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WATER QUALITY INDICES FOR EVALUATING THE GROUNDWATER FOR DRINKING AND IRRIGATION IN THE WANA DISTRICT OF NORTHWESTERN IRAQ

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ABSTRACT

The current study aims to assess the groundwater quality in the Wana area, Northwest of Mosul. Water samples were collected from 18 selected wells within the study area during the dry season of October 2020 and the wet season of April 2021. Field and laboratory measurements including electrical conductivity (EC), TDS, pH, Total hardness, and major and some minor ions analyses were performed following standard methods. The results revealed a wide variation of EC values ranging from 0.66 to 5.09 $ds \cdot m^{-1}$. All wells have hard water due to the presence of gypsum and carbonate rocks. The water quality index (WQI) values showed that wells drilled in the Fatha Formation and wells of mixed water from both the Fatha Formation and the Quaternary sediments provide low-quality drinking water. Wells that only penetrate the Quaternary sediments yield good-quality drinking water. According to the irrigation WQI, the Fatha Formation wells produce low-quality irrigation water, and the water quality of wells drilled in Quaternary sediments or that penetrate both the Fatha Formation and Quaternary sediments (mixed water) ranges from excellent to acceptable for irrigation purposes.

INTRODUCTION

Groundwater is one of the main sources of water supply forming the most important natural resource for human life relied on by people all over the world. However, the importance of this resource varies mainly depending on its quality, which in turn determines its suitability for different uses (Bun *et al*., 2021; Khattab *et al*., 2021). Groundwater is subject to natural deterioration in quality where it is in direct contact with problematic mineral and rock components in the aquifer. It may also be degraded by pollution due to human activities including industrial, agricultural, and other urban uses, plus changes over time in land use cover (Li *et al*., 2021; Ram *et al*., 2021; Xiaodong *et al*., 2019). The reliance on, and consumption of, poor-quality water leads to health and economic problems. Consumption of contaminated water can lead to an increase in morbidity and mortality (Mukate *et al*., 2018), and the use of poor-quality water for irrigation will cause reduced production, and long-term negative effects on soil properties (Wei *et al*., 2019).

There are many parameters and indicators that are based on the physicochemical data of water that facilitate the assessment of water quality. One of the most important of these

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indicators is the Water Quality Index (WQI), which is one of the most effective tools for assessing water quality. It expresses a set of variables that affect water quality expressing them with a single value that characterizes the general state of the water quality (Kaurish and Younos, 2007; Babamiri *et al*., 2020). Sustainable groundwater management and development are critical for ensuring adequate water supply. This issue represents a major challenge for developing countries, including Iraq. Here the reliance on groundwater for irrigation and other purposes has recently increased (Khattab *et al*., 2021), due to the recent decline in the country's surface water sources. In addition, there has been an urgent need to exploit groundwater to expand agricultural land use in rural areas. This is the situation in the current study area, located northwest of Mosul City. Here farmers have recently been randomly digging shallow and deep wells using the groundwater for various purposes, without sufficient information about the quality of the water or the aquifer conditions. Therefore, the current study aims to contribute to better groundwater management and sustainability in the Nineveh Governorate. It is doing this by conducting an assessment of groundwater quality in one of the governorate's most important agricultural areas, determining the validity of using this water for drinking and agricultural purposes, and determining the status of groundwater and the impact of agricultural activities on its quality.

STUDY AREA

Wana region is located in northern Iraq, ~50 Km, northwest of Mosul city center. It is bordered by the Mosul Dam reservoir in the north, the Tigris River in the west and south, and the international road between Mosul and Duhok governorates in the east (Figure 1). The climate of the study area is dry in the summer and autumn and wet in the spring and winter; the annual rainfall reached around 367 mm.

GEOLOGY AND HYDROGEOLOGY

Geologically, the Wana area includes sediments and sedimentary rocks from geological time extending from the middle Miocene to the Quaternary periods. The Fatha Formation represents the middle Miocene sediments, comprising a succession of gypsum, marl, limestone, and mudstone. The Quaternary sediments include the residual soil, slope sediments, river terraces, and floodplain sediments (Figure 2). There are two main aquifers in the studied area, the Fatha aquifer and the Quaternary aquifer. All the studied wells penetrate either the Fatha aquifer, the Quaternary aquifer, or both aquifers; the wells range from 18 to 80 m deep. The average depth to the groundwater level from the well surface varies from 3.67 m in well No.7 to 34.9 m in well No.2. The wells discharge capacities range from very low (1.32 $m^3 \cdot hr^{-1}$) in well No.5 to a high (72.25 $m^3 \cdot hr^{-1}$) in well number 14. Wells 3, 6, 7, 8, 9, 10, 11, 12, and 13 penetrate the Fatha Formation; wells number 1, 2, 14, 15, and 18 are in the Quaternary sediments, while the rest of the wells penetrated both units.

METHODOLOGY

To evaluate the groundwater for different usages, thirty-six groundwater samples were collected from selected wells in the study area (Figure 1); 18 samples during October 2020 (dry season) and 18 samples during April 2021 (wet season). Some parameters were measured in the field including electric conductivity EC, total dissolved solid TDS, and pH using a portable field kit for the EC-pH meter. All the samples were collected in polyethylene one-liter bottles that were rinsed with the well water at least three times before filling. After collection, all the samples were transferred from the field to the laboratory under cool conditions at 4 ^{o}C. The laboratory chemical analysis (Table 1) included water hardness (TH), major cations, and anions including calcium, sodium, magnesium, potassium, chloride, bicarbonate, and sulfate. Some minor ions were also analyzed including nitrate and phosphate PO_4. The majority of analyses were carried out in the College of Agricultural and Forestry laboratories and the remainder in the laboratory of the Agriculture Directorate Ninawa office.

Table 1: Methods used for water samples analysis.

Ions or parameters	Analytical method
K^+, Na^+	Flame photometer
TDS	gravimeter
$SO_4^=$, $NO_3^=$, PO_4^{-3}	Spector photometer
T.H, Ca^{++}, Mg^{++}, Cl^-, HCO_3	Titration
pH	pH-meter
EC	EC-meter

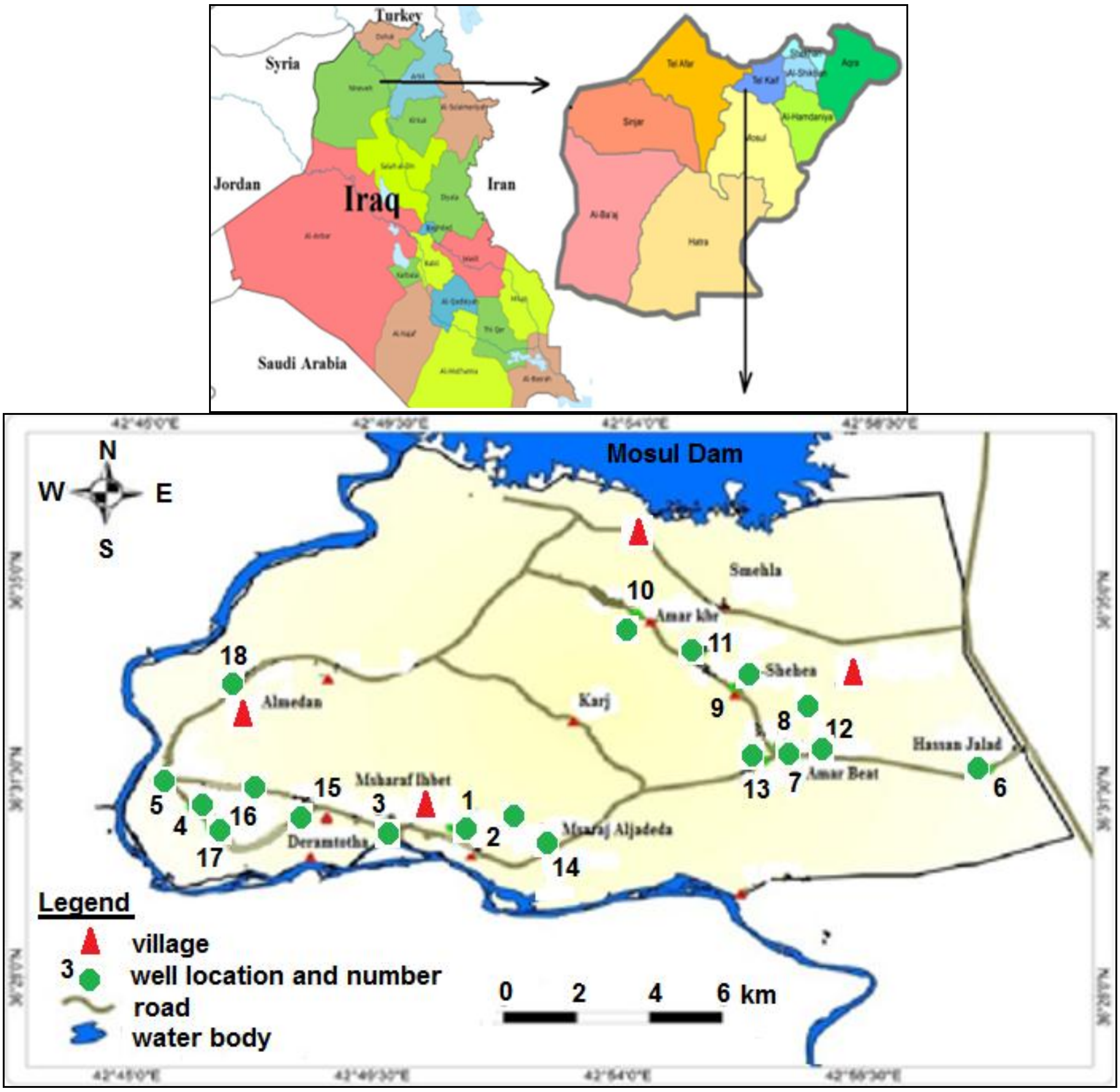

Figure 1: Location map and sites of wells in the study area.

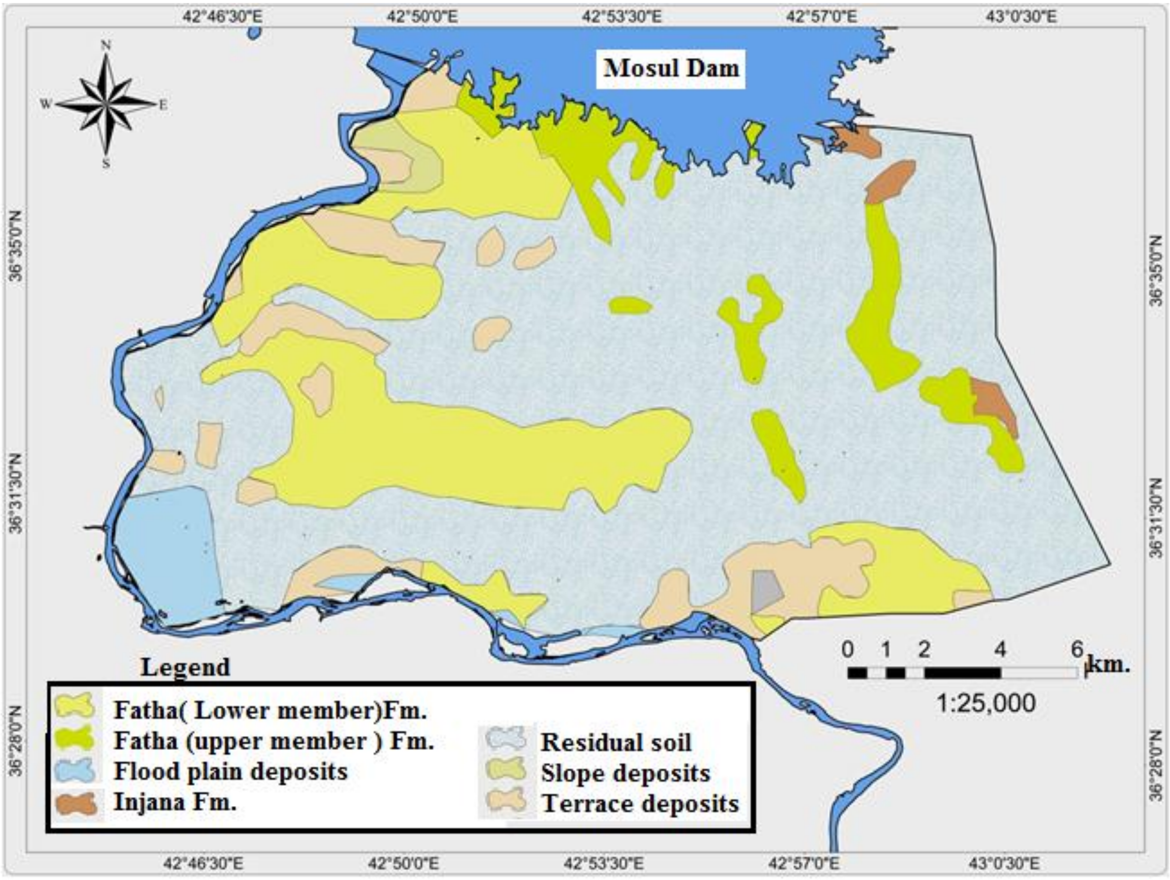

Figure 2: Geological map of the study area (Sissakian, 1995).

RESULTS AND DISCUSSION

The results of the analyses are shown in Tables 2 and 3. The salinity of the water wells ranges from 0.79 – 5.09 ds·m^{-1} in the dry season to 0.66 – 4.52 ds·m^{-1} in the wet season. The pH of all the wells ranges from 6.5 to 7.6 in both seasons. Total hardness ranges from 403 – 1594 mg·L^{-1} in the dry season to 309 – 1574 mg·L in the wet season. Sodium ranges from 0.98 – 2.65 meq·L^{-1} (dry season) to 0.28 – 3.44 meq·L^{-1} (wet season); sulfate from 2.19 – 29.46 meq·L^{-1} (dry season) to 2.93 – 24.36 meq·L^{-1} (wet season); nitrate from 0.13 – 0.88 meq·L^{-1} (dry season) to 0.08 – 0.62 meq·L^{-1} (wet season). More than one-quarter of the well samples showed pollution with nitrate at concentrations in excess of 0.81 meq·L^{-1} in the dry season, while in the wet season, nitrate concentration did not exceed 0.62 meq·L^{-1} in any of the wells. The majority of samples showed the concentrations of calcium to be higher in the wet season than in the dry season. The magnesium concentration in more than of the one-third samples was higher in the wet season compared to the dry season. Chloride concentrations for about half of the samples were higher in the wet season compared to the dry season. About one-third of bicarbonate concentration samples were higher for the dry season compared to the wet season (Tables 2 and 3).

Table 2: Results of laboratory analyses for the main and minor components of the study area in the dry season.

Well No.	EC ds/m	pH	TH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	SO_4^{-2}	HCO_3^{-}	NO_3^{-}	PO_4^{-3}	TDS	E%
			$mg \cdot l^{-1}$	$meq \cdot l^{-1}$									$mg \cdot l^{-1}$	
1	0.91	7.25	408	4.81	3.34	1.43	0.06	2.47	2.37	5.01	0.82	0.003	505	5.01
2	1.15	7.04	523	6.18	4.27	1.37	0.07	4.55	3.93	4.82	0.77	0.002	638	8.42
3	4.12	6.81	1234	19.44	5.25	2.09	0.09	4.46	23.77	3.79	0.13	0.001	2269	8.94
4	1.75	6.96	660	6.20	6.99	2.44	0.13	2.96	7.32	6.01	0.75	0.005	967	3.93
5	1.55	6.93	719	6.72	7.66	2.47	0.23	2.96	6.84	5.68	0.79	0.003	857	2.43
6	5.09	7.34	1268	12.80	11.43	1.40	0.07	4.94	20.28	4.80	0.37	0.002	2801	8.37
7	4.62	6.64	1445	20.08	8.82	2.54	0.46	5.92	25.12	5.79	0.88	0.004	2547	8.33
8	4.43	6.62	1557	23.82	7.31	1.71	0.18	4.44	24.94	5.01	0.85	0.003	2439	3.24
9	4.29	6.45	1482	21.97	7.68	1.47	0.12	3.46	23.31	7.01	0.86	0.002	2363	5.14
10	3.63	7.16	1371	21.61	5.82	1.30	0.07	1.97	27.59	4.01	0.22	0.002	2001	7.99
11	4.29	6.75	1594	20.93	10.94	1.43	0.20	4.94	25.78	5.01	0.87	0.002	2361	4.41
12	4.41	6.61	1408	17.25	10.91	2.23	0.12	5.43	22.40	7.68	0.50	0.002	2431	8.26
13	4.39	6.77	1594	20.07	11.80	1.78	0.10	3.46	29.46	5.37	0.59	0.002	2416	7.06
14	0.83	6.92	482	4.74	4.89	0.98	0.03	1.97	2.19	6.75	0.47	0.012	459	3.37
15	0.91	7.03	442	6.45	3.95	1.19	0.04	2.47	4.48	6.34	0.29	0.003	504	7.78
16	2.09	6.74	623	9.20	4.85	2.65	0.10	3.95	9.46	5.51	0.82	0.001	1155	8.02
17	2.12	7.22	719	10.55	6.22	1.67	0.19	4.57	11.70	4.56	0.37	0.002	1167	6.44
18	0.79	7.13	403	5.10	4.28	1.02	0.12	3.50	4.55	3.87	0.53	0.003	436	8.46

Table 3: Results of laboratory analyses for the main and minor components of the study area in the wet season.

Well No.	EC $ds \cdot m^{-1}$	pH	TH	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	SO_4^{-2}	HCO_3^{-}	NO_3^{-}	PO_4^{-3}	TDS	E%
			$meq \cdot l^{-1}$										$mg \cdot l^{-1}$	
1	0.92	7.52	483	5.83	4.77	1.02	0.05	4.5	3.26	5.01	0.54	0.003	510	6.54
2	1.15	7.34	574	7.67	5.14	1.40	0.03	2.0	7.35	5.68	0.41	0.002	637	4.08
3	3.44	7.31	1301	20.17	8.45	2.14	0.07	3.0	19.24	7.68	0.08	0.001	1897	1.34
4	1.65	7.16	628	6.67	7.14	3.25	0.09	3.5	8.15	8.68	0.54	0.005	909	6.82
5	1.27	7.42	409	7.12	3.18	2.28	0.20	3.1	6.71	4.74	0.47	0.003	701	8.02
6	3.62	7.60	1302	20.83	7.79	1.02	0.05	4.0	21.34	6.68	0.18	0.002	1996	4.04
7	4.11	6.91	1328	23.33	5.89	2.46	0.75	5.5	17.44	7.68	0.58	0.004	2266	1.93
8	4.17	7.15	1501	25.00	8.02	2.97	0.21	4.5	20.74	8.35	0.60	0.003	2297	2.86
9	3.87	7.13	1383	25.33	5.09	2.28	0.16	4.0	21.11	8.35	0.58	0.002	2133	1.76
10	3.28	7.17	1392	25.67	4.96	1.95	0.08	3.0	21.86	6.68	0.12	0.002	1806	1.55
11	4.52	7.43	1501	25.67	7.36	3.44	0.38	5.5	24.36	7.68	0.62	0.002	2488	1.74
12	4.10	7.15	1256	22.33	5.29	2.32	0.18	4.5	20.74	5.01	0.33	0.002	2257	0.75
13	4.13	7.23	1574	22.00	12.62	1.30	0.16	4.5	22.49	5.01	0.55	0.002	2273	5.14
14	0.66	7.41	309	5.83	1.17	0.28	0.02	1.5	2.93	4.01	0.32	0.012	367	6.02
15	0.80	7.48	374	5.17	3.24	0.47	0.03	2.0	3.03	5.01	0.20	0.003	444	6.99
16	2.26	7.26	692	9.67	5.54	2.32	0.12	4.5	8.25	5.34	0.59	0.001	1249	2.84
17	2.14	7.24	646	9.01	5.21	2.55	0.24	3.5	9.93	5.68	0.55	0.002	1181	7.24
18	1.04	7.43	465	6.33	3.87	0.56	0.06	2.5	5.53	4.01	0.24	0.003	577	6.27

- **Water quality index for drinking**

The WQI is considered to be one of the main tools for water resources management; it can be used in a simple way to express the various and complex data detailing the water quality (Sun *et al*., 2016). The WQI is represented by a unique number that is dimensionless, and calculated from the various parameters of water quality. The WQI is useful in studies that monitor water quality (Kachroud *et al*., 2019) and many researchers have used it to assess water quality.

Khudair *et al*. (2018) utilized the WQI for drinking water from 114 wells around the capital city of Baghdad. They used the following parameters, TDS, SO_4, Cl, and pH, and identified five water classes with the following percentages present: 14.9% excellent, 39.5% good, 22.8% poor, 6.1% very poor, and 16.7% unfit for drinking.

The World Health Organization standard (WHO, 2006) for drinking water has been used to determine Wi from Equation 1:

$$W_i = \frac{1}{ST_i} \text{ -------------------- } 1$$

Wi = standard value for the variable according to (WHO, 2006)
ST_i = standard value for the variable according to (WHO, 2006)

Using the upper limit for drinking water, which includes TDS = 1000 mg·l^{-1}, total hardness (TH) 500 mg·l^{-1}, Calcium 75 mg·l^{-1}, magnesium 100 mg·l^{-1}, sodium 250 mg·l^{-1}, potassium 12 mg·l^{-1}, chloride 250 mg·l^{-1}, sulfate 250 mg·l^{-1}, and finally, nitrate 50 mg·l^{-1}.

Table 4 shows the classification of the WQI according to (Tyagi *et al*., 2013). There are many steps to calculate WQI. The first step is to calculate the sub-water quality index Qi, from Equation 2 (Tyagi *et al*., 2013):

$$Q_i = \left(\frac{N_i - N_o}{ST_i - N_o}\right) \times 100 \text{ -------------------- } 2$$

N_i = the concentration of variable in a water sample
N_o = typical value of the variable in water

From this WQI is calculated using the equation below

$$WQI = \frac{\sum Q_i \times W_i}{\sum W_i} \text{ -------------------- } 3$$

Qi = sub-index for ith water quality parameter;
W_i = inverse value for the parameter
WQI = water quality index

The results showed that the WQI for drinking water ranged between 68.82 to 249.73 for the dry season. The wells numbered 1, 2, 14, 15, and 18 fall season into the good water class. Conversely, wells numbered 3, 4, 5, 6, 12, 16, and 17 have a poor water class. The remainder of the wells all fall under the very poor water class accounting for around one-third of the total wells (Table 5). In the wet season, the WQI for drinking ranged from (56.08 to 252.01). The wells numbered 1, 2, 14, 15, and 18 all had a good water class. While wells numbered 3, 4, 6, 16, and 17 all had a poor water class. The very bad water class was found in about one-third of the wells including those numbered 7, 8, 9, 10, 11, and 13. Comparing the WQI values between the two seasons, most of the wells remain in the same water class. However, two wells numbered 5 and 12 fall into different water classes between the dry and wet seasons, due to a change in the concentration of dissolved ions (Table 3).

Table 4: Classification of the WQI for drinking according to Tyagi *et al*. (2013).

Water quality rating	Value of WQI
Excellent	< 50
Good	50 – 100
Poor	100 – 200
Very poor	200 – 300
Polluted	300 – 400

Table 5: Values of the WQI for drinking water of the groundwater for the study area.

Well No.	WQI in the dry season	WQI in the wet season	Water class
1	81.15	82.21	Good
2	94.76	92.23	Good
3	184.27	185.92	Poor
4	104.6	100.67	Poor
5	110.1	87.39	Poor in the dry season, good in the wet season
6	163.58	195.99	Poor
7	233.23	222.42	very poor
8	249.73	242.69	very poor
9	235.51	236.13	very poor
10	205.19	217.31	very poor
11	242.13	252.01	very poor
12	199.08	207.02	Poor in the dry season, and very poor in the wet seasons
13	230.42	233.45	very poor
14	68.82	60	Good
15	72.94	56.08	Good
16	125.24	119.07	Poor
17	120.88	113.78	Poor
18	76.26	71.27	Good

- **Evaluation of groundwater for irrigation in the study area**

Irrigation with bad-quality water not only has a negative effect on agricultural products and production. However, it also has a negative effect on soil fertility affecting the physical and chemical properties of the soil (Al-Omran *et al*., 2010). A decrease in soil productivity can be due to irrigation with saline water which can cause many elements in the soil to reach levels toxic to the majority of crops leading to a significant decline in crop yield (Talukder *et al*., 1999).

- **Sodium Adsorption Ratio (SAR)**

The Sodium Adsorption Ratio (SAR) is considered to be one of the most important indicators showing the level of sodium in irrigation water. High levels of Na in irrigation water lead to soil dispersion and destroy the soil structure, which leads to a drop in soil permeability. A high SAR value indicates high concentrations of sodium in irrigation water that are considered toxic to plants (Aleem *et al*., 2018). Land irrigated with water containing high concentrations of Na and low concentrations of Ca leads to ion exchange. The soil saturated with sodium ions leads to clay dispersion and a significant drop in the soil infiltration rate (Todd, 1980). The SAR has been calculated according to the following equation (Doneen, 1964):

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \quad \text{-------------} \; 4$$

Where all ions in meq·l^{-1} as stated in

Table 6, show the SAR results for the wet and dry seasons.

Table 6: Results of some parameters used to evaluate irrigation water in both the wet and dry seasons.

Well No.	Wet seasons					Dry seasons				
	KR ratio	RSC meq·l^{-1}	PI%	SAR meq·l^{-1}	MH%	KR ratio	RSC meq·l^{-1}	PI%	SAR meq·l^{-1}	MH%
1	0.10	-5.6	28.05	0.44	44.99	0.18	-3.14	38.31	0.71	40.97
2	0.11	-7.13	26.6	0.55	40.13	0.13	-5.62	30.2	0.6	40.28
3	.07	-20.94	15.96	0.57	29.53	0.08	-20.89	15.09	0.6	21.26
4	0.24	-5.12	36.34	1.24	51.70	0.18	-7.18	31.29	0.95	52.97
5	0.22	-5.56	35.42	1	30.86	0.17	-8.7	28.82	0.92	53.27
6	0.04	-21.94	12.17	0.27	27.2	0.06	-19.43	14.01	0.4	47.17
7	0.08	-21.54	16.52	0.64	20.16	0.09	-23.12	15.73	0.67	30.53
8	0.09	-24.68	16.28	0.73	24.3	0.05	-26.13	12.02	0.43	23.49
9	0.07	-22.08	15.8	0.58	16.74	0.05	-22.64	13.23	0.38	25.92
10	0.06	-23.95	13.92	0.5	16.2	0.05	-23.42	11.48	0.35	21.23
11	0.10	-25.35	17.02	0.85	22.28	0.04	-26.86	11.03	0.36	34.33
12	0.08	-22.61	15.23	0.63	19.15	0.08	-20.48	16.46	0.59	38.73
13	0.04	-29.61	9.86	0.31	36.45	0.06	-26.49	12.18	0.45	37.03
14	0.04	-3	31.33	0.15	16.74	0.10	-2.88	33.75	0.45	50.82
15	0.06	-3.4	30.5	0.23	38.52	0.11	-4.05	32.01	0.52	37.97
16	0.15	-9.87	26.44	0.84	36.43	0.19	-8.54	29.91	1	34.53
17	0.18	-8.54	29.45	0.96	36.63	0.10	-12.21	20.63	0.58	37.08
18	0.05	-6.2	23.8	0.25	37.94	0.11	-5.51	28.7	0.47	45.61

The lowest SAR value was 0.35 meq·l^{-1} recorded from well No.10 in the dry season; in the wet season the lowest value was 0.15 meq·l^{-1} recorded from well No.14. The highest SAR value was 1 meq·l^{-1} for well No.16 in the dry season, while the highest value in the wet season was 1.24 meq·l^{-1} in well No.4.

The comparison of SAR between the two seasons shows a slight variation. In general, all the SAR values are very low and do not exceed 1.5 meq·l^{-1}. Ayers and Westcot (1985) pointed out that a SAR value of less than 10 is considered excellent for irrigation water and there is no hazard of sodium to the soil. All the wells in the Wanna study area have a low sodium (Na^{+}) content not exceeding 80 ppm in either season.

The diagram shown in Figure 3 has been proposed by Richard (1954) for use in the evaluation of water wells for irrigation. For the current study, the wells numbered 1, 2, 4, 5, 14, 15, 16, 17, and 18 fall season in the field of $C_3 – S_1$ represent high salinity and a low SAR. Wells numbered 3, 6, 7, 8, 9, 10, 11, 12, and 13 all fall season in the field $C_4–S_1$ represent very high salinity and a low SAR in the dry season. In the wet season, wells numbered 1, 2, 4, 5, 15, 17, and 18 fall season in the field of $C_3 - S_1$, while wells 3, 6, 7, 8, 9, 10, 11, 12, 13, and 16 fall season in the field $C_4 - S_1$. Finally, only well 14 falls in the C_2-S_1 zone, which represents a medium salinity and low SAR hazard (Figure 4).

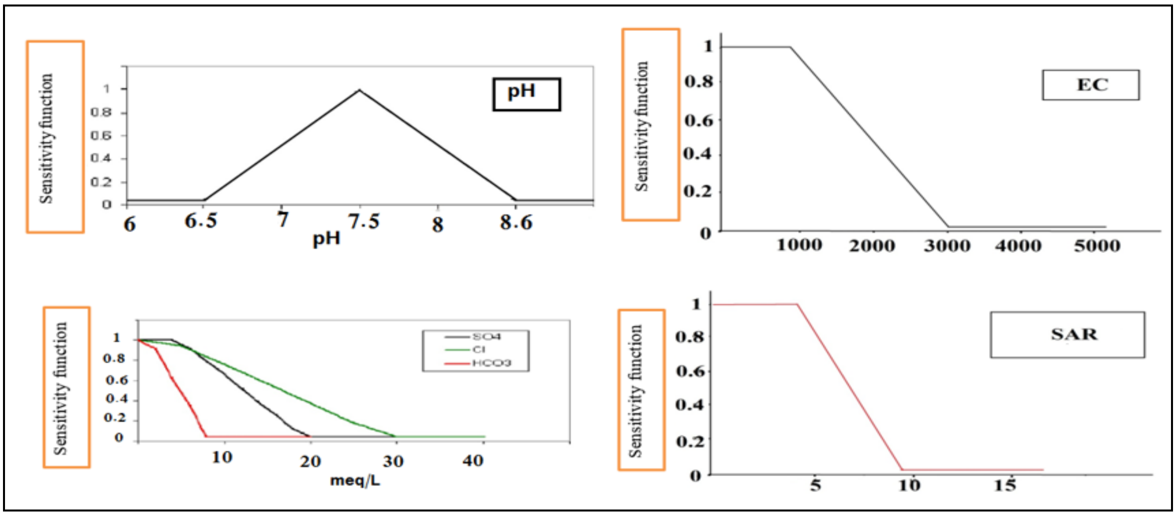

Figure 3: Sensitivity curve for irrigation parameters according to FAO.

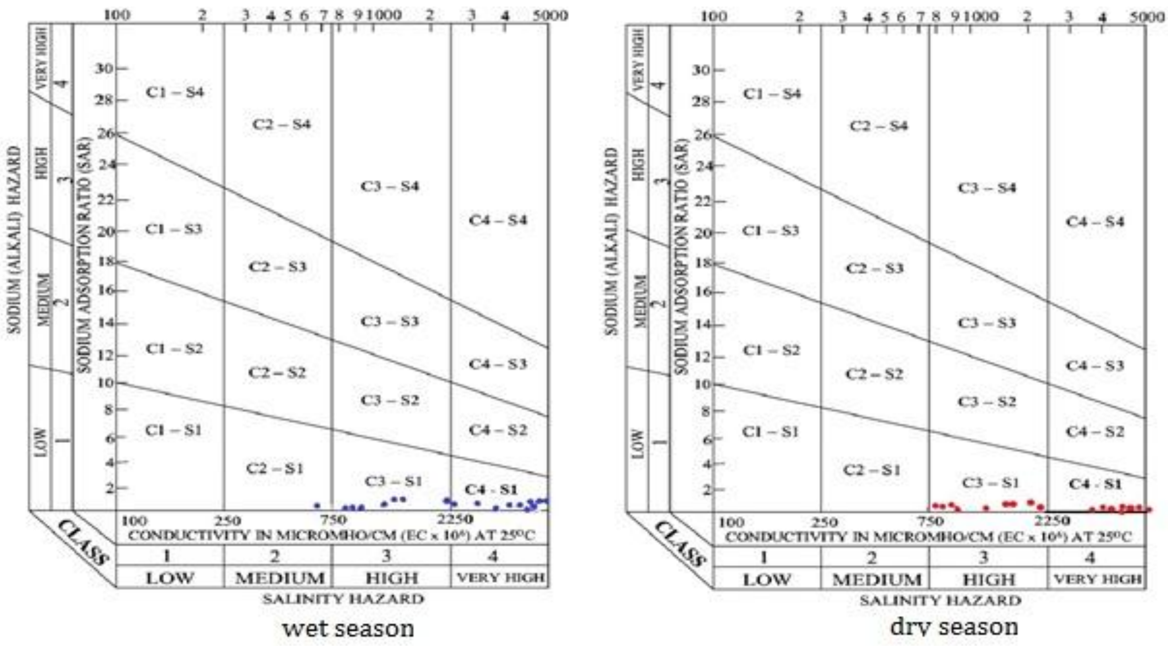

Figure 4: Richard's diagram classifying water in the study area.

- **Residual Sodium Carbonate (RSC)**

RSC is one of the key factors in irrigation water evaluation. It depends on three ions concentrations namely sodium, carbonate, and bicarbonate, and is demonstrated by the flowing equation:

$$RSC = [(HCO_3^- + CO_3^{-2}) - (Ca^{+2} + Mg^{+2})] \text{ -------------------- } 5$$

Where all ions in meq·l^{-1}

The results of the RSC for each well in both seasons showed that all the values are negative ranging between -2.88 to -26.4 in the dry season and -3 to -29.6 in the wet season, (Table 6). The negative values indicate that calcium and magnesium have higher concentrations than carbonate and bicarbonate. The figures also indicate that there is no negative impact from sodium in the irrigation water. These results are similar and compare well with other studies including that by Al-Hamdani (2020) who also got negative RSC values ranging from -1 to -25 meq·l^{-1}, for his assessment of a group of wells on the west bank of the Tigris River near Mosul City and not far away from the current study area.

- **Kelley ratio**

The Kelley ratio (Kelley, 1963) has been used to evaluate the balance between sodium, calcium, and magnesium, it can be calculated from the equation below:

$$KR = \frac{Na^{+}}{Ca^{2+}+Mg^{2+}} \text{ -------------------- } 6$$

where all ions in meq·l^{-1}

A Kelley ratio bigger than 1 indicates water that is not good for irrigation due to its high and dominant sodium ion content when compared with the other cations. A ratio of less than 1 indicates water is suitable for irrigation. In the Wanna study area, the KR value ranged from 0.04 to 0.19 in the dry season, and 0.04 to 0.24 in the wet season (Table 6). All the KR ratios are less than 1 for all the studied wells in both seasons indicating that the water is suitable for irrigation with regard to this parameter.

- **Magnesium hazard (MH%)**

The high and very high concentrations of magnesium in groundwater have a negative impact on some soil properties. It can help to convert good and fertile soil to alkaline and saline soil. This will contribute to a decline in crop yields (Gautam *et al*., 2015) and a decline in dissolved PO_4 which is absorbed by plant roots (Joshi *et al*., 2009). The magnesium hazard (MH%) has been calculated according to the following equation:

$$MH\% = \frac{Mg}{Ca+Mg} \times 100 \ldots\ldots\ldots\ldots 7$$

where all ions in meq/l

Khodapanah *et al*. (2009) point out that when the Magnesium hazard (MH%) exceeds 50% the water is not recommended for irrigation. For the Wanna area the MH% ranges from 21.23 to 53.27 % in the dry season and 16.2 to 51.7 % in the wet season, see Table (6). The majority of the results are below 50%, except for well No 4, in both the wet and dry seasons, and well No.5 in the dry season. This indicates that the majority of the water wells are suitable for irrigation with regard to this parameter.

- **Permeability index (PI)**

The Permeability index (PI) is another parameter for determining the suitability of water for irrigation. This variable takes into account the effect of ions in the water and how they influence soil permeability. The formula is calculated from the concentrations of Ca, Mg, Na, and HCO_3 according to the equation below:

$$PI = \left[\left(\frac{Na + \sqrt{HCO_3}}{Na + Mg + Ca}\right) \times 100 \ldots\ldots.8\right]$$

where all ions in meq/l

High PI leads to a decrease in the porosity of soil caused by the destruction of the soil structure leading to a negative impact on plant life (Verma *et al*., 2020).

Table 6 shows the results of calculations for both the dry and wet seasons. The highest permeability index was 38.31% recorded in well No.1 during the dry season. In the wet season, the highest permeability index was 36.34 % recorded from well No.4. The lowest permeability index was 11.03% from well No.11 in the dry season; in the wet season the lowest PI was 9.86% seen in well No.13. Ten water wells out of 18 are not suitable for irrigation in the wet and dry season, which have permeability index (PI%) less than 25%, these wells are numbered (3, 6, 7, 8, 9, 10, 11, 12, 13, and 18) in the wet season and wells numbered (3, 6, 7, 8, 9, 10, 11, 12, 13, and 18) in the dry season. According to Doneen (1964), PI% of less than 25% is classified as water not suitable for irrigation. These results are similar to the results got by Talat *et al*. (2019) for their study in the Alkosh area, which is located to the north of the study area and not far away from it.

- **Irrigation water quality index (IWQI)**

The assessment of water for irrigation is considered a vital factor for land management, optimal long-term agricultural production (Bauder *et al*., 2004), and the sustainability of key natural resources. Long-term monitoring programs are needed to identify any changes that take place in water quality over time (Raihan and Alam, 2008). The following parameters have been used to evaluate groundwater for irrigation purposes: EC, SAR, pH, and concentration of some dissolved ions including sulfate SO_4, bicarbonate HCO_3, chloride Cl, and sodium Na (Michael, 1992). The analyses have then been interrogated using the equation of Bhargava (1983) based on the geometric mean to calculate the water quality for irrigation. Seven variables were chosen in order to complete these calculations; they include water salinity EC, SAR, pH, Cl, SO_4, Na, and HCO_3- examined according to the UN-FAO irrigation and drainage paper (Ayers and Westcost, 1985). The sensitivity function was calculated for each parameter dependent on the calibration curves (Figure 4). The sensitivity function value ranges from zero to one. When this value is equal to or very close to one the variable lies within the lower limit and the water is good for irrigation. On the other hand, when the values are low or very close to zero the water has concentrations of that variable exceeding the upper limits and making the water unsuitable for irrigation (Figure 4).

The WQI for irrigation ranges from 11.7% to 89.5% in the dry season to 17.9% to 95.4% in the wet season, see Tables (7 and 8). According to Bhargava's (1983) classification, the wells numbered 3,6,7,8,9, 10,11,12, and 13 fall season within the poor water class for irrigation in both seasons; this accounts for around 50 % of the studied wells. Wells 2, 5, and 17 are classified as having good water for irrigation in both seasons. Well number 1 is categorized as good in the dry season rising to excellent in the wet season. Well number 4 is located in the good water class in the dry season reducing to acceptable in the wet season. Well number 16 was in the acceptable water class in the dry season, but improved to a good water class in the wet seasons. Finally, the remaining wells (14, 15, 18) all had good-class water in the dry season becoming excellent in the wet season (Table 9). In general, the majority of the irrigation WQI in the wet season have higher values than in the dry season.

Table 7: sensitivity function of EC, SAR, and pH for each well in the dry season.

Well No.	Na	HCO_3	Cl	SO_4	pH	SAR	EC	A*	$A^{1/n}$**	WQI in dry
1	1	0.665	0.934	1.000	0.700	1	1	0.4349933	0.8878808	88.79
2	1	0.697	0.864	1.000	0.502	1	0.914	0.2763209	0.8321507	83.22
3	1	0.868	0.867	0.010	0.304	1	0.01	0.0000228	0.2172529	21.73
4	1	0.499	0.917	0.844	0.403	1	0.61	0.0950328	0.7144666	71.45
5	1	0.556	0.917	0.876	0.403	1	0.71	0.1278379	0.7453838	74.54
6	1	0.700	0.851	0.010	0.800	1	0.01	0.0000476	0.2412827	24.13
7	1	0.537	0.817	0.010	0.105	1	0.01	0.0000046	0.1729021	17.29
8	1	0.665	0.867	0.010	0.105	1	0.01	0.0000061	0.1797607	17.98
9	1	0.334	0.901	0.010	0.010	1	0.01	0.0000003	0.1170500	11.71
10	1	0.833	0.951	0.010	0.601	1	0.01	0.0000476	0.2412858	24.13
11	1	0.665	0.851	0.010	0.204	1	0.01	0.0000116	0.1971039	19.71
12	1	0.226	0.834	0.010	0.105	1	0.01	0.0000020	0.1531996	15.32
13	1	0.605	0.901	0.010	0.204	1	0.01	0.0000111	0.1960758	19.61
14	1	0.378	0.951	1.000	0.403	1	1	0.1446184	0.7586334	75.86
15	1	0.445	0.934	1.000	0.502	1	1	0.2088343	0.7995191	79.95
16	1	0.583	0.884	0.702	0.204	1	0.44	0.0325724	0.6131262	61.31
17	1	0.741	0.863	0.553	0.700	1	0.43	0.1065320	0.7262206	72.62
18	1	0.854	0.899	1.000	0.601	1	1	0.4619438	0.8955383	89.55

*A= Na× HCO_3× Cl ×SO_4 × pH ×SAR ×EC

**n= number of variables

Table 8: Sensitivity function of EC, SAR, and pH for each well in the wet season.

Well No.	Na	HCO_3	Cl	SO_4	pH	SAR	EC	A*	$A^{1/n}$**	WQI in Wet
1	1	0.666	0.865	1	0.99	1	1	0.575292	0.924056	92.41
2	1	0.555	0.95	0.841	0.79	1	0.91	0.325424	0.851824	85.18
3	1	0.224	0.916	0.053	0.79	1	0.01	0.000088	0.263484	26.35
4	1	0.059	0.899	0.788	0.6	1	0.66	0.016829	0.557933	55.79
5	1	0.709	0.913	0.884	0.89	1	0.85	0.441795	0.889850	88.99
6	1	0.390	0.882	0.01	0.89	1	0.01	0.000030	0.226878	22.69
7	1	0.224	0.831	0.172	0.4	1	0.01	0.000130	0.278500	27.85
8	1	0.114	0.865	0.01	0.6	1	0.01	0.000005	0.179239	17.92
9	1	0.114	0.882	0.01	0.6	1	0.01	0.000006	0.179736	17.97
10	1	0.390	0.916	0.01	0.6	1	0.01	0.000021	0.215369	21.54
11	1	0.224	0.831	0.01	0.89	1	0.01	0.000016	0.207897	20.79
12	1	0.666	0.865	0.01	0.6	1	0.01	0.000034	0.230582	23.06
13	1	0.666	0.865	0.01	0.7	1	0.01	0.000040	0.235668	23.57
14	1	0.831	0.967	1	0.89	1	1	0.722911	0.954705	95.47
15	1	0.666	0.95	1	0.89	1	1	0.568854	0.922571	92.26
16	1	0.610	0.865	0.781	0.7	1	0.35	0.104099	0.723828	72.38
17	1	0.555	0.899	0.67	0.7	1	0.42	0.098919	0.718569	71.86
18	1	0.831	0.933	0.962	0.89	1	0.97	0.651533	0.940631	94.06

Table 9: Values of the WQI for irrigation water for the studied wells in both seasons.

Range of WQI	Classification	WQI % values in wet seasons	WQI % values in dry seasons
Less than 40	poor	W_3 = 26.35, W_6 = 22.69, W_7 = 27.85, W_8 = 17.92, W_9 = 17.97, W_{10} = 21.54, W_{11} = 20.79, W_{12} = 23.06, W_{13} = 23.57	W_3 = 21.73, W_6 = 24.13, W_7 = 17.29, W_8 = 17.98, W_9 = 11.71, W_{10} = 24.13, W_{11} = 19.71, W_{12} = 15.32, W_{13} = 19.61
41 – 50	marginal		
51 – 70	acceptable	W_4 = 55.79	W_{16} = 61.31
71 – 90	good	W_2 = 85.18,W_5 = 88.99, W_{16} = 72.38, W_{17} = 71.86	W_1 = 88.79, W_2 = 83.22, W_4 = 71.45 W_5 = 74.54, W_{14} = 75.86, W_{15} = 79.95, W_{17} = 72.62, W_{18} = 89.55
91 – 100	excellent	W_1 = 92.41, W_{14} = 95.47, W_{15} = 92.26, W_{18} = 94.06	

CONCLUSION AND RECOMMENDATIONS

The rock types forming the aquifer are the dominant factor that affects the quality of groundwater in the current study area, as evidenced by:

- The results of the drinking WQI revealed that wells dug in the Fatha formation aquifer and those wells that penetrate both the Quaternary and Fatha aquifers (mixed water) have poor drinking water quality. While the wells that produce water from the Quaternary aquifer have good drinking water quality.
- The irrigation WQI results revealed that the water produced from the Fatha Formation aquifer is of poor quality for irrigation. However, wells that produced water from the Quaternary aquifer, or those that penetrate both aquifers, produce excellent and good quality irrigation water.

Finally, chemical fertilizers can be used in an actual scientific manner as their excessive use pollutes the groundwater with nitrates and phosphate. In addition, the use of modern irrigation techniques, such as drip irrigation rather than surface irrigation, can utilize water in a wise way and reduce water loss. We advise against drilling wells at random without a proper understanding of the geology of the area. A good understanding of the rocks and Quaternary deposits helps to determine the well depths required to yield the most appropriate water. It is also important for the construction and casing of the wells, to avoid mixing good quality water from the Quaternary aquifer with the poor quality water from the Fatha aquifer.

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