Research Article

Monitoring of Some Physico-Chemical Parameters of Groundwater and Variations in Static and Pumping Levels of Wells of Badra and Zurbatiyah Districts of Iraq

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Abstract | Water scarcity is one of the most significant and escalating problems, receiving particular attention in arid and semi-arid regions. In recent years, efforts have been made to find solutions, methods, or alternatives to address this problem. This has increased demand for groundwater, resulting in increased drilling of wells, both planned and unplanned, without determining the quality and proper uses of this water. Twenty-one regular wells were identified, *i.e.,* 7 in Zurbatiyah and 14 in Badra. Water samples were collected from the wells over four seasons, and the static and dynamic levels and productivity of the wells were calculated. Moreover, electrical conductivity, pH, total hardness, turbidity, total dissolved solids, and total suspended solids were also measured. The results showed that the static groundwater level in the wells of the Zurbatiyah region was lower than that in the Badra region. The static groundwater levels were shallower in the spring season compared to the autumn season at both study sites. Furthermore, the change in static levels between the two seasons for the same area was highest in Badra than in Zurbatiyah between the two seasons. Pumping groundwater levels, however, were at higher depths in Zurbatiyah than in Badra in both seasons. The difference between the static and pumping levels indicates that the value was greater at the Badra well site in the autumn season. The pH values of well water at all locations ranged from 7.42 to 7.31, and no significant differences were observed in pH values. Total suspended solids (TSS) results indicate significant differences between the two locations. TDS results indicate significant differences between the two locations and across seasons, with significant overlap between them. Total hardness values indicated significant variation between the two locations and across seasons, with significant overlap between them. EC results indicated significant differences between the two locations, across seasons, and with a significant overlap between them. The quality of well water is not suitable for human consumption unless it is treated. However, it is suitable for irrigating crops, except fruit crops, which are usually sensitive to salinity. It is also suitable for livestock drinking, except for some restrictions for poultry, particularly for some wells.

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Introduction

Water scarcity is one of the contemporary problems facing most countries around the world, particularly in arid and semi-arid regions. Climate change has exacerbated this problem, expanding to Africa and the Middle East (Ramos *et al*., 2023). The Middle East, including Iraq, is currently among the most vulnerable regions to this problem. A focus has been placed on finding solutions to this problem by investing in other water resources, particularly alternative sources, including groundwater (Marcellin *et al*., 2024). Indeed, groundwater reserve is a primary water resource in Iraq and in many other countries. It may be present in large quantities in some countries, and it is the most important strategic water reserve in Iraq (Alattar, 2024).

The importance of groundwater for various uses and the means to manage it sustainably necessitate the study of groundwater reservoirs, their locations, and their water quality. This requires increased attention to the study of groundwater and the identification of its characteristics and types in terms of quantity, quality, depth, underground water movement, and recharge sources (Basharat *et al*., 2025). In addition, it is important to consider the high cost of constructing a single well, the extent of its exploitation capacity, and its vulnerability to depletion and increased salinity (Wang, 2022). Demand for groundwater has increased recently, particularly in arid and semi-arid regions. This is due to severe water scarcity, as well as attempts to expand agricultural land in these areas due to population growth (Bierkens *et al*., 2019).

The demand for well construction is at its peak in various regions, including Iraq, particularly in areas where the water quality is desirable. Consequently, well drilling has increased in excessive quantities (Wortmann, 2021). Specifically, in areas adjacent to the Iraqi-Iranian border, drilling of these wells has increased without assessing the physico-chemical characteristics of the water, particularly its ionic composition, the extent of its heavy metal contamination, or the concentration of other pollutants (Al-Zubedi, 2022; Khan *et al*., 2022).

Therefore, farmers, researchers, and relevant authorities should investigate the physico-chemical quality of the well water in these areas in order to determine its quality according to the national and international standards. To this end, this study aimed to identify the changes in groundwater quality in the Badra and Zurbatiyah areas of the Wasit Governorate of Iraq over four seasons and to study the spatial variations of wells in the study area by determining the well depths, seasonal changes in their static and pumping levels, and the level of well productivity (discharge). It was also aimed to determine the quality of well water, its classification, and its suitability for various uses.

Materials and Methods

Study area

The study area is located in eastern Iraq within Wāsiṭ Province or Governorate, specifically in Badra and Zurbatiyah districts. Zurbatiyah district is located to the northeast of Badra, which represents the international border between Iraq and Iran. The area of the study was approximately 6,500 km^2 and is situated between the longitudes 33°08'60.00" N and 46°02'60.00" E, respectively (Figure 1).

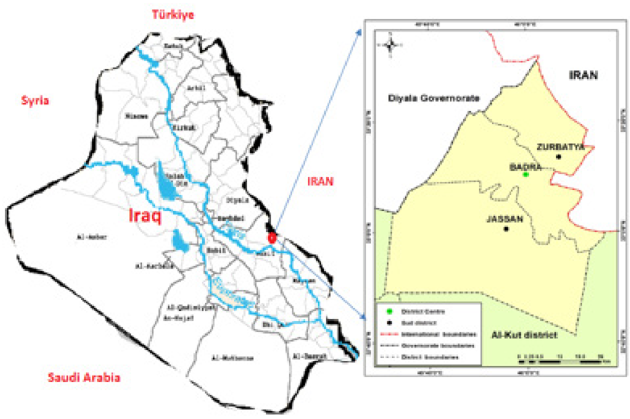

Figure 1: *Study site and sample collection*

Collection of water samples

Twenty-one water wells were randomly selected within the study area in order to determine some chemical and physical characteristics and the suitability of groundwater for various uses. Their locations were determined using a GPS device. Samples were taken from the wells after the pumps, installed in these wells, were turned on. The samples were taken after continuous pumping of the well water for more than half an hour to ensure the removal of stagnant water and to stabilize the well water level. The samples were placed in 1.5 L plastic bottles. Water sample collection was carried out four times throughout the year to assess the depth of the groundwater and determine its static and variable levels. These dates of sampling were August 15, 2024, November 15, 2024, January 15, 2025, and March 15, 2025.

Measurement of well depth, groundwater levels, and discharge

Well depth assessment

The depths of all water wells, from where study samples were taken, were accurately obtained with the assistance of the Groundwater Department in Wasit Province, Iraq.

Static and pumping water level measurement

Static and pumping water levels were determined by the Electric Water Level Probe (EWLP) method described in the Washington State Department of Health (2024). The method involves lowering a probe, connected by an electric wire, into the well until it reaches the water level inside the well. When the probe comes into contact with the water, it completes the electrical circuit, which results in the glow of the bulb within the circuit. The depth of the well was then calculated from the reading of the distance recorded on the wire extended vertically from the beginning of the well mouth to the probe, on which the distance was recorded. The static groundwater level in the well was measured at the stationary phase of water, when the pump has been off for a prolonged period of time, preferably for more than 24 hours, while pumping water level was determined when the electric pump of well has been running for at least an hour, preferably until the water depth in the well stabilizes at a certain point.

Water discharge calculation

A direct measurement method was used to determine the well pump discharge by measuring the time required to fill a container of a known volume. The container was a 55-gallon plastic drum. The process was repeated 3–5 times to achieve a reliable flow rate per unit of time. The volume of water flowing over a specific unit of time was calculated by dividing the volume of water flowing in liters or gallons by the time (seconds or minutes), as described by Taghvaeian *et al*. (2020).

Determination of water physico-chemical properties

Electrical conductivity (EC), pH, and turbidity of the groundwater samples taken from the wells were measured at a temperature of 25° using a COND EC-meter, a pH meter, and a turbidity meter, respectively, as described in Jackson (1958). The total hardness of the water was estimated using ethylene tetraacetic acid (EDTA), according to the method described in APHA (1999), using the following equation:

$$Total\ hardness\ as\ CaCO3 = Volume\ of\ EDTA\ \times 50\ \times \frac{1000}{Volume\ of\ sample}$$

Measurement of total dissolved and suspended solids (TDS and TSS)

TDS (mg/L^{-1}) in the groundwater of wells were measured using a TDS meter. TSS values (mg/L^{-1}) were estimated in groundwater by filtering 100 ml of a well water sample onto a filter paper with a known weight (B) of 0.45 µm diameter using a Millipore® filtration apparatus (Millipore, Billerica, USA). The paper was oven-dried at 103–105°C for one hour. After drying, it was weighed (A) according to the method mentioned in APHA (2007). TSS were calculated according to the following formula:

$$Total\ suspended\ solids = \frac{(A - B) \times 1000}{Volume\ of\ sample\ (100mL)}$$

Global determinants of some water types

The groundwater types from the studied wells were classified according to certain established criteria and classifications, as shown in Tables 1–5.

Results and Discussion

Static water level

The results showed that the static groundwater level in the study wells in the Badra area during the autumn and spring seasons ranged between 5.46 and 22 m, and between 5.22 and 15.61 m, with an average of 11.37 and 23.30 m, respectively. While, the static groundwater level in the wells of Zurbatiyah area during the same seasons ranged between 5 and 9.23 m and between 4.85 to 9.63 m, with an average of 7.53 and 7.37 m, respectively (Table 6).

The results showed that the groundwater depths in the Zurbatiyah area were shallower than in the Badra area. This may be due to the topography of the area and the elevation of the groundwater table above sea level, which affected the depth of groundwater in the aquifers (Saleh, 2020). It may also be due to the greater exploitation of groundwater in Badra compared to Zurbatiyah, or to the proximity of the Zurbatiyah area to groundwater sources that come from the mountainous regions of Iran or are close to

Table 1: *The ability of agricultural crops to tolerate salt concentrations according to the classification (Todd, 2007).*

Crop Division	EC					
	Low salt tolerance crops		Medium salt tolerance crops		High salt tolerance	
Fruit Crops	(0 – 3000)(µS /cm)	Limon, Peach, Pear Apricot, Orange, Apple.	(3000 – 4000) (µS /cm)	Cantaloupe, Olive, Figs, Pomegranate.	(4000 – 10000) (µS /cm)	Date palm
Veg-etable Crops	(3000 – 4000) (µS /cm)	Green beans, Celery, Radish.	(4000 – 10000)(µS / cm)	Cucumber, Peas, Onion, Carrot,Potatoes, Lettuce, Cauliflower, Tomato.	(10000 – 120000)(µS / cm)	Spinach, beets
Field Crops	(4000 –6000) (µS /cm)	Field beans	(6000 –10000) (µS /cm)	Sunflower, Corn, Rice, Flax, Sorghum	(10000 – 16000)(µS /cm)	Cotton, Sugar beet, Barley (grains)

Table 2: *Standard limits for Iraqi and international drinking water*

Present study Minimum & Maximum	Living aquatic	Irriga-tion	USA specifi-cations	Canadian specifications	European specifications	WHO (2018)	Iraqi Spec-ifications 2009 (IQS)	Parameters l)/(mg
18.2-37.5	-	-	-	-	-	25		Temperature
7.18-7.61	9-6.5	8.5-6.5	8.5-6.5	8.5-6.5	8.5-6.5	8.5-6.5	8.5-6.5	PH
3.06-5.06	-	2250	-	-	-	1500	1530	EC(µs/cm)
2.3-15.5	5	-	5-1	5	4	5	5	Turb $_{NTU}$
600-1599	-	-	-	-	-	500	500	TH
68-299	-	-	-	-	-	-	51.34	TSS
1803-2989	500	-	500	500	-	1000	1000	TDS

surface rivers. Groundwater is likely continuous in the study area (Ostad-Ali-Askari and Shayannejad, 2021; Majumder, 2024).

Table 3: *Water classifications for total hardness*

Type water	Altoviski- 1962	Boyd - 2000	Todd - 2007
Soft	0 - < 75	0 - 50	0 – 60
Moderate hard	75 - < 175	50 - 150	60 - 120
Hard	175 - < 300	150 - 300	120 – 180
Very hard	> 300	> 300	> 180

Table 4: *Water classifications for TDS (ppm)*

TDS (ppm)			Water class
Todd (2007)	Drever (1997)	Altoviski (1962)	
10 - 1000	<1000	0 - 1000	Fresh water
- - - - -	1000 - 2000	1000 – 3000	Slightly -Brack-ish Water
1000 - 10000	2000- 20000	3000 - 10000	Brackish water
10000 - 100000	35000	10000 - 50000	Salty water
> 100000	> 35000	> 50000	Brine water

Moreover, it was found that groundwater levels were shallower in the wells relative to the constant level in the spring season compared to the autumn season at both sites, whether in Badra or Zurbatiya. This may be because the spring season coincides with the rainy season and floods, which is the period of recharge and storage of groundwater and groundwater with rainwater and floods, while the autumn season represents the dry season and scarcity and increasing demand for groundwater (Alattar, 2024). The soil characteristic presence of rocks, gravel, and coarse soil facilitates the transfer of surface water, whether from floods or rain, to groundwater (Ngah and Nwankwoala, 2013).

Pumping water level

According to the results, the pumping groundwater level in the study wells in the Badra area during the autumn and spring seasons ranged between 9 to 31.66 m, and between 15.75 to 35.94 m, with an average of 21.74 and 25.85 m, respectively. While the pumping groundwater level in the wells of Zurbatiyah area during the same seasons ranged between 14 to 36.31 m and between 13.65 to 36.26 m, with an average of 26.55 and 26.39 m, respectively (Table 6).

Table 5: *The suitability of groundwater for animal drinking according to the US Environmental Protection Agency (USEPA)*

Types of animals	TDS (PPM)
Poultry	2800
Horses	6400
Milk cattle	7150
Beef cattle	10000
Sheep	12900

Overall, these results showed that the water depths were higher in Zurbatiyah than in Badra in both seasons. This may be due to the geological nature of the area, the variation in the study area's levels from sea level, and the proximity or distance to the aquifer feeding zone (Wei *et al*., 2024). It is also evident that there is a seasonal variation in the pumping water level, particularly in the Badra region, where the decrease in the pumping water level was greater in spring compared to autumn. This might be due to the significant variation in water temperatures in both seasons, as temperatures remained higher in autumn than in spring, with a clear difference (Table 6). Lower temperatures affect the viscosity of the water and increase it, which affects the water conductivity of the aquifer and feeding layers of the well. Thus, the water level inside the well decreases in colder seasons due to the decreased water conductivity of the feeding layers (Xie *et al*., 2022).

Discharge capacity of water wells

The results showed that the productivity values of the wells in the study area within the Badra site during

Table 6: *Static and pumping water levels, actual and design depth, and discharge of the wells in the study area for two different seasons*

Study area	Well code	Depth (m)	Fall 2024					Spring 2025				
			Static (m)	Pumping (m)	Difference between levels	Productivity (discharge) L/s-1	Temperature (°C)	Static (m)	Pumping (m)	Difference between levels	Productivity (discharge) L/s-1	Temperature (°C)
Badra	S1	60	8.00	17.00	9.00	7.00	31.8	7.75	16.76	9.01	7.15	26.7
	S2	54	7.33	31.66	24.33	8.00	31.9	7.00	31.32	24.32	8.2	25.7
	S3	60	14.00	24.00	10.00	8.00	32.5	13.60	23.58	9.98	8.1	25.8
	S4	60	8.00	22.00	14.00	9.00	28.8	7.71	21.73	14.02	9.3	25.5
	S5	60	5.46	22.00	16.54	10.00	36.5	5.22	21.76	16.54	10.3	27.9
	S6	60	9.00	22.00	13.00	5.00	34.4	8.77	21.79	13.02	5.18	29.7
	S7	60	22.00	5.64	16.36	10.00	33.2	5.55	21.90	16.35	10.21	31.5
	S8	60	8.00	19.5	11.5	6.00	32.8	7.83	19.33	11.5	6.19	28.9
	S9	54	9.5	36.00	26.5	4.00	32.1	9.45	35.94	26.49	4.23	24.9
	S10	67	18.00	9.00	9.00	7.00	33.5	8.91	17.92	9.01	7.08	25.2
	S11	60	12.00	20.00	8.00	7.00	33.5	11.66	19.65	7.99	7.14	25.3
	S12	60	9.00	16.00	7.00	7.00	31.1	8.78	15.75	6.97	7.22	24.9
	S13	60	16.00	30.00	14.00	7.00	32.5	15.61	29.59	13.98	7.16	22.1
	S14	60	13.00	29.61	16.61	8.00	31.5	12.55	29.20	16.65	8.05	24.7
Lowest		_	5.46	9.00	7.00	4.00	28.8	5.22	15.75	6.97	4.23	22.1
Highest		_	22.00	31.66	24.33	10.00	36.5	15.61	35.94	24.32	10.21	31.5
average		_	11.37	21.74	13.98	7.35	32.57	9.31	23.30	13.99	7.587	26.34
Zurbatiyah	15S	60	9.23	32.5	23.27	8.00	37.5	9.09	32.36	23.27	8.00	27.2
	16S	60	5.59	35.71	30.12	6.5	35.7	5.5	35.62	30.12	6.6	23.4
	17S	48	8.00	27.35	19.35	7.00	33.6	5.65	36.26	30.61	6.1	27.4
	18S	60	5.71	36.31	30.6	6.00	35	7.91	27.26	19.35	7.00	24.9
	19S	60	5.00	25.00	20.00	7.00	35.3	4.85	24.83	19.98	7.10	28.5
	20S	55	10.00	14.00	4.00	8.00	33.8	9.63	13.65	4.02	8.15	23.5
	21S	60	9.20	15.00	5.8	7.00	34.3	9.00	14.79	5.79	7.20	29.3
Lowest		_	5.00	14.00	4.00	6.00	33.6	4.85	13.65	4.02	6.10	23.4
Highest		_	9.23	36.31	23.27	8.00	37.5	9.63	36.26	30.61	8.15	29.3
average		_	7.53	26.55	19.02	7.07	35.02	7.375	26.39	19.02	7.16	26.31

the fall season ranged between 4–10 Ls^{-1} at an average of 7.35 Ls^{-1}. The highest value was 10 (Ls^{-1}) in well S5, and the lowest was 4 Ls^{-1} in well S9. During the same season in the Zurbatiyah area, the production capacity of the wells ranged between 6–8 Ls^{-1} at an average of 7.07 Ls^{-1} (Table 6). As for the spring season, it appears that the productivity of the wells in the Badra area ranged between 4.23–10.21 Ls^{-1} at an average of 7.587. The highest productivity value was 10.3 Ls^{-1} in well S5, and the lowest was 4.23 Ls^{-1} in well S9. For the Zurbatiyah region and the spring season, the productivity of the studied wells ranged between 6.1–8.15 Ls^{-1}, with an average of 7.16. The highest value was 8.15 Ls^{-1} in well S20, and the lowest was 6.1 Ls^{-1} in well S17 (Table 6).

There is variation in water productivity from one well to another within the Badra region or within Zurbatiyah. This might be due to variations in the installation and design of pumps on the wells, as well as differences in the type, capacity, and size of the pumps used to draw water from the wells, in addition to variations in the depths of the static and pumping water levels in the wells (Benghanem *et al*., 2014;). However, despite differential static and pumping levels and other factors previously mentioned, no significant or clear differences had been found for the variance in average productivity values between the two sites and across the two seasons. The reason for the lack of variance in averages may be due to the interaction of more than one cause, whether positive or negative, in increasing or decreasing the wells' productivity. For example, lower temperatures increase water viscosity, accompanied by a decrease in the pumping level (Ma and Zheng, 2010). These two characteristics are opposite to each other in pump productivity, and vice versa (Xie *et al*., 2022).

Disparity between static and pumping levels of wells

The difference between the static and the pumping levels indicates several factors, including the well's ability to feed water to the pump, which reflects the amount of water-rich layers present along with the depth, as well as the location of these layers along with their water conductivity (Xie *et al*., 2022). It is clear from the values of the difference between the static and pumping levels in Table 6 that the value at the Badra well site during the autumn season was approximately 7–24.33 m with an average of 13.98 m. At the Zurbatiyah site during the same season, the values were approximately 4–30.12 m with an average of 19.02 m. For the spring season, the difference between the levels for the Badra wells ranged from 6.97 to 26.49 m with an average of 13.99 m. In the same season, the difference between the levels for the Zurbatiyah wells ranged from 4.02 to 30.61 m with an average of 19.02 m (Table 6).

These findings showed differential levels among the wells of the same site, in addition to the differential statistic and pumping water levels among both sites within the same season. This discrepancy between the sites, whether between the wells of the same site or between the wells of the two sites, may be due to several differences, including the design of the well or pump, its efficiency, and its production capacity, as well as the variation in the depth of the pumps in the wells, as shown by the production values. Furthermore, as previously mentioned, the reason for the discrepancy may be due to the nature of the water conductivity of the underlying water layers prepared for the wells, in terms of their thickness, hydrological characteristics, their preparation, depth, and location (Åberg *et al*., 2021).

Table 7: *Average temperature values (°C) for well water in the study area*

Season	Sites		Average
	Zarbatiya	Badra	
Summer	35.02	32.58	33.39
Fall	26.40	23.66	24.58
Winter	22.53	21.33	21.73
Spring	26.31	26.34	26.33
Average	27.57	25.98	---
LSD	Site:0.849	Season:1.125	Combined:1.69
* (P≤0.05)			

Physico-chemical characteristics of well water

Water temperature

A significant difference in groundwater temperature values across the two locations and across seasons was found, although no difference was observed for water temperatures of different wells within the same area or season (Table 7). This might be because the groundwater is characterized by its temperature being almost constant at short distances due to the thermal conductivity of water (Ramires *et al*., 1995). The average well water temperature in the Zurbatiyah and Badra were 27.57 and 25.98°C, respectively (Table 7).

Regarding seasonal analysis, the highest water temperature was recorded in the summer (33.39°C), while the lowest was in winter (21.73°C). This would be due to climatic influences and their impact on water temperatures (Kumar, 2012). Indeed, the Iraqi climate is continental, characterized by hot, dry summers and cold winters, and by the large annual and daily variations in temperatures. Moreover, it was noted that the level of temperature decreased in the Zurbatiyah location during the summer by 55% compared to the Badra site (52%). The overlap between location and season in temperature is due to the aforementioned factors. This may be due to the variation in some climatic conditions between the two regions, in addition to the influence of several factors, most notably the variation in the depths of the aquifers equipped for wells between the locations, as well as differences in their sources and water quality (Riedel, 2019). Since groundwater is deep, temperatures are related to geological composition and structural movements (Manga, 2001; Alattar, 2024). Temperatures also vary with depth and proximity to the Earth's surface, with the temperature of the Earth's crust increasing by one degree Celsius with every 33-meter increase in depth, depending on the nature of the geological formations (Eppelbaum *et al*., 2014).

Water turbidity

A significant difference in groundwater turbidity across the two locations was found, although no difference was observed for the water turbidity of both seasons. The average turbidity value (10.33 NTU) was higher for the Zurbatiyah area than the Badra area, with an average turbidity value of 6.19 NTU (Table 8). The reasons for the low turbidity values in all the study wells may be because groundwater is generally characterized by high purity and low turbidity due to the filtration process that the well water undergoes through the soil layers, thus eliminating suspended matter such as silty and clayey sediments, particularly colloidal ones which increase the water turbidity (Otieno *et al*., 2012).

Table 8: *Average turbidity values for well water in the study area.*

Season	Sites		Average
	Zarbatiya	Badra	
Summer	10.44	5.86	7.39
Fall	10.51	6.29	7.70
Winter	9.71	5.68	7.02
Spring	10.63	6.93	8.17
Average	10.33	6.19	---
LSD	Site:0.961	Season:1.28	Combined:1.92
* (P≤0.05)			

Differential turbidity values between the two sites may be due to the variation in the surface of the land in terms of the nature of the vegetation cover and the geological terrain of the region, as well as the variation in human activities, including agricultural and industrial activities, which contribute to the movement of fine colloids to the bottom of the soil layers with rain. Suspended particles are considered sediments such as clay, soil, organic and inorganic materials, and phytoplankton, are among the most important factors contributing to increased water turbidity (Ahmed *et al*., 2025). However, the most important reasons for the discrepancy between the two sites may be due to the geological composition of the soil layers, the variation in their colloid content, and the variation in weathering processes that may occur within the two regions, which are reflected in the number of colloids supplied. In addition, there are variations in the depth of the pipes, pump specifications, and well dimensions, which result in variations in the disturbances of standing water during water withdrawal, which contribute to the lifting of suspended matter with the withdrawn water.

Water pH

The results showed that the pH values of well water in all locations ranged from 7.42 to 7.31. No significant differences were observed between the wells in all study locations, nor between the seasons(Table 9). The pH values of well water were within the neutral range and tended toward alkalinity, with all values greater than 7. This may be due to the calcareous soils in the study area and the fact that the source rocks in Iraq are predominantly calcareous, as calcium carbonate tends toward alkalinity (Al-Shihmani, 2022).

Table 9: *Average pH values of well water in the study area*

Season	Sites		Average
	Zarbatiya	Badra	
Summer	7.31	7.42	7.39
Fall	7.33	7.41	7.38
Winter	7.31	7.42	7.38
Spring	7.32	7.39	7.37
Average	7.32	7.41	---
LSD	Site:0.12	Season:0.27	Combined:0.322
* (P≤0.05): NS			

Total suspended solids (TSS) and total dissolved solids (TDS)

TSS and TDS values were significantly different between both sites, although no significant differences were recorded for the seasons (Table 10 and Table 11). The average value of TSS in the Zurbatiyah site was 217.46 mg/L compared to the average value in the Badra area of 181.13 mg/L^{-1}, while the average TDS value for the Badra area was 2362.82 mg/L^{-1} as compared to the average TDS value of the Zurbatiyah area (2173 mg/L^{-1}). Moreover, there was a significant variation in the TDS values across the four seasons. The highest level was recorded in winter (2372.76 mg/L^{-1}) in the Badra area, while the lowest was in spring (2253.19 mg/L^{-1}) in the Zurbatiyah area. It was found that the decrease in dissolved salts in Badra during the winter season was about 6.2% as compared to 3.2% in Zurbatiyah.

Table 10: *suspended solids (TSS) in (mg/L-1) for well water in the study area*

Season	Sites		Average
	Zarbatiya	Badra	
Summer	223.71	178.86	193.81
Fall	220.14	189.50	199.71
Winter	209.86	175.50	186.95
Spring	216.14	180.64	192.48
Average	217.46	181.13	---
LSD	Site:20.44	Season:27.26	Combined:40.80
* (P≤0.05): NS			

Table 11: *total dissolved solids (TDS) for well water in the study area (mg/L^{-1})*

Season	Sites		Average
	Zarbatiya	Badra	
Summer	2140.86	2349.21	2279.76
Fall	2132.71	2372.36	2292.48
Winter	2245.00	2436.64	2372.76
Spring	2173.43	2293.07	2253.19
Average	2173.00	2362.82	---
LSD	Site:74.84	Season:99.79	Combined:149.7
* (P≤0.05)			

These differential TSS and TDS values in the wells at both sites might be due to the differences in well design, including well dimensions, pump depth within the well, well production capacity, and installed pump size (Aliewi and Alomirah, 2020). These differences may cause differences in the intensity of sediment disturbance within the well when the pump is operating. Consequently, the pump may draw sediment along with the water, which may then reappear with the water flowing out from the well (Ikramov *et al*., 2021). In addition, this may also be due to differences in the nature of the mineral composition or sediment content of the aquifers. Some aquifers equipped with groundwater may contain fine sediments between their layers, and these sediments, which are confined between the feeding layers, move with the flow of water from the aquifers into the well (Kirsch, 2006; George-Williams *et al*., 2024). Consequently, these sediments are drawn by the pump during water withdrawal. Moreover, the infiltration of wastewater into groundwater reservoirs and the extensive use of chemical fertilizers may lead to increased concentrations of dissolved salts (Mohammed, 2016; Su *et al*., 2022).

Hardiness of well water

A similar trend of significance was found for water hardiness for both sites. There were also significant differences in total hardness values between seasons. The average total hardness value in Badra was 1002.05 mg/L^{-1}, while it was 918.18 mg/L^{-1} for Zurbatiyah (Table 12). This may be due to variations in the chemical composition of groundwater rocks and their content of soluble salts, particularly those containing chlorides, sulfates, carbonates, and calcium ions (Kudryashova *et al*., 2021). Increases in these salts cause higher total groundwater hardness values. Moreover, addition of geological weathering-mediated minerals and compounds, including ions, calcium, magnesium, sulfates, chlorides, can ultimately increase the water hardness values.

Table 12: *total hardness for well water in the study area (mg/L^{-1})*

Season	Sites		Average
	Zarbatiya	Badra	
Summer	1152.71	1275.29	1234.43
Fall	1175.29	1288.79	1250.95
Winter	685.14	745.64	725.48
Spring	659.57	698.50	685.52
Average	918.18	1002.05	---
LSD	Site:39.15	Season:52.19	Combined:78.29
* (P≤0.05)			

Regarding seasonal difference, the highest water hardness (1250.95 mgL^{-1}) was recorded for the fall season, while the lowest value (685.52 mgL^{-1}) was recorded for the spring season. The reason for the lower hardness values in the spring may be due to the effect of higher electrical conductivity and TDS values for the reasons mentioned above. This may be due to higher sodium ion concentrations in the water during the spring season compared to calcium and magnesium concentrations, which contribute to lower turbidity, as sodium does not cause hardness. The interaction between location and season, there is a significant overlap. The highest total hardness levels were recorded in the Badra and Zurbatiyah areas during the fall, at 1288.79 mgL^{-1} and 1175.29 mgL^{-1}, respectively. It is noted that the level of decrease in total hardness during the fall season was 82% in the Badra area, compared to 78% in the Zurbatiyah area.

Electrical conductivity of water

EC values of groundwater were also significantly different for both study sites. The highest average value of water EC was found for Badra (4.01 dsm^{-1}), compared to 3.67 dsm^{-1} in the Zurbatiyah area (Table 13). Differential EC values among both sites may be due to the variation in the mineral content and chemical composition of the geological formations of the water-bearing layers in both locations, as well as the variation in the quality and concentration of dissolved salts in both areas as a result of the interaction of water with these components. This leads to variations in the degree of solubility of salts and minerals present in the geological formations. Variations in geochemical processes, such as reverse exchange processes and interactions between rocks and water, affect the groundwater content (Al-Obaidi *et al*., 2022). In addition to the proximity or distance of wells from their sources of supply from surface water or other water sources, the further the groundwater flows, the greater the salt dissolution process, which leads to an increase in electrical conductivity (AL Zubadi, 2022). Moreover, human activities may affect the increase in dissolved salts and thus an increase in EC (Elnazer and Salman, 2021).

The highest salinity level (4.06 dS^{-1}) was recorded in the winter, while the lowest level was recorded during the autumn (3.79 dS^{-1}). The results obtained are clearly contrary to what is commonly known. As is typical, the dry climate, the lack of groundwater reservoir preparation in the summer or autumn, and the increased demand for groundwater during those seasons lead to increased electrical conductivity concentrations in groundwater during dry seasons. However, our results were contrary, as this may be due to the arrival of surface floods laden with saline water from neighboring countries, which seeped into the groundwater in the study area or in areas that may not be far from the study area, whether in Badra or Zurbatiyah, and then seeped into the groundwater during the winter (Singh, 2022). In addition, it was noted that the salinity decrease in the Zurbatiyah region during the summer was 12% higher than 6% recorded for the Badra region. This indicates that the Zurbatiyah region is more exposed to variations between seasons and locations.

Table 13: *Electrical conductivity values EC dS/1 for well water in the study area*

Season	Sites		Average
	Zarbatiya	Badra	
Summer	**3.49**	**3.98**	3.82
Fall	**3.58**	**3.90**	3.79
Winter	**3.91**	**4.14**	4.06
Spring	**3.69**	**4.00**	3.89
Average	3.67	4.01	---
LSD (P≤0.05):*	Site:0.148	Season:0.197	Combined:0.295

Groundwater quality

The electrical conductivity values for all the studied wells over the four seasons ranged from 3060 to 5060 μScm^{-1}. When compared with the values given in Table 1, which specifies the ability of crops to tolerate salt concentrations according to Todd (2007), the well water was found suitable for irrigating all crops and vegetables, but was not suitable for most of the fruit crops, such as those with low salt tolerance (lemon, peach, pear, apricot, orange, and apple) (Kirby and Ahmad, 2022).

As for its suitability for human drinking, when compared with international and Iraqi standards, as given in Table 2, which specifies the standard limits for Iraqi and international drinking water, it is clear that the electrical conductivity and TDS values were high and rendering the well waters unsuitable for drinking under all circumstances, except after treatment.

Table 3 specifies water classifications according to total hardness, and according to this table, all wells' water quality was classified as very hard. As for water quality, according to international classifications for

TDS (Table 4), it is evident that the well water in the region was classified as "slightly brackish water." As for its use for animals, according to the classification mentioned in Table 5 regarding the suitability of groundwater for drinking by animals, and according to the US Environmental Protection Agency (USEPA), well waters were suitable for all animals, except for some caveats regarding its use during periods when levels exceed the undesirable limits for poultry.

Conclusions and Recommendations

Based on overall study results, it is concluded that static and pumping water levels and most of the groundwater characteristics exhibited significant variations (at $p \leq 0.05$) for both locations (*i.e.*, Zurbatiyah and Badra) of the Wāsiṭ Governorate of eastern Iraq. Similarly, a differential trend was recorded for all studied parameters across the four seasons and between the wells of the same area or with the same season. These differences might be explained on the basis of many factors, including the design and depth of the well or pump, its efficiency and production capacity, as well as on differential geological composition, anthropogenic activities, and prevailing climatic conditions of the sites. Moreover, the quality of well water was found not suitable for human drinking but suitable for irrigating crops and rearing livestock animals.

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Novelty Statement

The static groundwater level in the wells of the Zurbatiyah region was lower than that in the Badra region. The static groundwater levels were shallower in the spring season compared to the autumn season at both study sites

Author's Contribution

Ban Firas Jalil Al-Saaeidi: Article idea and writing collect data from the field.
Layth Saleem Salman Al-Shihmani: Editing first dirf, article idea, Jamal Naser Abedalrahman data analysis.

Generative AI or AI assisted technology statement
The authors declare that they have not used generative AI or AI-assisted technologies in this manuscript.

Conflict of interest
The authors have no conflict of interest.

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