5-8.5             | --             | 6-8                              |

All units are in (ppm) except pH unit less

Groundwater suitability for agriculture purpose

The significance of assessing the irrigation groundwater suitability comes from the significant impact that water quality on both soil system and the plant are ultimately impacts the crop productivity [14]. The tolerance of plants to total dissolved solids and electrical conductivity in water used in irrigation varies depending on plants quality [17]. According to the classification suggested by [15] all water samples of the study area are suitable for most growing kinds of crops (Table 10).

Table 10: Todd classification [15] for crops tolerance by relative salt concentrations for agriculture.

| Crop Division | Low Salt Tolerance crops Ec (µS/cm) | Medium Salt Tolerance crops Ec (µS/cm) | High Salt Tolerance crops Ec (µS/cm) |
|---------------|------------------------------------|----------------------------------------|-----------------------------------|
| Fruit Crops   | 0 - 3000 Limon, Strawberry, Peach  | 3000 - 4000                            | 4000 - 10,000                     |
|               | Apricot, Almond, Plum Orange, Apple | Cantaloupe, Olive, Figs, Pomegranate   | Date palm                        |
|               |                                    |                                        |                                   |
Groundwater suitability for irrigation purposes

The suitability of water for irrigation and agriculture depends on the type and amount of salts present in the water and their impact on growth and development of crops \[15\]. The acceptability of water for irrigation is controlled by its mineral components and the kind of plant and soil to be irrigated \[18\]. Then, to classify the quality of water and to assess its suitability for irrigation purposes, Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Sodium percentage (Na%), and Permeability Index (PI), should be determined, as showing below:

### Sodium Adsorption Ratio (SAR)

In the use of groundwater for irrigation purposes, SAR is an important parameter for soil alkalinity or alkali hazard evaluation. The Sodium Adsorption Ratio (SAR) parameter is the ratio of sodium ions to calcium and magnesium ions (meq/l). SAR is determined by the following equation \[15\]. The Na percentage values for groundwater samples in the area of study, were compared to the suggested limits based on SAR values for \[19\] shown in Table (12), which compared with Table (11). The obtained results revealed that all samples belong to (S1) which means that sodium does not have harmful effects.

\[
SAR = \frac{rNa}{\sqrt{r(Ca+Mg)/2}}
\]

SAR; sodium adsorption ratio. \( rNa^+ \), \( rCa^{+2} \), and \( rMg^{+2} \). Concentration of Ions by (epm) units.

| Level | SAR | Hazard | Level in the selected samples |
|-------|-----|--------|------------------------------|
| S1    | <10 | No harmful effects from sodium. | S1<10 |
| S2    | 10-18 | Appreciable sodium hazard in fine-textured soils of high CEC but could be used on sandy soils with good permeability. |
| S3    | 18-26 | Harmful effects could be anticipated in most soils and amendments such as gypsum would be |
necessary to exchange sodium ions.

| Well no. | SAR   | Na%    | RSC     | PI     |
|---------|-------|--------|---------|--------|
|         | dry   | wet    | dry     | wet    | dry    | wet    | Dry    | wet    |
| W-1     | 2.647 | 2.517  | 40.912  | 40.187 | -2.176 | -1.895 | 83.678 | 84.872 |
| W-2     | 3.747 | 3.611  | 40.244  | 39.588 | -8.823 | -8.838 | 68.139 | 67.206 |
| W-3     | 3.759 | 2.792  | 43.035  | 48.929 | -0.954 | -0.463 | 90.773 | 94.716 |
| W-4     | 2.788 | 2.479  | 40.654  | 38.397 | -3.403 | -3.235 | 77.434 | 76.697 |
| W-5     | 3.078 | 2.723  | 40.273  | 37.630 | -4.333 | -4.246 | 77.097 | 75.606 |
| W-6     | 3.427 | 3.440  | 40.695  | 41.539 | -6.458 | -6.203 | 71.656 | 71.108 |
| W-7     | 3.340 | 3.320  | 41.139  | 41.726 | -6.000 | -5.438 | 71.206 | 72.501 |
| W-8     | 2.875 | 2.867  | 39.898  | 39.912 | -3.892 | -3.826 | 76.839 | 76.818 |
| W-9     | 2.590 | 2.371  | 41.949  | 40.650 | -0.887 | -0.635 | 92.565 | 94.161 |
| W-10    | 2.650 | 2.649  | 42.440  | 45.139 | -2.002 | -1.426 | 83.470 | 85.563 |
| W-11    | 3.584 | 3.389  | 41.892  | 41.195 | -5.702 | -5.069 | 75.153 | 76.244 |
| W-12    | 3.173 | 3.028  | 42.891  | 42.498 | -3.855 | -3.438 | 77.187 | 78.234 |
| W-13    | 2.667 | 2.621  | 41.894  | 42.713 | -2.611 | -2.0314 | -     | - |
| W-14    | 2.480 | 2.380  | 40.404  | 40.285 | -2.475 | -2.1804 | -     | - |
| W-15    | 2.304 | 2.236  | 40.804  | 41.040 | -1.449 | 1.0512 | 85.787 | 88.734 |
| W-16    | 2.255 | 2.028  | 42.123  | 40.815 | -1.382 | -1.286 | 84.456 | 83.700 |
| W-17    | 3.060 | 2.881  | 42.584  | 41.728 | -4.123 | -3.878 | 74.121 | 73.864 |
| W-18    | 2.751 | 2.542  | 41.473  | 41.011 | -3.176 | -2.269 | 77.181 | 81.404 |
| W-19    | 3.245 | 3.200  | 40.216  | 41.195 | -5.938 | -4.925 | 71.775 | 74.191 |
| W-20    | 2.882 | 2.671  | 37.908  | 37.024 | -6.016 | -5.397 | 69.841 | 70.402 |

Percent Sodium Na%

Sodium % is another term used to report sodium in the classification of irrigation water. The sodium concentration percentage calculation can be achieved using the following equation \[15\]

\[
Na\% = \frac{r_{Na}+r_{K}}{r_{Ca}+r_{Mg}+r_{K}} \times 100
\]

Where: Concentrations of ions by (epm) units.

The values of (Na%) of groundwater samples in the study area for dry and wet periods are shown in Table 12. Where groundwater is classified for irrigation purposes, it depends on pH, TDS, EC, Na% and SAR parameters (Table 13). It was found that all groundwater samples in the study area fell within good and doubtful range, for the two periods

Table 13: Classification of irrigation waters according to Don (1995) \[20\]
Residual Sodium Carbonate (RSC)

In irrigation water, a high concentration of bicarbonate can lead to the precipitation of calcium and magnesium in the soil, resulting in a relative increase in sodium concentrations. The sodium hazard would then increase (Van Hoorn, 1970[20]). The values for residual sodium carbonate (RSC) are determined using the following equation (Turgeon, 2000[18]).

\[
RSC = ([\text{CO}_3^{2-}] + [\text{HCO}_3^-]) - ([\text{Ca}^{2+}] + [\text{Mg}^{2+}])
\]

The ion concentrations in equation (4) are in (epm) units. It is clear that all (RSC) values are low in the groundwater samples for both periods (Table 12). Since, RSC values for the groundwater samples in the study area are less than zero, this gives an indication that sodium hazard is unlikely and lies within the acceptable limits according to Turgeon[19] (Table 14).

Table 14: Classification of water irrigation according to Turgeon[19] based on RSC values

| RSC   | Hazard                                           |
|-------|--------------------------------------------------|
| < 0   | None                                             |
| 0-1.25| Low, with some removal of calcium and magnesium from irrigation water. |
| > 2.50| High, with most calcium and magnesium removed leaving sodium to accumulate. |

Permeability Index (PI)

The permeability of the soil is affected by the long-term use of sodium and irrigation water, soil bicarbonate content, calcium, and magnesium[21]. In order to assess groundwater suitability for irrigation purposes, Doneen (1964)[22] developed a Permeability Index (PI) method for measuring soil permeability. This index is based on the Ca, Mg, Na and HCO$_3$ ions according to the following equation.

\[
\text{PI}\% = \left( \frac{\text{Na}^+ + \text{HCO}_3^-}{\text{Ca}^2+ + \text{Mg}^2+ + \text{Na}^+} \right) \times 100
\]

Where;

ions concentration is expressed in meq/l (epm)
Groundwater was classified according to the PI values using Nagaraju classification (2006)\textsuperscript{(23)} (Table 15). The obtained results are ranged between Class-I to reach Class-II which means that the water quality ranged between good and very good for irrigation when comparing Table (12) with Table (15).

Table 15. Classification of permeability index (PI) for irrigation according to Nagaraju, (2006)\textsuperscript{(23)}.

| PI %  | Class   | Water quality                      |
|-------|---------|------------------------------------|
| < 25  | Class-III | Unsuitable for irrigation         |
| 25-75 | Class-II  | Good quality for irrigation       |
| >75   | Class-I   | Very good quality for irrigation   |

4. Conclusions

The present study explains that:

- All concentrations in dry period are higher than those in the wet period.
- The groundwater in the study area is suitable for livestock, building, agriculture and irrigation purposes, but it is unsuitable for human drinking and industrial purposes.

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