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Hydrochemical Investigation and Water Quality Index of Groundwater in the Abu Ghraib District, Western Baghdad Governorate, Iraq

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Abstract

The groundwater quality in the Abu Ghraib area of Baghdad governorate was estimated using a water quality index. Abu Ghraib area is located between latitudes (33° 10' 5" - 33° 22' 4" N) and longitudes (44° 1' 0" - 44° 13' 7" E) where twenty samples sixteen from groundwater, three from the Main drain, and one channel from the Euphrates River were collected and analysed between September 2023 and April 2024 for physical and chemical data. Which include TDS, pH, EC, Cation and anion. The sampled water was neutral to slightly alkaline based on pH results. Groundwater samples are categorized as fresh to mildly salted according to TDS classifications. Every sample water is excessively mineralized according to Ec.. By applying the Kurlolov equation, it has been found that most water samples are of $CaSO_4$ type, and the other samples range between $NaSO_4$, NaCl, and CaCl. When using the Durov classification, it was found that the samples were chloride-sulphate. The water quality in the study area for two period are categorized as good water (Ch) and poor water for (W16), while the remaining samples are classified as very poor water to unsuitable for ueses water due to high values of the calculated WQI values. It can be used for agricultural activity, with the except of W2 and W7, although it is good for livestock, building, and irrigation .

Keywords: Hydrochemical , Water quality , Abu Ghraib , Groundwater , irrigation , Baghdad.

دراسة الخواص الهيدروكيميائيه وجوده المياه للمياه الجوفية في منطقه ابوغريب غرب محافظة بغداد ، العراق

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الخلاصة

تم تقدير جودة نوعية المياه الجوفية في منطقة أبوغريب بمحافظة بغداد باستخدام مؤشر جودة نوعية المياه. تقع منطقة الدراسة في ابوغريب بين خطي العرض (33° 10' 5" – 33° 22' 4" شمالاً) وخطي الطول (44° 1' 0" – 44° 13' 7" شرقاً) حيث تم جمع وتحليل 20 عينة (16عينة من المياه الجوفية و3 عينات من المصب العام وعينه واحدة من قناة نهر الفرات) في (ايلول 2023) و(نيسان 2024) درست البيانات الفيزيائية والكيميائية. التي تشمل المواد الصلبة الذائبة الكلية، الرقم الهيدروجيني، الموصلية الكهربائية و الايونات الموجبة والسالبة ، ,وجد أن مياة العينات متعادلة إلى قلوية قليلاً بناءً على النتائج pH . وتم

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تصنيف عينات المياه الجوفية على أنها عذبة إلى مالحة قليلاً وفقًا لتصنيفات المواد الصلبة الذائبة .جميع عينات المياه الجوفية معدنية بشكل عالي وفقا لتصنيف Ec . وبتطبيق معادلة كورلولوف وجد أن أغلب عينات المياه من نوع $CaSO_4$، وتتراوح العينات الأخرى بين NaSO4 وNaCl وCaCl. وعند استخدام تصنيف دوروف وجد أن
العينات كانت من نوع كلوريد–كبريتات. تم تصنيف جودة المياه في منطقة الدراسة لفترتي الدراسة كمياه جيدة Ch) ومياة رديئة بالنسبة (W16) اما باقي العينات فتتراوح بين رديئة جدا الى غير مناسبة للاستخدام بسبب ارتفاع قيم WQI المحسوبة. ويمكن استخدامها للنشاط الزراعي باستثناء W2 وW7، بالرغم من أنها جيدة للثروة الحيوانية والبناء و الري

1. Introduction

One of the world's most important natural resources is groundwater. Population increase causes a greater demand for groundwater resources, which has resulted in a variety of environmental problems in recent years[1]. The most important natural resource on Earth is groundwater. Groundwater is a vital source of water for industry, agriculture, and human consumption for most people on the earth [2]. Most dry and semiarid regions depend on groundwater for development because they receive little precipitation or surface water [3].The hydrographic characteristics, terrain, and numerous climate conditions all affect the composition of groundwater. However, the chemistry of the rocks that contain water and the deep water that contributes to feeding water-bearing levels at the top and reaching it through weak permeability separating layers have the greatest influence on the quality of groundwater[4]. Understanding the mechanics and nature of chemical interactions between water and groundwater-bearing rocks can be facilitated by studying the hydrochemical characteristics of water, making protection more effective and straightforward [5].Depending on the kind of rock, its chemical and physical qualities, the direction and speed of water movement, and other geological and hydrological parameters, different groundwater characteristics can be found in the research region. On the other hand, its slow movement makes it more sanitized, while its rapid movement reduces the time needed for ion exchange between it and the rocks. Because water spends a significant amount of time in contact with rock units, a variety of elements, including temperature, oxidation, reduction, and the impact of vegetation cover, climate, and direct human and animal involvement, impact this process [6].Among the most prevalent contaminants in water are heavy metals. Drinking water and cooked food can expose people to chemicals in groundwater, which can build up in the body both directly and indirectly and cause health hazards such as respiratory problems [7].

Evaluating groundwater quality is crucial for the advancement of society. When considering the economic growth of water quality for human consumption, industrial, animal, and agricultural operations have not received enough consideration, particularly in emerging nations. [8] One way of reducing a set of factors to a single numerical number is to utilize the Water Quality Index (WQI). Around the world, indicators for water quality have been developed to evaluate the quality of both surface and groundwater. These indices utilized numerous attributes on water quality [9]. Many researchers have used WQIs in Iraq to assess water quality in different water resources [10, 11, 12, 13 and 14].

The research aims to evaluate hydrochemical investigation of the study area, and determine the quality of water for irrigation, agriculture, and construction purposes.

2. Location of study area

The Abu-Ghraib region spans longitudes (44° 1' 0" - 44° 13' 7" E) and latitudes (33° 10' 5" - 33° 22' 4" N). It is situated east of Fallujah City and west of the Baghdad Governorate (Fig. 1). An asymmetrical concave anticline basin containing quaternary sediment is representative of the Mesopotamian zone, which includes the Abu-Ghraib area [6]. Temperatures in summer in the Abu-Ghraib region are high, while temperatures in winter are low, which are indicative of a semi-arid and dry environment [15].In the southwest of the Abu Ghraib region are Pleistocene and Holocene river terrace deposits from the Euphrates River. The terraces are made of gravel and sand, but as they get closer to the river, they transform into clay and silt with sand lenses [16].

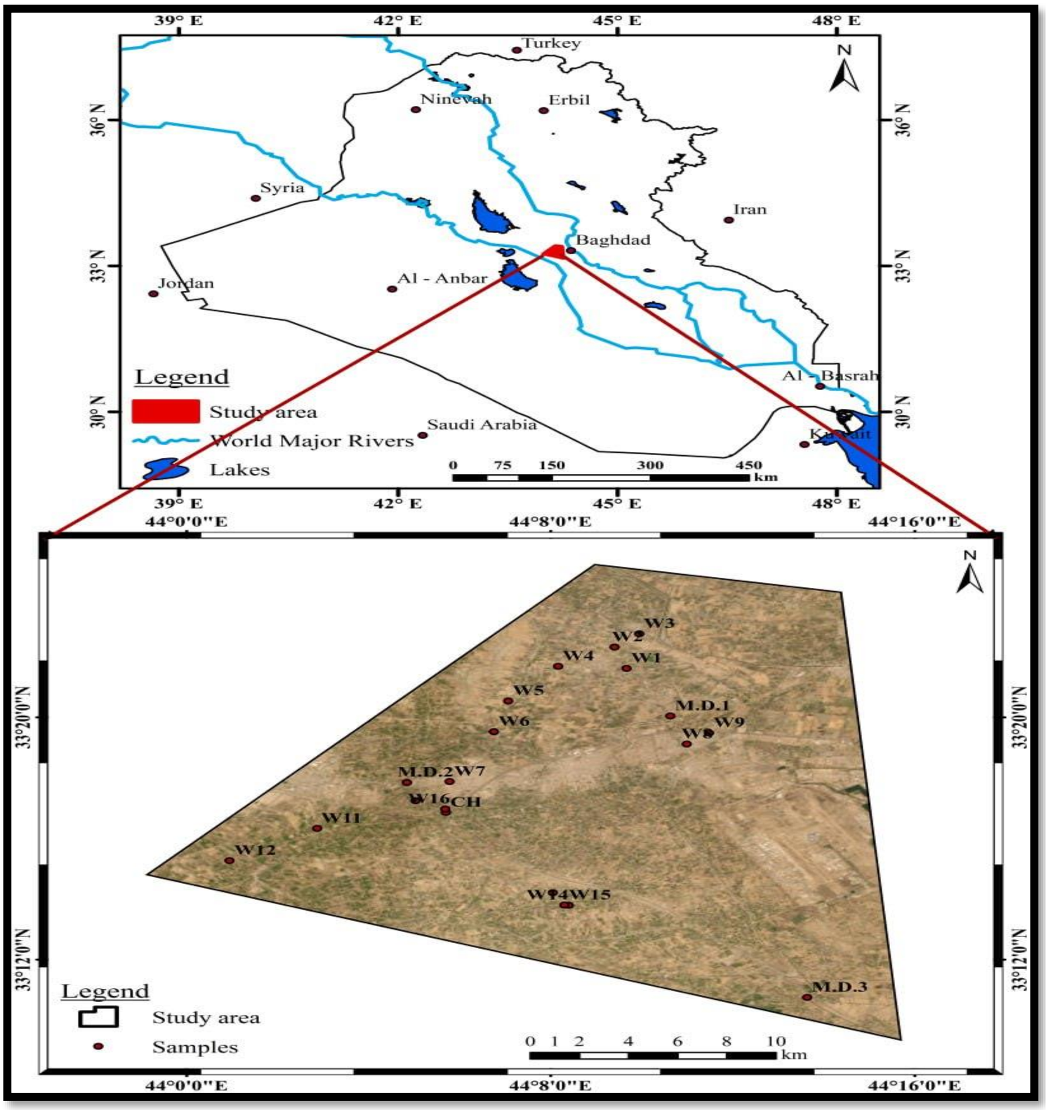

Figure 1: Map of the study area and the sampling locations.

3. Methods and materials

In the study area, water samples were collected from sixteen wells, three main drains, and one channel from the Euphrates River between the dry period in September 2023 and the wet period in April 2024. The samples' locations, elevations, and depths of the wells are displayed in Figure 1 and Table 1. Each sample's coordinates (longitude and latitude) are precisely determined using of a global positioning system (GPS) while, the Total Dissolved Solids (TDS), Temperature T(°C), and Electrical Conductivity (EC) have been measured in situ Table 2. Groundwater samples were brought to the laboratory at the Ministry of Science and Technology's for analysis, including pH, TDS, T.H, Na^{+}, Ca^{2+}, K^{+}, Mg^{2+}, SO_4^{2-}, HCO_3^{-}, Cl^{-}, PO_4^{3-}, NO_3^{-}. The calculations below have been utilized for calculating the Weighted Arithmetic Index Method (WQI), which assesses if an element is fit to be consumed by humans [17].

$$WQI=\sum QiWi / \sum Wi \quad (1)$$

Where: (Qi) This expression is used to calculate every parameter's quality rating scale: * 100

$$Qi-(V-Vo/ Si-Vo)*100 \quad (2)$$

Where: According to the rules of the[18] Vi is the concentration of every one of the parameters in every one of the water samples in mg/L, and Si represents Iraqi standard for drinking each chemical parameter in milliliters per liter. For every water quality metric, the unit weight (Wi) can be computed with the use of the formula below.

$$Wi-K/Si \quad (3)$$

Where: K is the constant of proportionality and can be computed with the use of the formula below:

$$K=\frac{1}{\Sigma(\frac{1}{Si})} \quad (4)$$

For every parameter, the weighted arithmetic and standard values are displayed in Table 3.

Table 1: Locations of the samples, depth,(m) water level(m) in the well and the elevation above sea level in the study area

Samples	Latitude	longitude	Total depth	Water level	Elevations (m)
W1	33.36024°	44.1611036°	16.42	5.4	29
W2	33.371928°	44.1567204°	14	4.5	30
W3	33.3792675°	44.1657904°	15.6	2.9	28
W4	33.3613809°	44.1360833°	10.7	5.4	28
W5	33.3423172°	44.117741°	16.95	3.8	28
W6	33.325402°	44.1125672°	15.85	8.2	28
W7	33.2979563°	44.0963068°	6.2	3	36
W8	33.3185859°	44.1831563°	11.45	5.1	25
W9	33.3246919°	44.1913053°	53	7.8	36
W10	33.2874012°	44.0838451°	18.5	3.3	36
W11	33.2721659°	44.0478719°	25	8	27
W12	33.2544915°	44.0157386°	30	4	30
W13	33.2367919°	44.1341197°	10	7.7	30
W14	33.2299076°	44.1399913°	15	3	23
W15	33.2299788°	44.1383528°	24	8.8	30
W16	33.2828401°	44.0947206°	15	3.4	31
M.D1	33.3340267°	44.1771979°	-	-	29
M.D2	33.2974411°	44.0806816°	-	-	30
M.D3	33.1791657°	44.2273082°	-	-	21
Ch	33.2809937°	44.0949543°	-	-	31

W= We1l, M.D= Main drain, and Ch= Channel from Euphrates river.

Table 2: Parameters and methods of analysis that are used in the laboratory

Parameters	Analysis Methods
Na^{2+} , K^+	Flame photometer (APHA, 1998)
Ca^{2+} , Mg^{2+}	Titration with EDTA (Ethylene Diamine Tetracitic Acid)
Cl^-	Technicon auto analyzer instrument (APHA, 1998)
SO_4^{2-}	Technicon in ultra violet spectra photometer (U.V)
HCO_3^-	Technicon in volumetric
pH	pH-meter HANNA HI83141
EC	Conductivity meter HANNA HI98192 device
TDS	Drying, in 105 C
NO_3^-	UV-Spectrophotometric method (λ = 500nm)
PO_4^-	Ascorbic Acid Method 4500-PE

Table 3: Standard values and weighted arithmetic for parameters

Chemical parameter	Si (standard Iraq)	1/Si	K	Relative weight(Wi)
pH	6.50 – 8.50	0.11764		0.41
TDS	1,000	0.001		0.0034
TH	500	0.002		0.0069
Ca2+	75	0.0133		0.0464
Mg	50	0.02		0.0697
Na	200	0.005		0.0174
K	10	0.1		0.349
Cl	250	0.004	3.4850	0.0139
SO4	250	0.004		0.0139
NO3	50	0.02		0.0697
Total		0.28694		∑= 1.0003

4. Results and Discussion

The relative difference (RD) results show the accuracy of chemical analyses and can be used to evaluate and validate the analyses' accuracy. It is calculated by dividing the concentrations of cation and anion by the summation of concentration in epm%. Table 4 illustrates that the outcomes fall within the permissible range.

Table 4: The water samples' chemical analysis's accuracy

Samples	Dry season			Wet season		
	R.D	A%	Decision	R.D	A%	Decision
W1	1.08	98.92	accepted	1.25	98.75	accepted
W2	0.49	99.51	accepted	1.14	98.86	accepted
W3	0.25	99.75	accepted	0.55	99.45	accepted
W4	2.16	97.84	accepted	2.4	97.6	accepted
W5	4.54	95.46	accepted	4.76	95.24	accepted
W6	0.47	99.53	accepted	0.63	99.37	accepted
W7	3.94	96.06	accepted	4.31	95.69	accepted
W8	1.12	98.88	accepted	1.32	98.68	accepted
W9	2.9	97.1	accepted	3	97	accepted
W10	3.47	96.53	accepted	3.73	96.28	accepted
W11	0.21	99.79	accepted	0.33	99.67	accepted
W12	1.87	98.13	accepted	2.31	97.87	accepted
W13	3.75	96.25	accepted	4	96	accepted
W14	3.94	96.06	accepted	4.31	95.87	accepted
W15	0.70	99.3	accepted	0.92	99.07	accepted
W16	0.92	99.08	accepted	1	99	accepted
CH	2.16	97.84	accepted	2.43	97.57	accepted
M.D.1	3.53	96.47	accepted	3.7	96.3	accepted
M.D.2	3.94	96.06	accepted	4.21	95.79	accepted
M.D.3	4.00	96	accepted	3.99	96.01	accepted

4 .1 physical-chemical characteristics

Among the physicochemical parameters that were examined for both surface water and groundwater were T, pH, EC, TDS, and T.H. The physical examination results of water resources in Abu-Ghraib district have been listed in Table 5.

Table 5: Physical properties of groundwater samples collected over two periods in the research area

Samples	T (℃)	pH	EC (µS/cm)	TDS (mg/l)	T. H (mg/l)	T (℃)	pH	EC (µS/cm)	TDS (mg/l)	T. H (mg/l)
	Dry period					Wet period				
Groundwater										
W1	24.5	7.3	7710	4367	1921	23.5	7.1	7123	4035	1798
W2	24.5	7.5	10740	5553	2891	23.5	7.3	9950	5145	2713
W3	24.6	7.6	5300	3180	1797	23	7.5	4961	2950	1682
W4	24.5	7.3	6500	4235	2317	23.1	7.2	6024	3925	2168
W5	24.5	7.9	3200	2100	1148	23.5	7.7	2231	1940	1077
W6	27	7.6	3200	2108	999	23	7.5	2967	1955	936.6
W7	27	7.3	10200	5823	3274	24.1	7.1	9459	5400	3073
W8	24.5	7.3	3300	2260	1200	23	7.2	3066	2100	1122
W9	25.5	7.5	2300	1355	716.6	23	7.4	2138	1260	671.4
W10	23.5	7.5	5200	2830	1574	23	7.4	4832	2630	1475
W11	23	7.7	2200	1235	609.4	23	7.6	2048	1150	571.2
W12	25	7.9	6500	4600	2163	23	7.7	5970	4225	2025
W13	27	7.6	5600	3250	1901	24	7.5	5181	3007	1780
W14	25.3	7.7	3300	1985	1069	24.5	7.6	3058	1840	1003
W15	25.3	7.7	3000	1915	1030	24	7.6	2788	1780	965.4
W16	25	7.9	2300	1180	583.4	23	7.7	2144	1100	547.2
Min	23	7.3	2200	1180	583.4	23	7.1	2048	1100	547.2
Max	27	7.9	10740	5823	3274	24.1	7.7	9950	5400	3073
Avg	25.04	7.6	5034.4	2998.5	1574.6	23.2	7.4	4774.3	2830.1	1512.6
Surface water										
M.D.1	25	6.9	5100	4380	1890	23	6.8	4722	4056	1777
M.D.2	25	6.8	6342	4500	1946	23	6.7	5891	4180	1833
M.D.3	24.4	7.2	5200	4710	2063	24	7.1	4784	4370	2063
CH1	25.4	7	1407	450	301.4	24	6.8	1328	510	283.1
Min	24.4	6.8	1047	450	301.4	23	6.7	1328	510	283.1
Max	25.4	7.2	6324	4710	2063	24	7.1	5891	4370	2063
Avg	24.9333	6.98	4507.8	3279	1427.5	23.5	6.8	4181.25	3200	1383.7

For groundwater samples, the average temperature during the wet period is 23.2C°, while during the dry period, it is 25.04C°. Regarding surface water, the value is 24.9 C° throughout the dry period and 23.5C°throughout the wet period. .The water resource's temperature in the study area is represented in Table 5. According to [19]. Classified reported that the study area's water was warm. The electrical conductivity of the aqueous solution can be used to determine its capacity to carry an electric current. For groundwater samples, the average Electrical conductivity during the wet period is 4774.3µS/cm, while during the dry period, it is 5034.4 µS/cm. Regarding surface water, the value is4507.8µS/cm during the dry period and 4181.25 μS/cm during the wet. According to classification [20], all surface and groundwater samples were excessively mineralized water. The electrical conductivity (EC) increases with increasing total dissolved salts.

The value of TDS in the wet season for groundwater ranges from 1100 to 5400mg/l, and in the dry season, it ranges from 1180 to 5823 mg/l. As for surface water, it ranges from 510 to 4370mg/l in the wet season, and in the dry season it ranges from 450 to 4710 mg/l .as shown in table 5. According to the classification [21], groundwater ranges from slight to slightly brackish water, while surface water ranges from freshwater to slightly brackish water. The total dissolved salt values are high in the study area due to its proximity to the drain channels and the scarcity of feeding sources. the wells W14, W15, and W16, which are close to the channel (Ch), have lower total dissolved salts values.

Total hardness in the wet season for groundwater ranges from 597.2 to 3073 mg/l , and in the dry season it ranges from 583.4to 3274 mg/l. As for surface water, it ranges from 283.1 to 2063 mg/l in the wet season, and in the dry season, it ranges from 301.4 to 2063 mg/l .Water samples in the studied location are categorized as very hard during the dry and rainy periods, according to [22]. The high total hardness indicates the presence of gypsum, anhydrite, and dolomite in the study area.

The hydrogen number in the wet season for groundwater ranges from 7.1- 7.7, and in the dry season it ranges from 7.3-7. As for surface water, it ranges from 6.7-7.1 in the wet season, and in the dry season it ranges from 6.8-7.2. According to [23], drinking water with a pH of 6.50 to 8.50 is sufficient. The pH levels of surface and ground-water samples are listed in Table 5.

4.2 Chemical analyze

Groundwater contains ions that dissolve slowly from rocks and soil particles as they move through the pores or cracks in the aquifer's mineral surface [7]. Table 6 presents the hydrochemical characteristics of water samples taken from the study region in two periods.

Table 6: Major cations and anions of water samples for the two periods

Samples	Na^+ ppm	K^+ ppm	Ca^{2+} ppm	Mg^{2+} ppm	SO_4^{2-} ppm	HCO_3^- ppm	Cl^- ppm	Na^+ ppm	K^+ ppm	Ca^{2+} ppm	Mg^{2+} ppm	SO_4^{2-} ppm	HCO_3^- ppm	Cl^- ppm
	Dry period							Wet period						
Ground water														
W1	730	10	530	145	1302	380	1250	671	9.5	493	138	1211	357	1150
W2	812	10.1	678	291	1453	320	1987	747	9.5	631	277	1351	300	1828
W3	347	7.3	500	133	1177	190	821	319	6.9	465	126	1095	178	755
W4	561	11.7	657	164	1193	300	1345	516	11.1	611	156	1110	282	1237
W5	255	9.5	280	109	869	220	340	234	9	260	104	808	206	313
W6	288	9.6	250	91	825	240	400	265	9.1	233	86	767	225	368
W7	823	11.9	734	350	1678	345	1876	757	11.3	683	332	1560	324	1726
W8	267	9.2	350	79	834	230	489	245	8.7	326	75	775	216	450
W9	139	18	188	60	435	320	190	128	17	175	57	404	300	174
W10	347	7.3	411	133	1177	190	564	319	6.9	382	126	1094	178	518
W11	133	16	155	54	410	284	181	122	15	144	51	381	266	166
W12	745	10	589	168	1278	313	1453	685	9	248	160	1188	294	1337
W13	376	8.9	522	145	1200	198	789	346	8.4	485	138	1116	186	725
W14	243	9.5	265	99	843	210	310	224	9	246	94	783	197	285
W15	210	8	254	96	823	200	322	193	8	236	91	765	188	296
W16	137	6	143	55	378	278	178	126	6	133	52	352	261	169
Max	823	18	734	350	1678	380	1987	757	17	683	332	1560	357	1828
Min	133	6	143	54	378	190	178	122	6	133	51	352	178	166
Avg	400.8	10.1	406.6	135.7	992.1	263.6	780.9	368.5	9.65	359.4	128.9	922.5	247.3	718.5
Surface water														
MD1	800	13	378	230	1689	250	1012	736	12.3	351	219	1571	235	931
MD2	836	17	318	280	1734	279	1034	769	16	296	266	1613	262	951
MD3	867	19	355	286	1767	288	1123	798	18	330	272	1643	271	1033
Ch	50	1.4	63	35	162	155	70	46	2	59	33	151	146	64
Max	867	19	378	286	1767	288	1123	798	18	351	272	1643	271	1033
Min	50	1.4	63	35	162	155	70	46	2	59	33	151	146	64
Avg	638	12.6	278.5	207.7	1338	243	809.7	587.2	12.07	259	197.5	1244.5	228.5	744

The range of the major cationNa^{+} , K^{+} ,Ca^{2+}, and Mg^{2+} in groundwater were (133-823), (6-18), (143-734),and (54-350) in the dry period and (122-757), (6-17), (133-683), and (51-332) in the wet period, while in surface water were (50-867), (1.4- 19), (63-378), and (35-286) in dry the period and (46- 798), (2-18), (59-351), and (33-272) in the wet period. As shown in Table 6.

The range of the major anion SO_4^{2-} , HCO_3^{-} , and Cl^{-} in groundwater were (378-1678),(190-380), and(178-1987) in the dry period and (352-1560), (178-357), and (166-1828) in the wet period, while in surface water were (162-1767), (155-288),and(70-1123) in the dry period and (151-1643),(146-271), and(46-1033) in the wet period . As shown in Table 6.

The range of the secondary element NO_3^{-} and PO_4^{3-} in groundwater were (1.2-23) and(0.089-0.65) in the dry period and (1.18-22.66) and (0.08-0.61) in the wet period, while in surface water were (12-29) and(0.29-0.51)in the dry period and (11.82-28.57) and(0.27-0.48)in wet the period as shown in Table 7.

Table 7: Secondary elements concentrations in the water samples in the study area for the two periods

Samples	Dry season		Wet season	
	NO_3^{-}	PO_4^{3-}	NO_3^{-}	PO_4^{3-}
W1	8	0.5	7.88	0.47
W2	8	0.65	7.88	0.61
W3	9	0.49	8.86	0.46
W4	10.7	0.42	10.54	0.4
W5	22	0.49	21.67	0.46
W6	1.2	0.56	1.18	0.53
W7	17	0.65	16.75	0.61
W8	23	0.62	22.66	0.59
W9	10	0.39	9.85	0.37
W10	11	0.089	10.84	0.08
W11	14	0.54	13.79	0.51
W12	12	0.099	11.82	0.09
W13	10.5	0.56	10.34	0.53
W14	9	0.54	8.86	0.51
W15	23	0.09	22.66	0.08
W16	12	0.51	11.82	0.48
CH	14	0.37	13.79	0.35
M.D.1	29	0.35	28.57	0.33
M.D.2	12	0.29	11.82	0.27
M.D.3	23	0.49	22.66	0.46

4.3 Gibbs plot

The Gibbs diagram contains three zones: precipitation dominance, evaporation dominance, and rock-water contact dominance [24]. Samples exhibit evaporation dominance in two periods due to semi-arid climatic conditions and surface pollution sources, especially excessive fertilizer application, irrigation return flows, industrial flows, sewage and domestic wastewater (Figure 2 and 3). Channel samples which fall within the rock-water interaction zone, show that chemical weathering of the rock-forming minerals

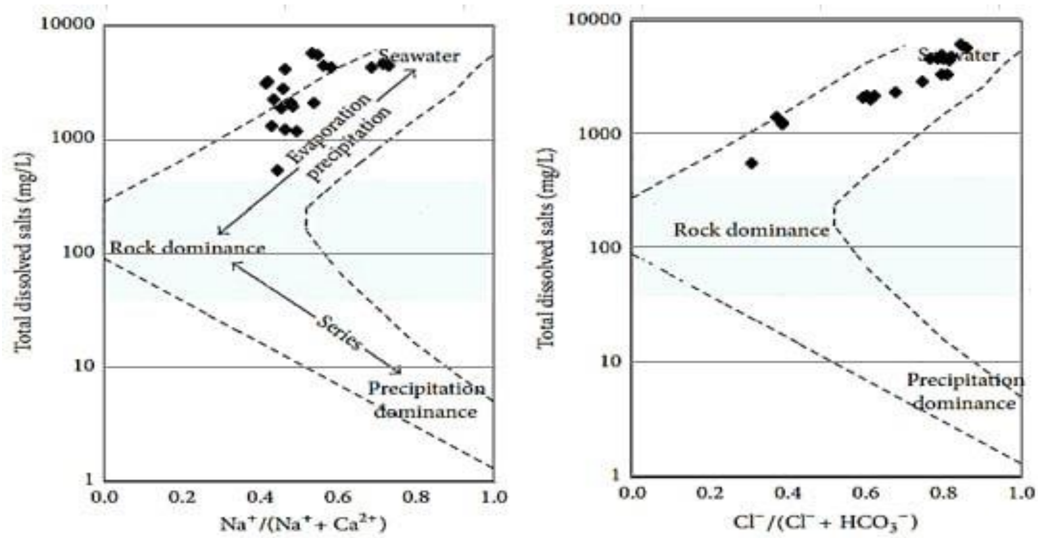

Figure 2: Gibbs plot for the water samples in the study area for the dry period.

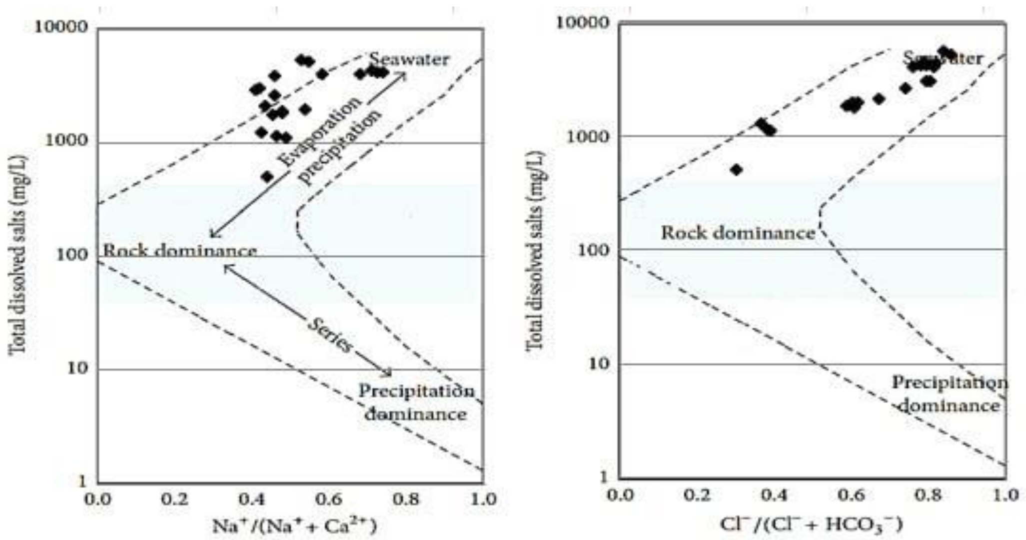

Figure 3: Gibbs plot for the water samples in the study area for the wet period

4.4 Water formula and Hydrochemical classification

According to the Kurolov hydrochemical formula, the ratio of main ions, (anions and cations) is arranged in descending order and then measured in epm %, that have over 15% availability ratio, anions are located above, and cations are at the base. In addition to that, TDS values and pH values are put in the following formula that has been obtained from [25]. Samples are divided into two types: groundwater, eleven of which are calcium sulphate (68.75%), three of which are sodium chloride (18.75%), and two of which are calcium chloride (12.5%). As for surface water, three are sodium sulphate (75%) and only one is calcium sulphate (15%). The formula was:

$$\text{TDS (mg/l)} = \frac{Anion(epm\%)in\ decreasing\ order}{Cation(epm\%)in\ decreaing\ order}\ pH \quad (5)$$

The average hydro-chemical formula for groundwater in dry periods is

$$\text{TDS (2993.5)} = \frac{\mathrm{SO_4^{2-}}(46.79)\mathrm{Cl^-}(41.31)\mathrm{HCO_3^-}(11.82)}{Ca^{2+}(42.03)Na2^{+}(34.08)Mg^{2+}\ (24.79)K^{+}\ (0.74)}\ 7.6 \quad (6)$$

The average hydro-chemical formula for groundwater in the wet period is

$$\text{TDS}\ (2774.5) = \frac{SO_4^{2-}(46.36)Cl^{-}(41.01)HCO_3^{-}(11.76)}{Ca^{2+}(41.96)Na^{+}(33.61)Mg^{2+}\ (23.61)K^{+}\ (0.73)}\ 7.4 \quad (7)$$

The average hydro-chemical formula for surface samples in the dry period is

$$\text{TDS}\ (3274) = \frac{SO_4^{2-}(48.88)Cl^{-}(38.30)HCO_3^{-}(12.73)}{Na2^{+}(42.22)Mg^{2+}\ (30.5)Ca^{2+}(26.76)\ K^{+}(0.51)}\ 6.9 \quad (8)$$

The average hydro-chemical formula for surface samples in wet period is

$$\text{TDS}\ (3200) = \frac{SO_4^{2-}(48.75)Cl^{-}(38.05)HCO_3^{-}(12.8)}{Na2^{+}(42.19)Mg^{2+}\ (38.05)Ca^{2+}(26.65)\ K^{+}(0.51)}\ 6.8 \quad (9)$$

The Durov Diagram is a tri-linear diagram type that Durov proposed [26]. The concentrations of the major cations and anions in percentage meq/l are shown in this graphic using two different triangles. The two triangles' sample points are projected onto a square field in the middle, signifying the entire chemical makeup of the sample. The chloride-sulfate, main sources of this ion in water are gypsum ($CaSO_4.2H_2O$) and evaporite rocks (anhydrite $CaSO_4$), and the pyrite oxidation process in clay and rocks. Water samples are indicated by the Durov diagram in Figures 4 and 5, which displays the locations of the samples of water from the study area.

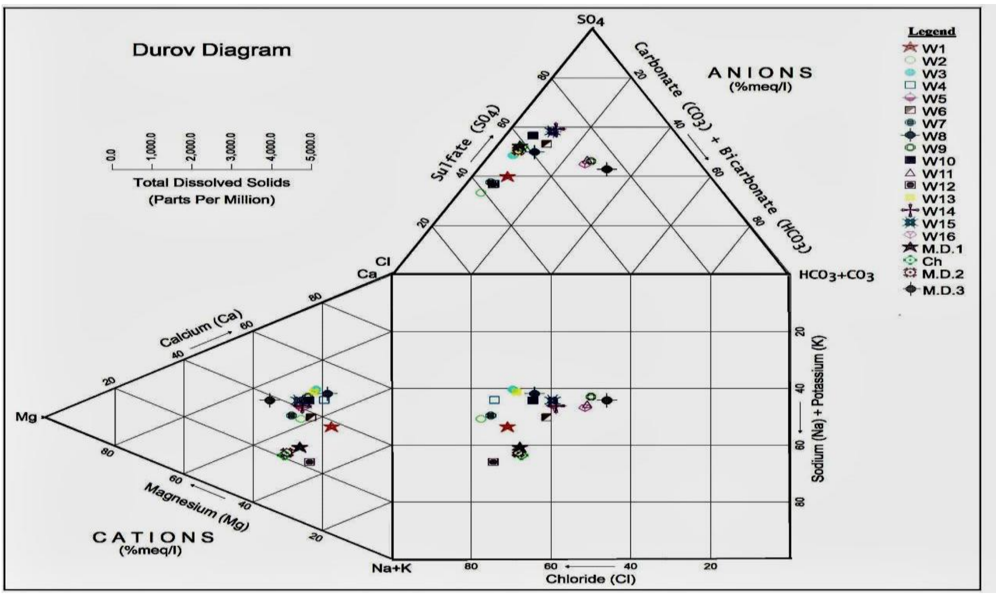

Figure 4: Durvo diagram shows the distribution of the water samples in the study area for the wet period

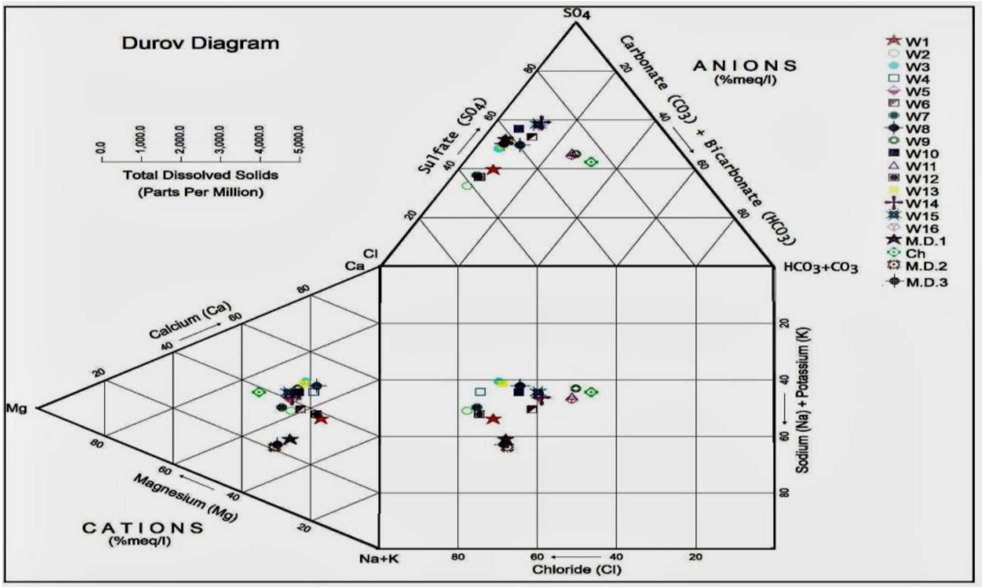

Figure 5: Durvo diagram shows the distribution of the water samples in the study area for the dry period

4 .5 Water Quality index

A set of factors can be reduced to a single numerical number using WQI [9]. Worldwide, water quality indicators have been developed to evaluate surface and groundwater quality. These indices used a range of water quality-related characteristics. Water quality is affected by climate (temperature) changes that extend over several centuries to several years, leading to a decrease in the discharge index and an increase in dissolved and all major cations [27]. The (WQI) model is computed using the World Health Organization Standard drinking guidelines [18]. For every parameter, the weighted arithmetic and standard values are displayed in Table 3. To ascertain if the water was fit for human consumption, this investigation employed a variety of chemical parameters, such as TDS, pH, TH, calcium, sodium, magnesium, potassium, sulfate, chloride, and nitrate ions. The water quality of all samples was evaluated with the use of the (WQI) standard; during the two periods, WQI classified the following as good water: Ch and poor water W16, while the remaining samples ranged from very poor water to unsuitable water according to [28] as can be seen from Table 8 .

Table 8: Water quality classification depends on [28]

WQI	Class	Caption	WQI in dry period	WQI in wet period
0-25	I	Excellent		
26-50	II	Good water	Ch	Ch
51-75	III	Poor water	W16	W16
76-100	IV	Very poor water	W6,W8,W10,W11,W14, W15	W3,W5,W6,W8,W9, W10,W11,W14,W15
> 100	V	Un suitable water	W1,W2,W3,W4,W5,W7, W9,W12,W13,M.D1,M.D 2,M.D3	W1,W2,W4,W7,W1 2,W13,M.D1,M.D2, M.D3

4.6 water use for agricultural purposes

Utilizing groundwater for agriculture, any crop's capacity to yield depends on various factors, including plant quality, climate tolerance, soil structure, water-holding capacity, organic matter content, irrigation technique, and crop type. The kind and amount of salts in the water, as well as their ability to affect crop growth and development, determine if the water is suitable for agriculture. Depending on the quality of the plant, plants have varying tolerances for electrical conductivity and total dissolved solids in water used for irrigation [29]. [30] Suggested a classification scheme that states that all groundwater samples in the research area are acceptable for producing any type of crop during rainy seasons. However, during the dry season, all groundwater is suitable except for (W2, W7) because of their high EC values.

4.7 Water use for irrigation

The types and concentrations of salts in the water determine whether or not they are suitable for irrigation. The primary soluble components are anions chloride, sulfate, and bicarbonate and cations calcium, magnesium, and sodium [31].Analyzing water quality is one of the most crucial groundwater research parts. Because of this, groundwater's hydrochemistry plays a crucial role in deciding how it is used for many different purposes, which include domestic, industrial, agricultural, and livestock ranching. The plant's capacity to tolerate the salt of the groundwater determines whether or not it is suitable for irrigation. Consequently the water a major factor in agriculture is quality. Many issues, including salinity, infiltration, and permeability, might arise when using water for irrigation because they affect sensitive crops. Therefore, groundwater with a high salinity ratio will have an impact on crop growth [32].There are trace amounts of the other ions. The irrigation's quality is evaluated using three criteria.

4.7.1 Sodium Hazard

The primary factor used to classify irrigation waters according to SAR is the impact of exchangeable sodium on the physical state of the soil. Using the following formula, the sodium adsorptive ratio (SAR) has been computed [33].

$$SAR = \frac{(Na2+)}{\sqrt{\frac{1}{2}[(Ca2+)+(Mg2+)]}} \tag{10}$$

According to [34] all samples in two periods is excellent.

4.7.2 Sodium ion present (Na %)

It expresses sodium out of total cations and approximates the sodium hazard of irrigation water [33]. The formula below can be used to compute Na% [30]:

$$Na\% = rNa + rK / rCa + rMg + rNa + rK * 100 \tag{11}$$

All samples in two period were good expect (W1, M.D1, M.D2, M.D3) were permissible according to[35] classification .

4.7.3 Kelly Index (KI)

The ratio of sodium ions to calcium and magnesium ions, or KI, is used to assess whether water is suitable for irrigation. Groundwater with a Kelly's index greater than one becomes unsuitable for irrigation; the method developed by [36] is used to determine KI.

$$KI = Na^{+} / Ca^{2+} + Mg^{2+} \tag{12}$$

Where: epm is the unit of expression for all ions. The values of (KI) for ground-water samples in the research area across two periods have been displayed in Table 9. The majority of groundwater samples may be utilized for irrigation.

Table 9: Values (SAR, Na%, and KI) in the study area for two periods

Samples	Na%	SAR	KI	Na%	SAR	KI
	Dry Period			Wet period		
W1	45.3	7.22	0.82	44.9	6.87	0.81
W2	37.9	6.54	0.61	37.5	6.21	0.59
W3	29.7	3.55	0.41	29.4	3.37	0.41
W4	34.7	5.05	0.52	34.3	4.81	0.51
W5	32.9	3.41	0.48	32.5	3.13	0.47
W6	38.9	3.95	0.62	38.4	3.75	0.61
W7	35.4	6.23	0.54	34.9	5.92	0.53
W8	33	3.34	0.48	32.6	3.18	0.47
W9	31.1	2.25	0.01	30.8	2.14	0.41
W10	32.6	3.79	0.47	32.2	3.61	0.47
W11	33.6	2.33	0.47	33.2	2.22	0.46
W12	42.9	6.94	0.74	42.5	6.61	0.73
W13	30.3	3.74	0.43	29.9	3.56	0.42
W14	33.5	3.22	0.49	33	3.06	0.48
W15	31.1	2.83	0.44	30.7	2.69	0.43
W16	34.2	2.45	0.51	33.8	2.33	0.49
M.D1	48	7.97	0.91	47.5	7.56	0.89
M.D2	48.4	8.21	0.92	47.8	7.78	0.91
M.D3	47.9	8.26	0.91	47.9	8.26	0.91
Ch	26.7	1.24	0.35	26.3	1.18	0.34

4.8 Water Uses for livestock

The kind of livestock, the amount of water each species needs each day, and information on which compounds are hazardous to which species are all considered when determining the suitability of livestock. According [37] all samples in two periods is very good to good uses for livestock.

4.9 Water uses for Building

Water quality appropriate for construction to evaluate if water samples from the research region were appropriate for use in building, the [37] categorization was employed. The water in the research region (surface water and wells) is found to be suitable for construction and building during both times, and a table 10 indicating its suitability for building purposes is displayed as the acceptable limit.

Table 10: Comparing major cations and anions concentrations in water samples with water classification for building uses according to [37]

Elements	Permissible limit	Average value of parameters in dry period	Average value of parameters in wet period
Ca^{2+}	437	381	339
Na^{+}	1160	448	412
Mg^{2+}	271	150.1	143
Cl^{-}	2187	787	724
SO_4^{2-}	1460	1061.3	987
HCO_3^{-}	350	260	244

5. Conclusion

This research evaluated physicochemical properties of the groundwater in Abu Ghraib, Western Baghdad. Depending on pH and values, the water samples in the studied area were classified from neutral to slightly alkaline and fresh to slightly brackish water respectively. In groundwater, the main anion is SO_4^{2-}, followed by Cl^- and HCO_3^-, whereas the predominate cation is Ca^{2+}, followed by Na^+, Mg^{2+}, and K^+, while in surface water, the main anion is SO_4^{2-}, followed by Cl^- and HCO_3^-, whereas the predominate cation is Na^+, followed by Mg^{2+},Ca^{2+}, and K^+. Most types of water in the study area are $CaSO_4$ followed by $NaSO_4$ with others types such as NaCl and CaCl. By applying WQI, the groundwater and surface water in the study region for two periods has been categorized as good water by many international quality indexes for the samples is good water for ch and poor water for W16, while the remaining samples are range from very poor to unsuitable water. Except for W2 and W7, it may be used for farming. Not only is it excellent for animals, but irrigation benefits greatly from it as well and good for building.

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