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# Interaction of Rutba-Dhabaa Groundwater with the Mulussa Aquifer Host Rocks, Western Iraq

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**Abstract.** Mulussa aquifer extended the area of Rutba-Dhabaa, Western Iraq, has been studied in order to determine the most important chemical functions and interaction between rocks and groundwater (Groundwater–rocks interaction). The results of wet and dry periods indicated that  $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$  in the groundwater are the dominant ions. Average of Hydrogen Number (pH), Total Dissolved Solids (TDS), calcium ( $\text{Ca}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ), sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), chlorine ( $\text{Cl}^-$ ), sulfate ( $\text{SO}_4^{2-}$ ), bicarbonate ( $\text{HCO}_3^-$ ) and nitrate ( $\text{NO}_3^-$ ) are 7.43, 718.25 mg/l, 120.8 mg/l, 40.875 mg/l, 32.865 mg/l, 2.93 mg/l, 103.527 mg/l, 195.9 mg/l, 214.85 mg/l and 4.275 mg/l respectively in the dry period, while its averages 7.33, 664.2375 mg/l, 114.25 mg/l, 35.8 mg/l, 29.28 mg/l, 2.33 mg/l, 90.3 mg/l, 181.1 mg/l, 203.85 mg/l, and 3.6 mg/l respectively in the wet period. The groundwater is characterized by low alkalinity hard to very hard water, between moderately and excessively mineralized water, and fresh to slightly water in both periods. Rock–water interaction processes are indicating that there is a possible contribution of the seawater in Mulussa aquifer, the dominant process is limestone–dolomite weathering, where the source of calcium is rather than gypsum or silicates rocks, and contribution of calcite more than dolomite in the Mulussa aquifer.

## 1. Introduction

The quality of groundwater is not less than (equal) its quantity in terms of importance. A realistic assessment of groundwater quality depends on the way and how to use water, in addition to its hydrochemical properties, where the water purity is a very important characteristic of water quality, but the quality is not judged by it, but by its appropriateness for the various uses for which it is intended [1]. Thus, water uses must be identified before water quality can be judged. It is essential to protect our water resources to ensure that sufficient quantities of high-quality water are available for future generations [2]. The groundwater quality depends both on the relationship between the groundwater with aquifer material (i.e., substances are dissolved in water) and on some specific properties and characteristics by which substances are transported into water [3]. The management of groundwater in the Rutba-Dhabaa area was recommended by [4], to ensure the best investment in the groundwater. Some studies conducted in this area are those provided by [5], [6], and [7] which focus on hydrogeological setting and groundwater management in the Rutba-Dhabaa area. Several formations affect the chemistry of groundwater in the studied area; Ga'ara, Mulussa, Zor Hauran, Ubaid, Mauddud–Nahr Umr, Rutba, Ms'ad, and Hartha Formations. In the study area, the groundwater is present as a store within the Mulussa aquifer which underlies all the formations above except Ga'ara formation that is surmounted. Mulussa Formation is composed of tropical to subtropical shallow water conditions and



lagoonal environments (limestone, dolomitic limestone, and sometimes oolitic) of Late Triassic, Carnian–Norian. It's appearing in the study area at a depth of 120 meters [8]. It is necessary to study the formations of the area because it clearly affects the quality of the water [9]. The study area is located in Al-Anbar Governorate, between the cities of Rutba and Dhabaa, to the west of the district of Ramadi in western Iraq. The area is stretching from Rutba to Dhabaa and is crossed by the highway (NO.1) and the old road (NO.2) between 3653442.86 m and 3659709.33 m to the north and 617632.76 m and 643771.85 m to the east (Fig.1). Identifying the main chemical functions is the aim of the study in addition to describing groundwater– Mulussa aquifer rocks interaction.

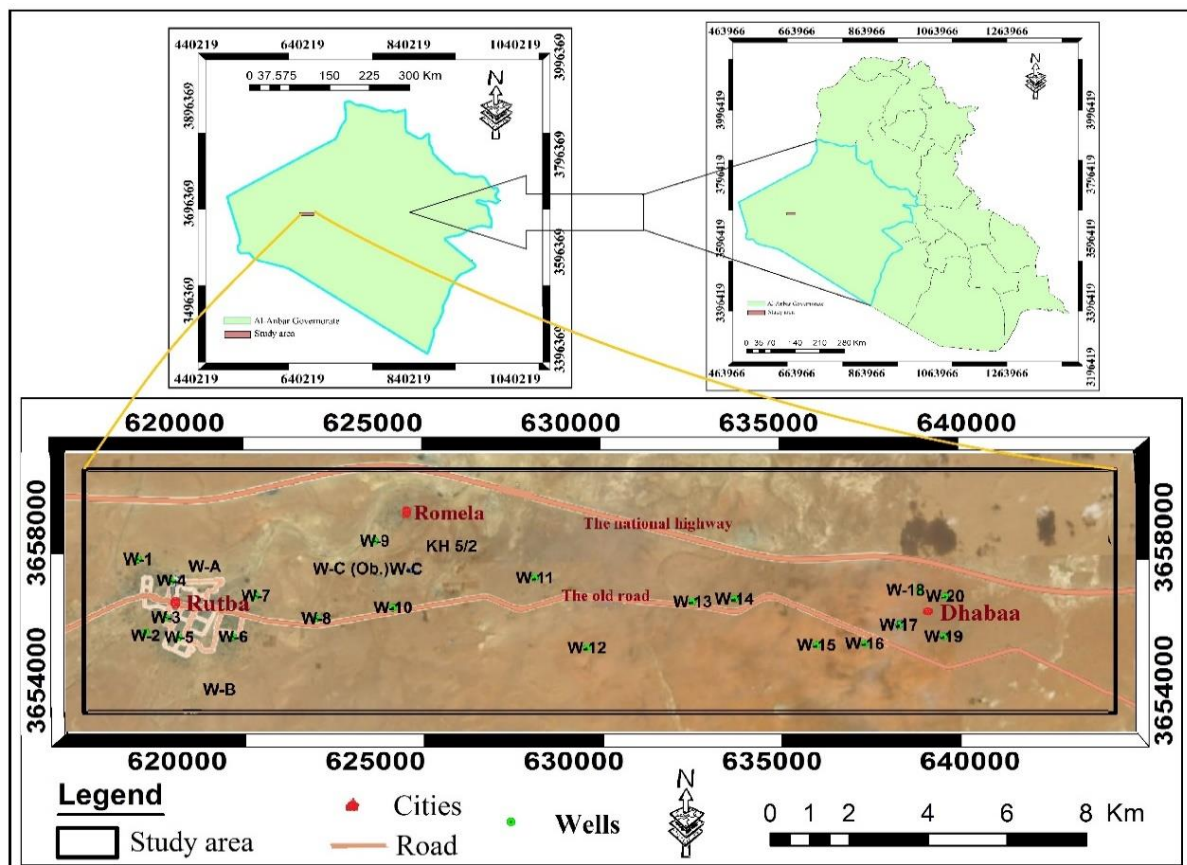


Fig. 1. Location map and the groundwater wells of the study area

## 2. Materials and Methods

Twenty water samples that covered the area almost evenly were collected during September 2017 (the dry period), and April 2018 (the wet period) from Rutba-Dhabaa wells that were drilled in the Mulussa aquifer (Fig. 1). Groundwater depth was measured by the groundwater depth detector (Sonder instruments, Type 010, France) and according to [7] the depths of the wells studied range from 110 to 231 m. The chemical analysis has been done in the chemical laboratory of the MST (Ministry of Science and Technology), where includes Major cations; ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ , and  $\text{K}^+$ ) and Major anions; ( $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ , and  $\text{HCO}_3^-$ ), and the Minor compounds of Nitrate ( $\text{NO}_3^-$ ). In addition to measuring the temperature (T), Hydrogen Number (pH), Total Dissolved Solids (TDS), and Electrical conductivity (EC) were measured in the field. The flame photometer was utilized to analyze sodium and potassium. The titrimetric method was utilized to determine calcium, magnesium, chloride, carbonate, and bicarbonate. The spectrophotometer was used to determine Sulfate.

Analytical accuracy is calculated by using the percentage of analysis accuracy method (U%), were calculated by the following formula [10]; [11]; [12]; [13]; [14].

$$U\% = \left| \frac{r\sum(\text{cations}) - r\sum(\text{anions})}{r\sum(\text{cations}) + r\sum(\text{anions})} \right| \times (100) \quad \text{-----(1)}$$

$$A = 100 - U \quad \text{-----(2)}$$

Where U: Reaction error (Uncertainty); A: Certainty or Accuracy; r: Equivalent per million (epm). Where the unites of cations and anions in epm.

According to the above formula, the results are accepted (less than 5%) for two periods. According to the formula of Kurlolov which was referred to in [15], the hydrochemical formula was calculated as an average formula for two periods.

### 3. Results and Discussion

#### 3.1. Groundwater characterization

The pH values range between 7.2-7.8 with an average of 7.43 in September 2017, while it ranges between 7.1-7.7 with an average of 7.33 in April 2018, as shown in tables 1 and 2. The pH values of water samples in both periods are of low alkalinity. Figures (2, a, and b) show the two-period spatial distribution of pH values in the studied area.

TDS values range between 365-1225 ppm with an average of 718.25 ppm in September 2017, while it ranges between 311.8-1110.4 ppm with an average of 664.2375 ppm in April 2018, as shown in tables 1 and 2. It's clear that the salinity in September 2017 is more than the April 2018 period and that is due to the dilution which happens in April 2018 (wet period) as a result of the occurrence of rainfall. According to [16]; [17]; and [18], the water samples are considered to be freshwater to slightly water in both periods. The figures (3, a, and b) show the spatial distribution of TDS values in the study area for the two periods.

The EC is ranging from 492.75 to 1500.7  $\mu\text{S}/\text{cm}$  with an average of 959.9075  $\mu\text{S}/\text{cm}$  in September 2017, while it ranges from 420.93 to 1382.535  $\mu\text{S}/\text{cm}$  with an average of 886.9589  $\mu\text{S}/\text{cm}$  in April 2018, as shown in tables 1 and 2, reflecting moderately mineralized water to excessively mineralized water for two periods [19]. The T.H values for the two periods in the study area are considered as very hard water according to [18].

Contribution of cations as an average in the Mulussa aquifer during the dry period is  $\text{Ca}^{2+}$  (28%),  $\text{Mg}^{2+}$  (16%), and  $\text{Na}^+ + \text{K}^+$  (7%), and anions contribution is  $\text{Cl}^-$  (14%),  $\text{SO}_4^{2-}$  (19%) and  $\text{HCO}_3^-$  (16%). While during the wet period the  $\text{Ca}^{2+}$  (29%),  $\text{Mg}^{2+}$  (15%), and  $\text{Na}^+ + \text{K}^+$  (7%), and anions contribution is  $\text{Cl}^-$  (14%),  $\text{SO}_4^{2-}$  (19%) and  $\text{HCO}_3^-$  (17%) (Fig. 4). These results indicated that  $\text{Ca}^{2+}$  and  $\text{SO}_4^{2-}$  are the dominant ions in the groundwater for the two periods. The prevailing cation in the groundwater samples is ( $\text{Ca}^{2+}$ ) refers to the dominant rock type (carbonate rocks). The concentration of ions in groundwater samples for the April 2018 (wet period) is lower than the September 2017 (dry period) due to the process of dilution.

Piper trilinear diagram applying on the water samples in the Mulussa aquifer for two periods as shown in figures (5 a, and b), where all groundwater samples for the two periods are located in class b and class c hydrochemical facies. This indicates that its type for two periods is " Normal earth alkaline water with prevailing bicarbonate and sulfate or chloride " and " Normal earth alkaline water with prevailing sulfate or chloride " respectively. Except for W-18 fall in class e which represents " Earth alkaline water with increase portion of alkali with prevailing sulfate and chloride".

Mulussa aquifer in Rutba-Dhabaa area is characterized by water type as  $\text{Ca-SO}_4$  for two periods which is represented in the following formula:

$$\text{TDS (718.05)} \frac{\text{SO}_4^{2-} (37.79) \text{HCO}_3^- (35.98) \text{Cl}^- (26.26)}{\text{Ca}^{2+} (54.35) \text{Mg}^{2+} (31.85) \text{Na}^+ (13.07) \text{K}^+ (0.71)} \text{pH (7.43)} \dots\dots\dots (\text{Dry period})$$

$$\text{TDS (664.23)} \frac{\text{SO}_4^{2-} (37.94) \text{HCO}_3^- (37.32) \text{Cl}^- (24.73)}{\text{Ca}^{2+} (56.33) \text{Mg}^{2+} (30.41) \text{Na}^+ (12.63) \text{K}^+ (0.61)} \text{pH (7.33)} \dots\dots\dots (\text{Wet period})$$

Table 1 The hydrochemical parameters of samples in September 2017

Well No.	Ca <sup>2+</sup> (mg/l)	Mg <sup>2+</sup> (mg/l)	Na <sup>+</sup> (mg/l)	K <sup>+</sup> (mg/l)	Cl <sup>-</sup> (mg/l)	SO <sub>4</sub> <sup>2-</sup> (mg/l)	HCO <sub>3</sub> <sup>-</sup> (mg/l)	pH	TDS (mg/l)	EC $\mu$ S/cm	T.H (mg/l)
W-1	177	85	36.7	3.4	270	290	225	7.4	1094	1476.9	791.85
W-2	120	36	25	2.5	116	112	231	7.2	649	876.15	447.96
W-3	110	42	28.7	1.8	111	125	256	7.5	681	919.35	447.62
W-4	140	73	54	0.1	136	310	259	7.6	979	1300.6	650.03
W-5	110	42	39.3	2.9	88	188	250	7.4	727	981.45	447.62
W-6	100	48	35.5	2.3	122	120	250	7.4	684	923.4	447.28
W-7	80	39	28.6	0.9	80	101	237	7.2	573	773.55	360.29
W-8	80	43	28.4	0	82	110	243	7.5	593	800.55	376.73
W-9	90	33	15	3.5	60	136	189	7.8	533	719.55	360.63
W-10	60	22	9.3	2.7	30	100	134	7.6	365	492.75	240.42
W-11	60	34	20.6	2.1	40	120	156	7.7	439	592.65	289.74
W-12	80	29	25	2.8	50	127	200	7.5	520	702	319.19
W-13	90	37	24.7	1.2	67	169	178	7.3	573	773.55	377.07
W-14	100	36	28	1.8	67	181	204	7.2	624	842.40	397.96
W-15	300	24	45	0.8	222	402	225	7.3	1225	1500.7	848.64
W-16	200	46	31	3.9	167	312	227	7.4	993	1330.5	689.06
W-17	149	55	60	10	120	366	200	7.3	967	1300.4	598.55
W-18	120	24.5	55	8	81.55	199	223	7.4	718	963.9	400.69
W-19	110	30.5	23.5	0.9	71	160	204	7.5	606	818.10	400.35
W-20	140	38.5	44	7	90	290	206	7.4	822	1109.7	508.23
Ave.	120.8	40.8	32.8	2.93	103.5	195.9	214.85	7.43	718.25	959.91	469.99

Table 2 The hydrochemical parameters of samples in April 2018

Well No.	Ca <sup>2+</sup> (mg/l)	Mg <sup>2+</sup> (mg/l)	Na <sup>+</sup> (mg/l)	K <sup>+</sup> (mg/l)	Cl <sup>-</sup> (mg/l)	SO <sub>4</sub> <sup>2-</sup> (mg/l)	HCO <sub>3</sub> <sup>-</sup> (mg/l)	pH	TDS (mg/l)	EC $\mu$ S/cm	T.H (mg/l)
W-1	171	77	33.4	2.8	251	271	211	7.3	1024.1	1382.53	743.97
W-2	116	34	24	2	110	96	225	7.1	616	831.60	429.74
W-3	104	35	25.4	1.6	98	106	248	7.3	626.5	845.77	403.85
W-4	133	63	49	0	118	283	242	7.5	894.9	1187.07	591.43
W-5	102	36	35.6	2.8	75	168	236	7.2	664.2	896.67	402.96
W-6	95	47	32	1.6	107	114	241	7.3	643.8	869.13	430.67
W-7	76	32	25.2	0.5	69	85	221	7.2	515.2	695.52	321.52
W-8	75	37	24.8	0	68	99	228	7.4	540.4	729.54	339.57
W-9	87	29	12	3	48	130	185	7.7	500.5	675.67	336.69
W-10	54	18	6.6	2.2	21	88	115	7.5	311.8	420.93	208.98
W-11	55	29	12.2	1.2	33	109	144	7.6	389.7	526.09	256.69
W-12	78	25	23	2.4	41	119	196	7.4	490.6	662.31	297.75
W-13	86	30	23.4	0.9	55	159	168	7.2	528.4	713.34	338.30
W-14	96	29	24	1.7	53	162	192	7.2	563.9	761.26	359.19
W-15	268	21	42	0.7	182	378	210	7.2	1110.4	1345.95	756.31
W-16	198	41	29	3.5	156	298	222	7.3	953.6	1277.31	663.51
W-17	143	51	53	8	106	356	190	7.3	916	1231.55	567.11
W-18	114	22	50	6	77	184	210	7.2	671.9	901.13	375.42
W-19	103	24	21	0.4	58	144	193	7.4	551.1	743.98	356.14
W-20	131	36	40	5.3	80	273	200	7.3	771.7	1041.79	475.46
Ave.	114.2	35.8	29.3	2.33	90.3	181.1	203.85	7.33	664.24	886.95	432.76

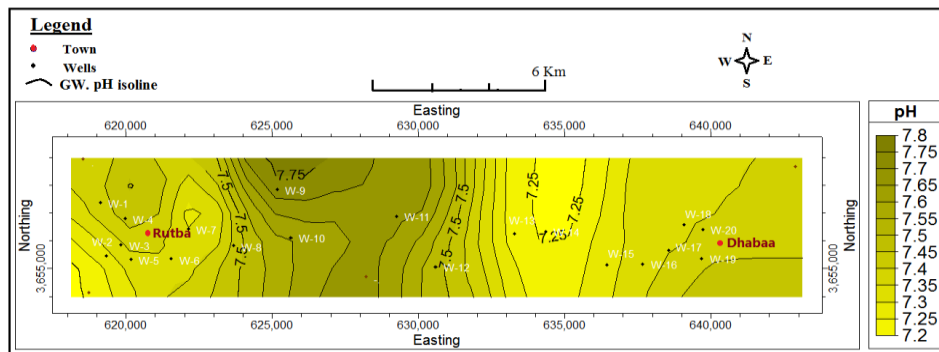


Fig. 2a. The spatial distribution of groundwater pH during dry period

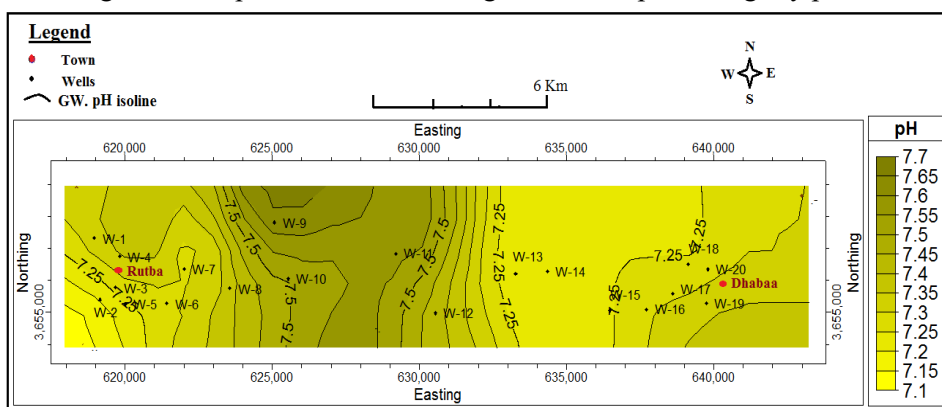


Fig. 2b. The spatial distribution of groundwater pH during wet period

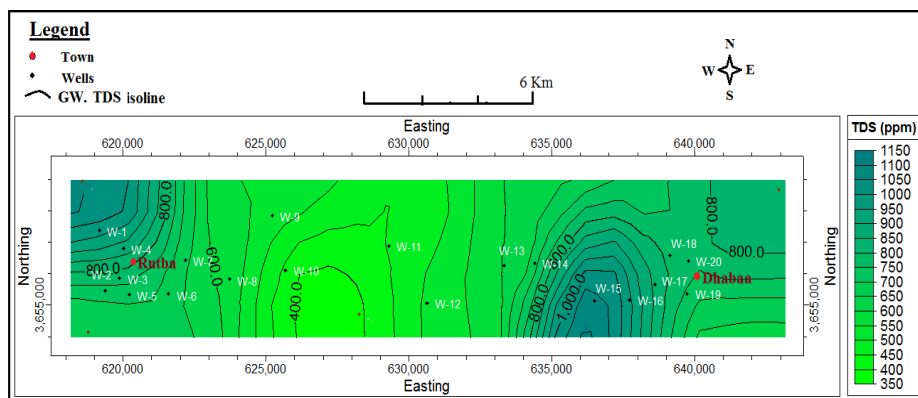


Fig. 3a. The spatial distribution of groundwater TDS during the dry period

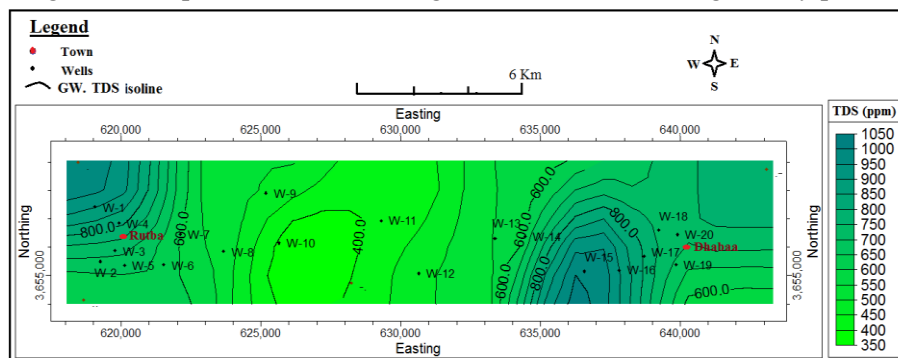


Fig. 3b: The spatial distribution of groundwater TDS during the wet period



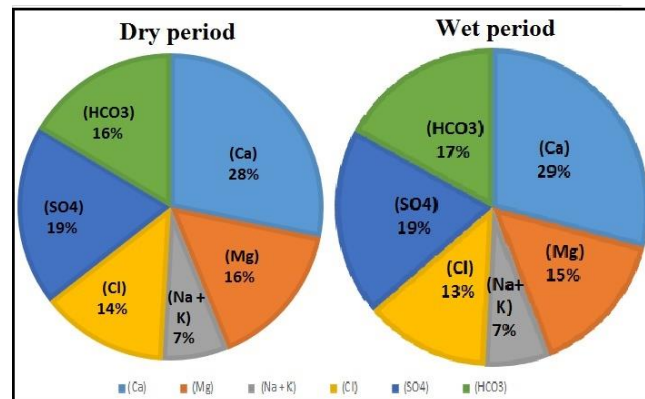


Fig. 4: The pie diagram of groundwater in the Mulussa aquifer for the two periods.

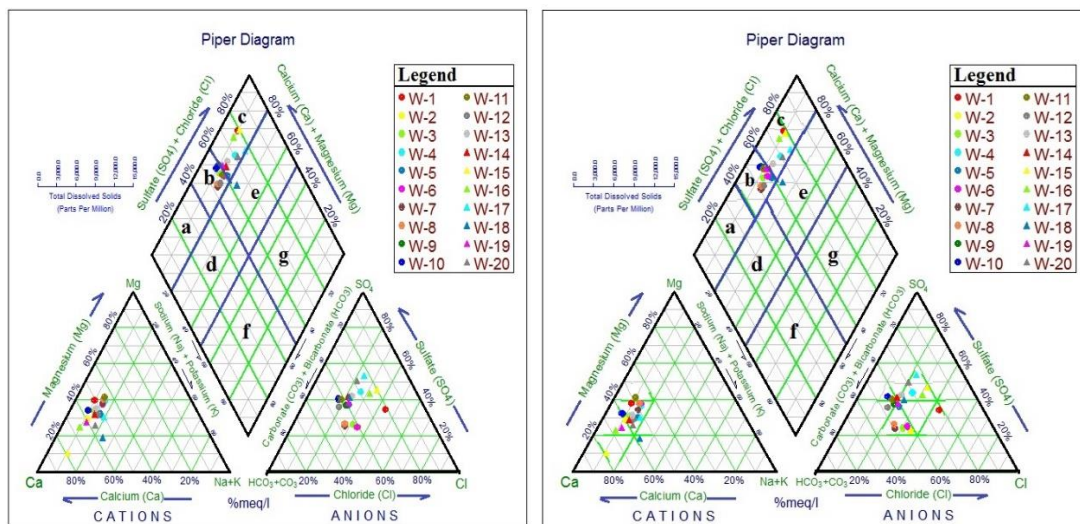


Fig. 5a: Piper diagram of the samples in the September 2017

Fig. 5b: Piper diagram of the samples in the April 2018

### 3.2. Groundwater-rock interaction

The ratio of  $rCa^{2+}/rMg^{2+}$  the interaction that occurs between aquifer rocks and water, this ratio was with the average value of 1.99 during the dry period and 2.14 during the wet period is between rainwater 7.14 and seawater 0.14 [20]. The value is a reflection of the dissolution of dolomite and limestone (carbonates rocks) under the pH of rainwater (acidic pH conditions). If  $rCa^{2+}/rMg^{2+}$  ratio is equal to one (1) indicates the dolomite dissolution, but more than one (higher ratio) reflects a greater calcite contribution [21]. In this study, the very high  $rCa^{2+}/rMg^{2+}$  values in two periods, more than 1.07 to less than 7.57 during the dry period and more than 1.15 to less than 7.74 during the wet period indicate the contribution of calcite to groundwater of Mulussa aquifer greater than dolomite. The  $rNa/rCl$  ratio can be used to identify the origin of the water (either meteoric water, if  $rNa/rCl > 1$  or marine water, if  $rNa/rCl < 1$ ). Based on this ratio, the groundwater of Mulussa aquifer in the Rutba-Dhabaa area come from the marine origin for all water samples in two periods (Table 3 and 4).

Many sequential steps representatives of chemical functions following are used to describe the source of ions and the rocks that affect the chemistry of the groundwater of Mulussa aquifer in the studied area for two periods (Tables 3 and 4), [22].

1. The values represented by the  $Na / (Na + Cl)$  ratio indicates that all the wells for two periods that penetrated the Mulussa aquifer are affected by the contribution of sea water because the calculated values of this function are less than half (0.5).

2. The values represented by the  $Mg/(Ca + Mg)$  ratio less than half (0.5) indicate weathering of limestone – dolomite, but if this ratio is more than half (0.5) indicates dissolution of dolomite mineral and precipitation of calcite mineral. The ratio value  $< 0.5$  (less than half) for two periods indicates the dominant process is dolomite–limestone weathering.
3. If the values represented by the  $Ca / (Ca + SO_4)$  ratio are  $< 0.5$ , this means that ion exchange or calcite precipitations occur, which leads to calcium removal, but if it is  $> 0.5$  reflect the source of calcium rather than silicates or gypsum. In the studied area, the ratio value  $> 0.5$  in 95% of wells for two periods, reflects the source of calcium rather than silicates or gypsum rocks for the Mulussa aquifer.
4. The values represented by the  $Mg / (Ca + SO_4)$  ratio are  $< 0.5$  in 85% wells for the September 2017 and 90% wells for the April 2018 period, indicating contribution calcite more than dolomite in the Mulussa aquifer.
5. The values represented by the  $(Ca + Mg) / SO_4$  ratio indicate dedolomitization when it falls within 0.80 – 1.20. The results for two periods indicated that there dedolomitization process about 100 % of the values represented by the above ratio.
6. The values represented by the TDS  $< 500.00$  ppm, reflect silicate weathering, and if  $> 500.00$  ppm, it reflects weathering of carbonate in mostly seawater or brine. Data of TDS reflects the weathering of carbonate in the Mulussa aquifer due to are  $> 500.00$  ppm in 90% wells for September 2017 (dry period) and 85% wells for April 2018 (wet period).
7. Rock weathering, when the values represented by the  $Cl/\Sigma$  anions ratio are  $< 0.80$ . Accordingly, the dominant process was the rock weathering in the Mulussa aquifer, so the ratio value is  $< 0.80$  for two periods.
8. The value indicates seawater or brine when it calculated the ratio of  $HCO_3/\Sigma$  anions is less than 0.8. Consequently, all values are  $< 0.80$  for two periods, then it reflects water of brine under the influence of fossils or connate water.

Table 3: Hydrochemical indicators of groundwater samples for the September 2017 period

Well No.	Na/(Na +Cl)	Mg/(Ca +Mg)	Ca/(Ca + SO <sub>4</sub> )	Mg/(Ca +SO <sub>4</sub> )	(Ca+Mg)/SO <sub>4</sub>	Cl/Σ anions	HCO <sub>3</sub> /Σ anions	rCa/rMg	rNa/rCl
W-1	0.17	0.44	0.59	0.47	2.60	0.44	0.21	1.26	0.21
W-2	0.23	0.33	0.70	0.35	3.57	0.35	0.40	2.02	0.31
W-3	0.28	0.39	0.67	0.42	3.33	0.32	0.42	1.59	0.38
W-4	0.37	0.46	0.51	0.44	1.91	0.26	0.29	1.16	0.58
W-5	0.40	0.39	0.58	0.36	2.24	0.24	0.39	1.59	0.67
W-6	0.30	0.44	0.66	0.52	3.41	0.34	0.41	1.27	0.43
W-7	0.35	0.45	0.65	0.52	3.33	0.27	0.47	1.25	0.54
W-8	0.34	0.47	0.63	0.56	3.22	0.27	0.46	1.13	0.52
W-9	0.27	0.38	0.60	0.36	2.44	0.22	0.41	1.66	0.37
W-10	0.32	0.38	0.58	0.35	2.24	0.16	0.43	1.66	0.46
W-11	0.42	0.48	0.52	0.49	2.13	0.18	0.41	1.07	0.73
W-12	0.43	0.37	0.60	0.36	2.35	0.19	0.45	1.68	0.75
W-13	0.35	0.40	0.55	0.37	2.07	0.23	0.35	1.48	0.55
W-14	0.38	0.37	0.56	0.33	2.06	0.21	0.37	1.69	0.63
W-15	0.23	0.12	0.63	0.08	1.96	0.34	0.20	7.57	0.30
W-16	0.22	0.27	0.60	0.23	2.08	0.32	0.25	2.64	0.28
W-17	0.43	0.38	0.48	0.29	1.51	0.24	0.23	1.64	0.74
W-18	0.50	0.25	0.58	0.19	1.82	0.23	0.36	2.98	0.99
W-19	0.33	0.31	0.61	0.28	2.30	0.23	0.39	2.20	0.49
W-20	0.42	0.31	0.53	0.24	1.64	0.21	0.28	2.21	0.74
Total	6.74	7.39	11.85	7.22	48.22	5.25	7.19	39.75	10.65
Ave.	0.34	0.37	0.59	0.36	2.41	0.26	0.36	1.99	0.53

All units in (epm%)



Table 4: Hydrochemical indicators of groundwater samples for the April 2018 period

Well No.	Na/(Na+Cl)	Mg/(Ca+Mg)	Ca/(Ca+SO <sub>4</sub> )	Mg/(Ca+SO <sub>4</sub> )	(Ca+Mg)/SO <sub>4</sub>	Cl/Σ anions	HCO <sub>3</sub> /Σ anions	rCa/rMg	rNa/rCl
W-1	0.17	0.43	0.60	0.44	2.60	0.44	0.21	1.35	0.20
W-2	0.23	0.33	0.72	0.35	3.90	0.35	0.42	2.07	0.31
W-3	0.28	0.36	0.70	0.39	3.59	0.31	0.45	1.80	0.39
W-4	0.38	0.44	0.52	0.40	1.90	0.25	0.30	1.28	0.61
W-5	0.42	0.37	0.59	0.34	2.26	0.22	0.41	1.72	0.72
W-6	0.30	0.45	0.65	0.53	3.37	0.32	0.42	1.23	0.43
W-7	0.35	0.41	0.68	0.47	3.54	0.27	0.49	1.44	0.55
W-8	0.36	0.45	0.64	0.52	3.23	0.25	0.48	1.23	0.55
W-9	0.27	0.35	0.61	0.33	2.41	0.19	0.43	1.82	0.37
W-10	0.32	0.35	0.58	0.32	2.17	0.14	0.44	1.82	0.46
W-11	0.36	0.46	0.54	0.47	2.21	0.17	0.42	1.15	0.56
W-12	0.46	0.35	0.61	0.32	2.35	0.17	0.47	1.89	0.84
W-13	0.39	0.37	0.56	0.32	1.99	0.20	0.36	1.74	0.64
W-14	0.40	0.33	0.58	0.29	2.06	0.19	0.39	2.01	0.68
W-15	0.26	0.11	0.62	0.08	1.86	0.31	0.21	7.74	0.35
W-16	0.22	0.25	0.61	0.21	2.08	0.31	0.26	2.93	0.28
W-17	0.43	0.37	0.48	0.28	1.49	0.22	0.23	1.70	0.75
W-18	0.49	0.24	0.59	0.19	1.88	0.23	0.36	3.14	0.96
W-19	0.35	0.28	0.62	0.24	2.30	0.21	0.41	2.60	0.54
W-20	0.43	0.31	0.53	0.24	1.65	0.20	0.29	2.21	0.76
Total	6.86	7.01	12.03	6.74	48.85	4.95	7.46	42.88	10.95
Ave.	0.34	0.35	0.60	0.34	2.44	0.25	0.37	2.14	0.55

All units in (epm%)

#### 4. Conclusion

The groundwater of Mulussa aquifer in the studied area is characterized by low alkalinity pH, hard to very hard water, between moderately and excessively mineralized water, and fresh to slightly water in both periods. The type of groundwater samples for two periods are " Normal earth alkaline water with prevailing bicarbonate and sulfate or chloride " and " Normal earth alkaline water with prevailing sulfate or chloride " respectively. Except for W-18 which represents " Earth alkaline water with increase portion of alkali with prevailing sulfate and chloride". According to the Kurlolov formula, the common water type is Ca-SO<sub>4</sub> for two periods

Contribution of cations as an average in the Mulussa aquifer during the dry period is Ca<sup>2+</sup> (28%), Mg<sup>2+</sup> (16%), and Na<sup>+</sup> + K<sup>+</sup> (7%), and anions contribution is Cl<sup>-</sup> (14%), SO<sub>4</sub><sup>2-</sup> (19%) and HCO<sub>3</sub><sup>-</sup> (16%). While during the wet period the Ca<sup>2+</sup> (29%), Mg<sup>2+</sup> (15%), and Na<sup>+</sup> + K<sup>+</sup> (7%), and anions contribution is Cl<sup>-</sup> (14%), SO<sub>4</sub><sup>2-</sup> (19%) and HCO<sub>3</sub><sup>-</sup> (17%). This result reflects that Ca<sup>2+</sup> and SO<sub>4</sub><sup>2-</sup> are considered the prevalent ions in Mulussa aquifer for the two periods.

The rCa<sup>2+</sup>/rMg<sup>2+</sup> ratio was with an average value of 1.99 during the dry period and 2.14 during the wet period, this ratio reflects the dissolution of dolomite and limestone (carbonates rocks) under pH of rainwater (acidic pH conditions). These results indicated the contribution of calcite to the groundwater of the Mulussa aquifer is greater than dolomite. According to rNa/rCl ratio, the groundwater of the Mulussa aquifer in the studied area comes from the marine origin for all water samples in two periods. The ratio of Cl/Σ anions reflects the dominant process was the rock weathering in Mulussa aquifer and the ratio of Mg/ (Ca + Mg) reflects the rock weathering is limestone–dolomite.

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